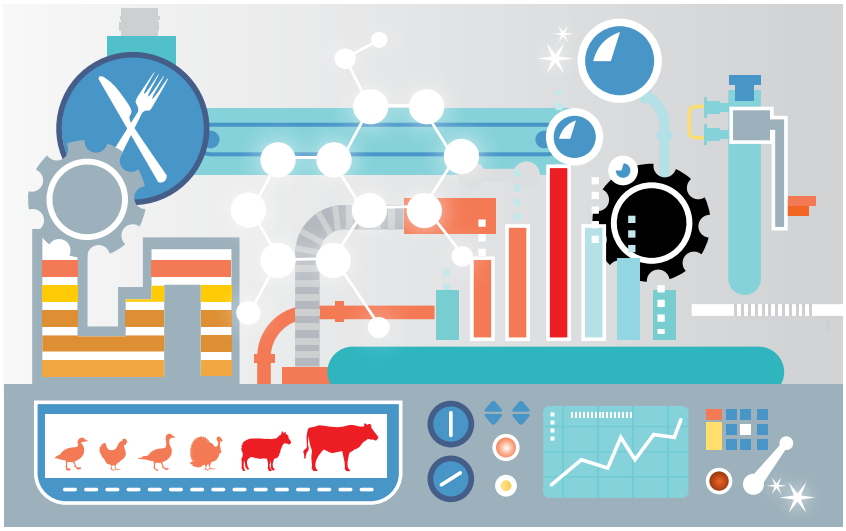
The Science of Poultry and Meat Processing



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To my past and current students

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PREFACE

The aim of The Science of Poultry and Meat Processing book is to provide students and industry personnel with a comprehensive view of the modernized primary poultry meat industry and further processing of both red meat and poultry. An emphasis is placed on basic concepts as well as recent advancements such as automation (e.g. increasing poultry line speed from 3,000 to 13,000 birds per hour over the last 40 years) and food safety (e.g. HACCP in primary and the further processing areas). The book also includes chapters explaining basic muscle biology, protein gelation, heat and mass transfer, microbiology, as well as meat colour and texture to help the reader understand the underlying scientific concepts of meat processing. The Science of Poultry and Meat Processing book is based on over two decades of university teaching experiences, and is designed to be used as a course textbook by students, as well as a resource for professionals working in the food industry. The book is available online, at no cost, to any interested learner. Using this format has also allowed me to include many colour pictures, illustrations and graphs to help the reader.

The book is dedicated to my past and current students who have inspired me to learn more and conduct challenging research projects. I see this as an opportunity to give back to the field that I have received so much from as a student and as a faculty member. Looking back, I have learned a great deal from my MSc and PhD advisor, Dr. A. Maurer, who was the student of Dr. R. Baker - the father of poultry processing in North America. I would also like to thank Dr. H. Swatland with whom I worked for almost 20 years, for the many challenging scientific discussions.

Writing The Science of Poultry and Meat Processing book was a long process, which also included having all chapters peer reviewed. I appreciate the help of my colleagues, but I still take responsibility for any inaccuracy in the book. If you have comments or **suggestions,** I would appreciate hearing from you (sbarbut@uoguelph.ca), as I am planning to revise and update a few chapters on a yearly basis.

I would like to thank the many people who have helped me during the writing process. To Deb Drake who entered all of the material for the book, to Mary Anne Smith who assisted in editing, and to ArtWorks Media for the design and desktop publishing of the book. I greatly appreciate the help of my colleagues who reviewed chapters and provided useful discussions. They include Mark B., Ori B., Sarge B., Gregoy B., Joseph C., Mike D., Hans G., Theo H., Melvin H., Myra H., Walter K., Roland K., Anneke L., Massimo M., Johan M., Erik P., Robert R., Uwe T., Rachel T., Jos V., Keith W., and Richard Z. I would also like to thank my family for their love and support during the entire process.

1

AUTOMATION

1.1 Introduction

The meat and poultry industry has seen greater changes over the past half century than it has seen over the past two millennia. The development of scientific knowledge and equipment as well as the discovery/introduction of electricity, computers, and cameras have had a major impact on the world including the meat industry. Since the industrial revolution, mechanization and automation have increased at a tremendous rate. At the beginning, the meat industry was lagging behind other industries (e.g., automotive) but today it is embracing mechanization and automation at a fast rate.

Table 1.1.1 Overview of steps in primary processing of meat producing animals.

• Live animal supply (catching, hauling, unloading)
• Stunning
• Bleeding
• Removing feathers/hair/scales
• Electrical stimulation*
• Evisceration
• Inspection
• Chilling
• Aging
• Portioning cutting
• Packaging and distribution
*Example of an optional procedure to help speed up rigor development (see text for details)

It is also interesting to note that the basic meat processing steps first used two thousand years ago are still used today. However, scale and scope have changed. The first step in the primary processing of meat producing animals, including poultry, (Table 1.1.1) is catching/gathering (e.g., placing birds in chicken coops), which is similar to what mankind has been doing for thousands of years. Today automated equipment can be used to harvest broilers in a growing house (see Chapter 4). Bringing the animals to a specialized abattoir was not always done but many cultures had a designated place to process the animals. Today with the use of highly specialized equipment (e.g., defeathering machine, cut up, packaging) and a skilled labour force, large, dedicated processing plants have been built to service an area of a few hundred kilometers around them (Barbut, 2014).

It is also important to realize that further processing steps have been automated to an even greater degree mainly due to the increasing uniformity of raw meat cuts arriving at and produced by the primary processing plant. An example of this is a fully automated battering and breading line where thousands of nuggets are produced every hour without human intervention. Nugget production usually starts with a forming machine that produces a few hundred identical nuggets/patties every minute (Fig. 1.1.1; see also Chapter 14). Another example is the co-extrusion process developed for direct semi-liquid casing application onto meat coming from the stuffer (see Chapter 10). These two examples illustrate how automation permits moving the process from a batch to a continuous operation.



Figure 1.1.1 Automated line producing hundreds of identical poultry nuggets every minute. Courtesy of Townsend.

Overall, the introduction of innovative equipment has allowed for the replacement of manual labour as well as increased efficiency, uniformity and sanitation standards. Also in the cutting and slicing operations one can see much more automation today. The equipment ranges from a water-jet knife (a high pressure narrow stream of water that is controlled by a computer) to the less expensive slicing knife controlled by laser vision (lasers determine the volume of the meat in order to optimize slicing; see photo later in the chapter). In general, where labour costs are expensive, more automation and robotics are seen as compared to areas where labour cost is low or where very complex operations are required (e.g., de-boning of a whole chicken leg meat with skin left on).

The use of machine vision to inspect a poultry/red meat processing line (Fig. 1.1.2) is a good example of affordable technology that assists in managing high speed lines. The system photographs every animal and uses image analysis software to determine the animal's conformation (anatomy, injuries, etc.). This information can then be used to make decisions about the end use of the bird (e.g., whole or cut up) three hours prior to its arrival in the cut up area. Machine vision represents a powerful management tool that assists plants that have an in-line process (i.e., animals are moved on a continuous line and retain their identity).



Figure 1.1.2 Computerized image analysis of poultry. Courtesy of Stork.

Robotics is another example of technology that has found applications in the meat industry. An example is the Robo Batcher that uses a lifting arm to pick up meat cuts from a moving conveyor belt and arrange them on trays (Fig. 1.1.3). The system pre-measures the weights of incoming portions, optimizes the best combination to achieve a specified package weight, and processes a few hundred portions per minute. This results in a significantly lower give-away compared to manual tray packing.

As indicated, the meat industry has experienced some major changes in the way it processes meat. Additionally, changes in marketing and consumer behaviour have had a large influence on the industry. Some important examples include:

a. Distribution → moved from local consumption to over sea shipping (e.g., export meat from Brazil to Japan)
b. Food safety → becoming a non-negotiable issue (see Chapters 12 and 15)
c. Sanitation and shelf life → improved interventions such as acid/steam washes, UV, radiation
d. Meat tenderness → special breeds are selected for tender meat (Tornberg, 1996)
e. Meat consumption → increased for the average person (see Chapter 2)
f. Time to prepare food at home → significantly reduced.

The last item especially represents a major change. Over the past half century the average time spent by North American consumers in preparing food dropped from 2.5 hrs to 10 min per day. The consumer expects meat that is tender (low connective tissue), free of defects (blood spots, broken bones), and pre-portioned. This created both a big challenge for the meat industry as well as an opportunity to move into the semi/fully prepared food market, also known as the convenience food arena. This is currently developing into a huge industry that provides semi/fully cooked products to restaurants, fast food outlets, and grocery stores; the value of this market segment is growing by several billion dollars every year and has created a need for increased automation.

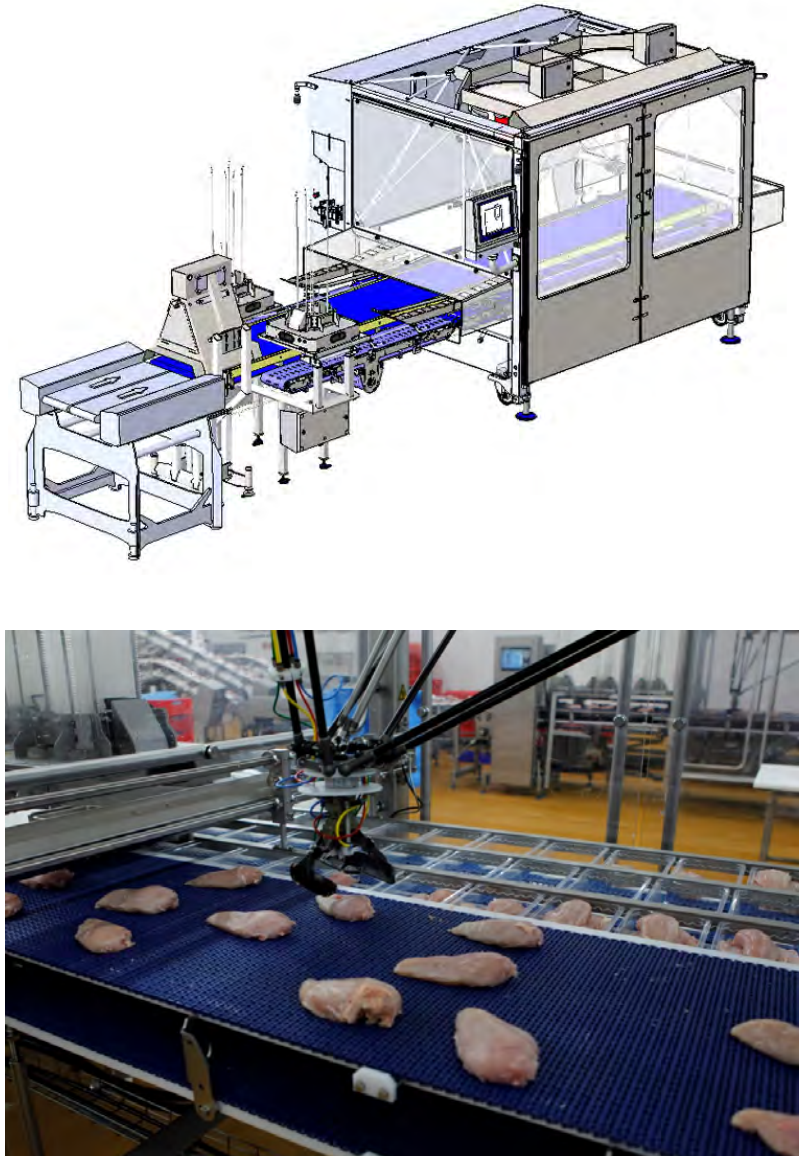


Figure 1.1.3 Robo batcher system capable of sorting and packing 300 chicken breast fillets per minute (first image), and a close-up of the gripper inside (second image). Courtesy of Marel.

Another very important issue is the production of meat under hygienic conditions to prevent the spread of diseases from animals to humans (Russell, 2012; Van Hoek et al., 2012). Until the microscope was invented by Robert Hooke in 1665, people did not know about microorganisms and did not fully understand the risk of diseases spread through food and other sources. The example provided in Figure 1.2.1 shows a fast automated evisceration machine for poultry which also includes continuous washing of the 'spoons' used to execute the procedures. It should be realized that as line speed increases from 3,000 to 13,500 workers would not have been able to follow the same standards such as washing their hands after working on each bird. Using automated equipment also provides the opportunity to use strong chemicals and/or steam which cannot be used when workers are present. Overall, the knowledge gained in the areas of microbiology and engineering has been essential in developing such high speed equipment.

Primary poultry processing line speed has increased fourfold over the past 40 years (Table 1.1.2) and has resulted in an increased processing capacity from 4,500 kg/hr in 1970 to 36,000 kg/hr for a single line. These advances have required a lot of work by animal scientists, physiologists, meat scientists, breeders, animal welfare people, and engineers who make sure meat quality is not negatively affected by increasing line speed and shortening time to deboning (Huff-Lonergam et al., 2010; Gregory, 2008). The purpose of this chapter is to illustrate some of the major changes in the meat industry in terms of mechanization/automation and to relate them to scientific knowledge from the areas of meat science, muscle biology, and chemistry.

Table 1.1.2 Increase in broiler processing line speed (bird/hr) from 1970 to 2015. Based on Barbut (2010).

Year	Line Speed	Equipment Development
1970	3,000	Mostly manual operation
1975	4,500	Automatic eviscerator
1980	8,000	Total automation in EV* department
1990	9,000	Giblet harvesting (automatic, semi-automatic)
2000	10,500	Cut up machine together with inline chilling
2010	12,000	Automated stunning (before shackling)
2015	13,500	Efficient vision inspection system
*EV = evisceration.		

Research advancements have led to impressive increases in turkey line speeds (Table 1.1.3) and significant increases in processing capacity per line (i.e., from 12,000 kg/hr in 1970 to 72,000 kg/hr in 2015). Major processing plant developments are also listed in Table 1.1.3.

Table 1.1.3 Increases in turkey line speed (bird/hr) and average weight (kg) from 1970 to 2015. Adapted from Barbut (2015).

Year	Line Speed	Live Wt.	Equipment Development
1970	1000	12	
1980	1500	15	1989 EV* machine 1990 Neck inside cropper
1990	1800	18	1992 Cut up system 1997 Filleting machine
2000	2400 toms 3000 hens	20	2000 Aqua film chilling 2002 CAS* system 2004 Vent cutter
2015	3000 toms 3600 hens	22	
*EV = evisceration; CAS = controlled atmosphere stunning.			

1.2 Advances in Line Speed and Automated Deboning

The major processing steps (Table 1.1.1) apply to all meat producing animals (e.g., chicken, beef) but variations exist depending on factors such as the size of the animal, presence of feathers, and projected end use of the meat. It is also important to note that large variations in procedures and techniques exist within the meat industry even when talking about the same species. An example is the stunning operation which can range from using electricity to a controlled atmosphere stunning to using no stunning whatsoever (e.g., for some religious slaughter; see Chapter 8). Also, within the same method, variation in conditions can be seen due to different customs and regulations (e.g., low voltage electrical stunning for broilers in North America vs. high voltage in Europe).

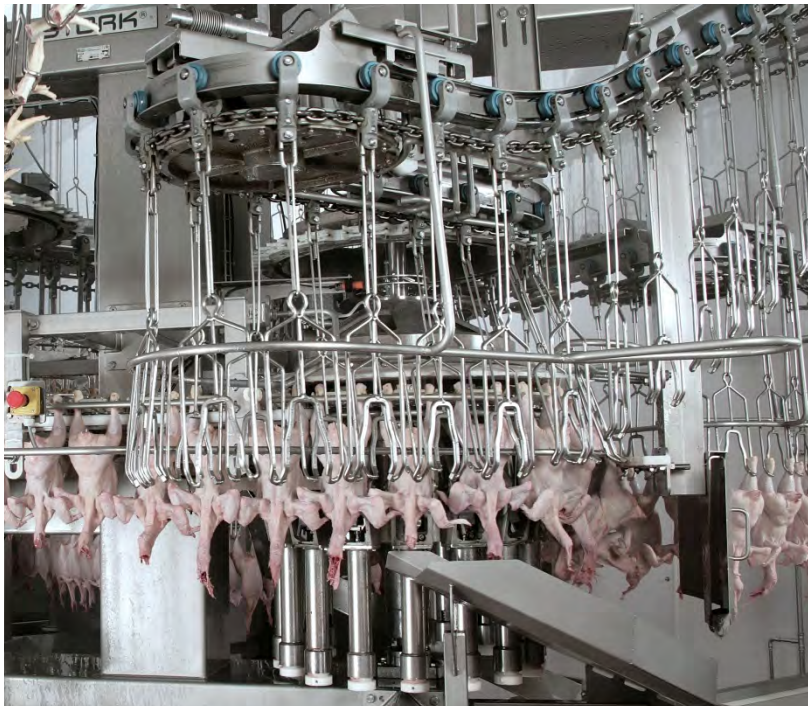


Figure 1.2.1 Broilers sent to automated evisceration equipment. Courtesy of Stork.

One of the first innovations that had a significant impact on increasing poultry line speed was realized in the area of evisceration, which traditionally required lots of manual labour and still is done by hand in countries where low cost labour is available. In such a plant, one can see hundreds of people standing along the processing line; each is responsible for one operation/cut. Figure 1.2.1 shows an automated evisceration system for poultry where >10,000 birds/hr can be processed almost without any manual labour. Developing the equipment has allowed a major increase in line speed and a mechanization of the whole process. For comparison purposes, in the beef and pork industries other challenges in the evisceration step exist (i.e., large size and variation between animals), which make the execution of repeated mechanical evisceration more complex. Overall, line speed at a modern fast pork processing plant today is 1,200 pigs/hr. However, this usually consists of two lines handling the live animals and later merging into one line in the bleeding area; i.e., a larger packer can process about 18,000 pigs/day. A moderate line will accommodate about 700 animals/hr while a small plant will only process a few pigs per day. In fast plants, robots are starting to appear in the

opening cut operation. A recently installed robotic arm in Australia uses a laser-guided system that is supposed to be accurate, but the price tag (US $700,000) makes it hard to justify the cost for many hog production facilities. A fast beef primary processing line usually runs at 400 animals/hr; i.e., a large processor typically handles about 5,000 animals/day in two shifts (16 hrs). A slower line, still at some large plants, will process about 250 animals/hr. The major reasons for the difference in line speeds are related to the larger size of beef animals and higher degree of weight variation (as compared to broilers). Currently, both factors limit the degree of automation and the affordability of equipment in the primary processing area. However, over the past few years quite a few improvements have been made to assist workers in red meat plants. Examples include a hide puller, lifts for employees to reach higher areas along the carcass, and saws and pneumatic shears suspended by cables. In any case, more automation can be seen in the pork and beef industries when it comes to cutting/slicing uniform pieces of sections without bones (e.g., loins, fillets).

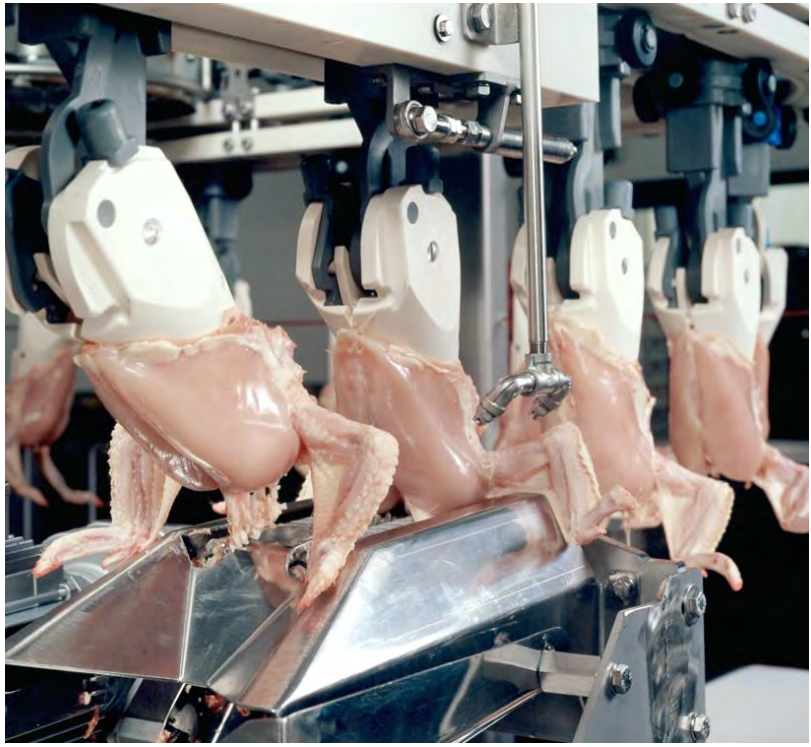


Figure 1.2.2 Automated equipment for broiler breast fillet deboning. Courtesy of Marel.

Figure 1.2.2 shows equipment used for harvesting chicken breast fillets; similar equipment is available for turkey. The equipment is mainly based on determining positions for cutting by first stretching the wings and bringing the wing joint to a certain position above a circular blade (i.e., cutting while the portion is moving on an overhead conveyer belt). After several incisions are made at the edge of the fillet, the meat is pulled away, by mechanical action, from the keel bone (see Chapter 9). While this might sound simple, it took quite a few years to develop a unique carrier that can rotate at different angles. In larger red meat animal processing some of the new developments direct the knife based on locating key points by laser, x-ray and/or ultrasound technology. This is a very important difference from cutting/deboning poultry meat. An example of beef cutting equipment, where X-ray guidance is used to obtain bone location, is shown in Figure 1.2.3. This equipment was produced by Guire et al. (2010), who studied the feasibility of cutting operations for beef and deboning of pork hams to enhance industrial applications of robotics by using vision or force control. In the first part of their study, they examined expert human operators and observed that their hand movements looked like the letter Z (Fig. 1.2.3). The researchers then worked on translating these actions into automatable operative tasks while identifying constraints of robotization. Later they analyzed the cutting and task constraints in order to begin developing a robotic cell model. Figure 1.2.3 shows the potential movement of the robotic cell (six-axis and a turntable) when following a path to do the so-called Z-cut. The first images show non-optimized positions of the robot and the next three images show the results of optimizing the motions according to criteria developed in the first part of their study. Overall, the authors proposed ways to solve the problem of high variability in beef carcass sizes. They also provided several ideas for deboning pork hams and indicated that there is a need to develop further strategies, sensors, and cell architectures to successfully complete this complex operation. The authors concluded by saying that because of the current choices of existing industrial robots, the tool paths available (especially with force control) are limited and should be further developed so the work can be continued. A similar approach for chicken breast meat deboning is now, for example, studied at Georgia Tech (Fig. 1.2.4) where a robotic arm is used.

It is interesting to note that in the fish industry there are now quite a few machines for automated filleting. This is a unique application as often there can be large variations in fish size. However, the idea is to find the mid line and cut out the back bone while obtaining the two fillets from both sides. This is done by placing the fish in a vertical position and using guides which can assess the width of the fish (i.e., no need to use x-ray); however, the fish have to be sorted into weight groups in order to properly adjust the equipment.

a)

b)

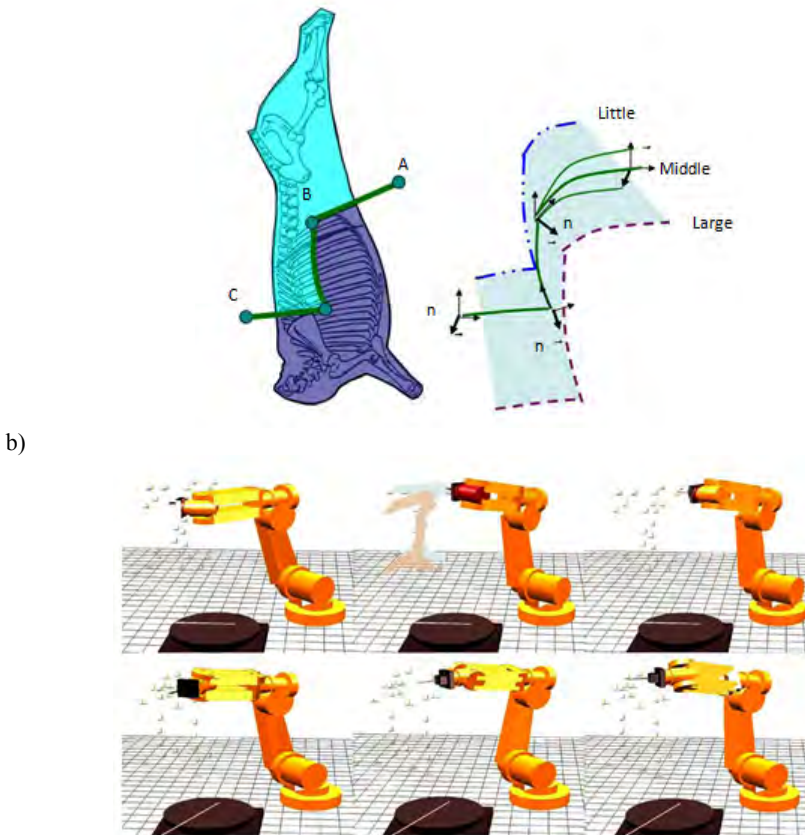


Figure 1.2.3 Illustration of the splitting of hind and forequarter in beef also known as the z-cut (a). Movement of a robotic cell when following the z-cut (b). See text for explanation. From Guire et al. (2010).

Overall, an important point that needs to be re-emphasized is the difference between the current automated cutup and deboning of poultry and red meat (beef, pork, sheep). While the former uses stretching and mechanical means to identify cutting locations (e.g., a joint), the latter needs the development of low cost sensors, software, and algorithms to guide the robotic arm so that equipment can deal with the complexity and size variation in red meat animals. This point represents a fundamental difference in moving towards increased automation in the red meat segment.



Figure 1.2.4 A robotic arm developed for chicken breast meat deboning. Courtesy of Georgia Tech.

1.3 Automation and Processes to Speed up Rigor Development

The industry needed to learn more about the rigor mortis process (i.e., muscle stiffness after death in which energy stored within the muscle is depleted and the muscle goes into a period of being very stiff before getting pliable again; see Chapter 3 for more details) in order to mechanize and speed up primary processing. Overall, this has required the industry to learn about muscle structure, composition, enzymatic processes, and the conversion of muscle to meat.

The overall goal of the meat processor is to complete the primary processing in a fast and efficient manner. However, if this process is sped up incorrectly, the resulting product will be negatively affected. For example, if the meat is deboned prior to the completion of rigor mortis, the resulting product will be tough and chewy (see reviews by Scheffler et al., 2011; Simmons et al., 2008). This illustrates the point that understanding what is happening on a cellular level is important for optimizing and designing adequate equipment. Knowledge gained in the area of muscle structure and functionality has helped the meat industry. Understanding the processes that take place in the sarcomere (the smallest contracting unit in which thick and thin filaments "slide" towards each other; see Chapter 3), both while the cell is living and post mortem, have helped the meat industry to develop innovative solutions to speed up and manage the rate of ATP depletion as well as

to achieve good meat quality at deboning time. Two examples of development processes that control and/or accelerate rigor mortis that will be discussed in detail later on are (a) electrical stimulation, which involves triggering muscle contraction and the use of ATP, and (b) maturation chilling, which refers to slow chilling while rigor mortis is occurring.

In order to explain these two processes, a brief introduction of the way muscle contracts in the living organism (called the sliding filament theory), and later the stiffness of the muscle during rigor will be provided. The theory explains that physical connections between the thick muscle filaments (mainly composed of the myosin protein) and the thin filaments (actin) are formed and broken down as energy is generated by several chemical pathways that use ATP as an intermediate molecule. Although the process of converting chemical energy consumed as food into mechanical energy (i.e., the movement of muscle) is very complex, understanding the process in general terms and relating it to meat science (Honikel et al., 1983; Huff-Lonergan et al., 2010; Scheffler et al., 2011) is crucial to our views of the induction of rigor mortis and its resolution after a few hours. The rigor process starts when the muscle is initially pliable and progressively becomes stiffer as time goes on. In brief, the stiffness is explained by the depletion of the energy reserves until getting to a point where most of the actomyosin connections/bridges are formed (>90%), but cannot be broken down. The resolution of rigor mortis (i.e., decline in muscle tension and muscle becoming pliable again) is due to proteolytic enzymes degrading the actomyosin bridges.

Another term that should be briefly introduced is cold shortening, as it can also help explain the need for electrical stimulation and maturation chilling. Cold shortening will take place if the muscle goes into rigor while the temperature is too low. This is an example of a practical problem that is still sometimes seen in the industry when meat is placed in the cooler too early or the cooler's operating temperature is too low (e.g., not adjusted to the volume of meat). A more severe case is the thaw shortening that will happen if the muscle is frozen prior to the completion of the rigor mortis process. Both are associated with an uncontrolled release of calcium ions that triggers a massive contraction of the structure and substantial squeezing out of water from the meat (Huff-Lonergan et al., 2010). Some of the classical studies on rigor mortis and temperature showed minimal shortening at 15°C (for excised muscle), which correlates well with minimal meat toughness.

Electrical Stimulation was developed originally in New Zealand in the 1950s (Chrystall and Devine, 1985) to manage toughening in lambs that were being frozen rapidly after slaughter (i.e., an extreme cooling regime that clearly produced cold-shortening and its associated toughening; see also Chapter 3). The process

uses an electric current to trigger muscle contraction, which increases the rate of glycolysis and results in an immediate pH decrease. Early studies in lamb and beef revealed that electrical stimulation can routinely decrease muscle pH by 0.5 units over a stimulation period of 60 sec. This represents a significant acceleration in the rate of muscle glycolysis and a clear indication of the tight coupling between the rate of glycolysis and ATP turnover in a muscle tissue. As electrical stimulation is used to activate muscle contraction by an outside stimulus, one must understand animal physiology, electricity, resistance, and the effect of wave forms, in order to apply it effectively and without lowering meat quality (Simmons et al., 2008). Different voltages and regimes are used by the industry for different species and also within the same species. It is also important to know that the muscle has other backup energy sources (e.g., creatine phosphate) which can provide energy before and after all of the ATP is consumed by the muscle. This is one of the reasons why repeated stimulation is applied in some cases, and why some muscle contraction can still be seen after conventional electrical stimulation.

At the beginning, electrical stimulation was applied to lamb and beef only, but today it is commonly used in poultry (especially over the past ten years) and some fish species to shorten the rigor period. In broiler processing it allowed the development of a continuous in-line processing, where broilers can be effectively deboned within 3.5 hrs after bleeding as opposed to 6-8 hrs without electrical stimulation. In this faster process the birds are kept on a moving shackle line during the entire process. This already streamlines the process, and saves labour and money as dropping and rehanging birds off the line (e.g., in a conventional water bath chiller operation) is estimated to cost about 5-10¢ per bird. Overall, when using an in-line process (birds kept on a moving shackle line throughout the whole process) birds can be weighed and graded by an automated scale. Later a picture is usually taken and processed by an image analysis system just after the evisceration, so a decision about cutting up or keeping the bird whole can be made 3 hrs prior to the actual deboning time. In this example one can start to appreciate the coupling of biological sciences and engineering to help design faster and more efficient processes.

Maturation chilling is done after the evisceration process to minimize microbial growth. However, as indicated before, rigor is also progressing at this point and decreasing the temperature too quickly will result in cold shortening and pronounced effects on meat tenderness and yield (Davey and Gilbert, 1975). Overall, broiler/turkey/duck can be chilled by either water, air, or their combination (see Chapter 5). In the case of water chilling, carcasses are either placed into a long screw/paddle type cold water bath where they are slowly moved to the end point (see Chapter 5) or are suspended from a shackle line where line speed and

water/air temperature can be adjusted to control chilling rate and time. All of these operations are automated in large processing plants. Like electrical stimulation, maturation chilling is an example of a development that illustrates the importance of combining biological sciences and engineering. In the past, and still today in smaller plants, poultry carcasses were chilled by immersion in large tubs filled with water and ice. Later, a long chiller with a device to advance the carcasses was introduced. This was followed by the introduction of a counter flow pattern where clean, cold water flows from the exit side, which improves the efficiency of the process and the hygiene of the meat. The use of cold air for large scale poultry operations was developed later. Today, the need for a continuous in-line operation demands fast and efficient processes, preferably without removing the carcasses from the line. Maturation chilling has been developed to achieve these goals without sacrificing quality (Fig. 1.3.1). Carcasses move on the line while the outside is initially fast-chilled with a stream of high velocity very cold air directed to the thick parts. This is followed by a period of exposure to slower moving air at a slightly higher temperature, which does not interfere with the rigor mortis process. This is an important point in understanding how to automate a meat processing plant, as dropping the birds into a water bath (as is done in most water chill operations) and later re-hanging them manually onto another shackle line breaks the flow of the process and results in the loss of the bird's identification number. As indicated before, the cost of re-hanging (done manually) is 5-10¢ per bird. This is important if initial image analysis is used to evaluate and grade the birds (i.e., after evisceration). Overall, installing a continuous line to hold a few thousand birds in a chilling tunnel is expensive initially (i.e., need a few km of line) but it is hoped the reader can see the benefits and potential return on investment when dealing with a high number of birds. In addition, traceability is becoming a very important issue and being able to retain the birds' identities on a line and use data from image analysis to plan ahead is worth a lot of money to a processor. In these examples, combining electrical stimulation and maturation chilling systems has allowed efficient and economical deboning of broilers at 3.5 hrs after bleeding, without meat toughening problems. The whole integrated process is often called 'tender-management' and is becoming popular in newly built plants (green fields) as well as some renovated plants. This is a significant improvement over older practices (still used in many places), where the products have to wait 6-10 hrs for the completion of rigor mortis prior to deboning, which usually results in next day deboning. The accelerated process requires understanding of muscle metabolism post mortem as well as an investment in hardware for a long continuous line so birds stay on the line for the entire process.



Figure 1.3.1 An air chilling operation. Birds are suspended from a moving shackle line and exposed to fast moving cold air. A fast line speed can run at 13,500 birds per hour. Courtesy of Stork.

1.4 Automation in Cutting and Portioning

As indicated before, more could be introduced at the cutting/slicing stage where more uniform portions (i.e., shape and weight) are processed. One example is the water jet knife (Fig. 1.4.1) which uses cameras to get a 3D image of the meat portion and calculates the optimum cutting to pre-determined specifications. The machine can cut a few thousand pieces per hr. Another less expensive example is a machine that uses a high speed rotating blade and laser scanners in front of it to take measurements and calculate the pre-defined portion shape (Fig. 1.4.2). For luncheon meat slicing (cooked in casings), faster speed equipment can be used because there is a higher degree of uniformity. Today there are ultra-high speed slicing machines that cut a few hundred slices per minute and, with a feedback control mechanism, adjusts the weight of each stack of sliced product.

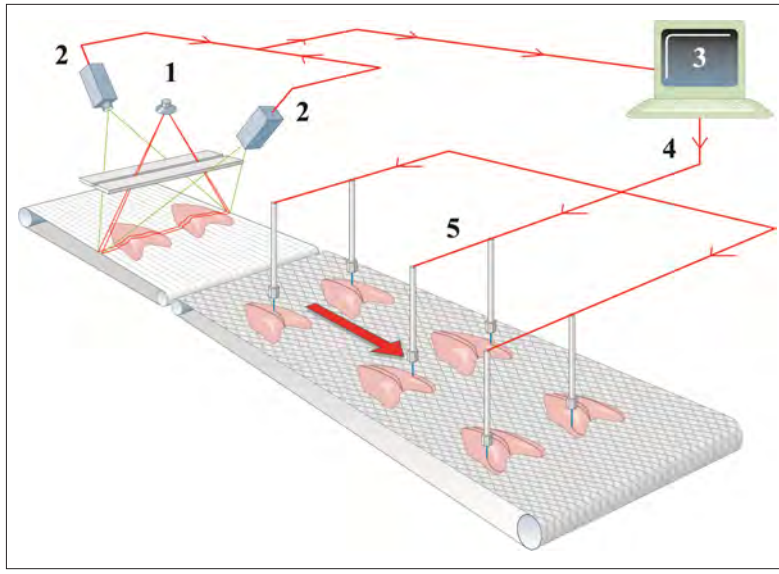


Figure 1.4.1 Water jet cutting system. Showing cameras taking pictures to create a 3D image which is later used to calculate cutting lines, and the high pressure jet streams coming from above to cut the meat. Courtesy of JBT.

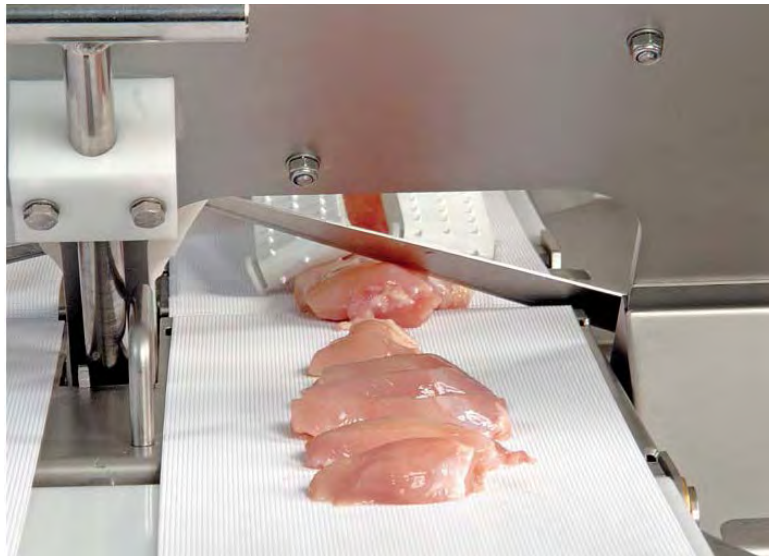


Figure 1.4.2 High speed slicing blade integrated with laser scanners to determine the 3D shape of the meat portion. Capable of making a few hundred cuts per minute. Courtesy of Marel.

1.5 Other General Developments/Improvements

Meat quality is very important to the modern consumer to whom food is part of the culture of enjoyment. In the past, food was mainly consumed for survival and issues such as meat tenderness or juiciness were not as important as getting the meat itself. Today, consumers are willing to pay a premium price for the high quality, tender meat cuts they consume at home or at a restaurant. Therefore, one can see a lot of advertisements focused on new, tender, juicy, flavour enhanced, healthy, local, and/or good-for-you products.

Developments in breeding and genetics have also contributed to improved meat quality. Until World War II, chicken meat and eggs were produced from the same breed. Only later did the development and selection of meat type birds start and today special breeds that grow quickly are used. Geneticists are busy identifying genes pertinent to the meat industry such as those associated with growth rate and tender meat (Dalloul et al., 2014). Overall, it should be realized that many factors are involved in meat quality including an animal's activity, nutrition, stress, ageing time, and interactions. In 2004, the chicken genome project was completed. This meant that the genetic material on each of the 39 pairs of chromosomes in a chicken were charted. This represents around 20,000 genes and about 1.5 billion base pairs. Recently, the use of single nucleotide polymorphism (SNP; pronounced 'snip') technology to identify genes of importance has become popular. Researchers are using units with a few thousand SNPs to correlate the presence of certain genes for traits like tenderness (as measured by shear force values). To illustrate this point, an example from the beef industry (where animals are older and heavier and there are more challenges with tough meat) will be used. Miller et al. (2010) reported that 1,000 beef animals were screened with a 50,000 SNP chip and several domains were identified. Through their study, a domain for calpastatin was identified and patented as a marker for tenderness. It is envisioned that marker-assisted management will become common place (e.g., a few hundred SNPs will be used to screen and select animals for traits such as tender meat and high milk production). Today, a commercial genomic testing service is using the results from the analysis to market a panel comprised of a subset of informative SNPs. Referred to as a 50k-derived product, it only costs US $65. In the past, beef cattle selection has not been efficient in achieving balanced improvement across the spectrum of traits that contribute to breeding goals. One reason for this has resulted from an inability to cost-effectively rank selection candidates for all the attributes of interest. This is because the reliability of quantifying the merits of animals relies on recording pedigree and performance information, primarily on the selection candidates themselves, their parents and perhaps their offspring. In the beef cattle context, this has led to low selection accuracy for mature size,

lifetime reproductive performance, satiability/longevity, and disease resistance. Other important traits such as tenderness, overall eating quality, and feed efficiency have had no prospects for selection as there are no phenotypic measures that could be used to readily and cost-effectively evaluate large numbers of seed-stock animals. Therefore, molecular information is now a promising tool to improve the prediction of young animals by first using phenotypic markers, then using microsatellite markers, and most recently using ever-increasing densities of SNPs.

In poultry, SNPs can be used as genetic markers. There are 15 to 20 million SNPs in a chicken, each of which consists of two sequences of 100 to 200 bases. Of interest is that two joint base sequences can differ by a single base, (i.e., one sequence has a C and the other sequence has a T at the same location). Recently automated equipment has been developed to read SNPs and the cost has decreased to approximately 0.2¢ per SNP. It should also be mentioned that genetic markers are used today to trace animals and later meat from a specific animal in food borne outbreaks. Overall, it is expected that this technology will become more common in the near future and will help the industry. As for turkeys, Dalloul et al. (2014) indicated that 95% of the genome has been sequenced and soon the complete genome will be published. As with the chicken genome the material is expected to be published on line so researchers all over the world can access the data.

In summary, integrating information generated by animal physiologists, meat scientists, nutritionists, engineers, veterinarians, animal welfare specialists and marketers has helped to move the industry forward. Significant developments have been made in increasing line speed, tenderness, and shelf life. New computer control systems are finding their way into meat processing plants where they are used to control a single operation, a processing area, or the entire plant (Fig. 1.5.1). Sophisticated software programs for an entire meat plant record results and show data in real time (materials coming in, inventory, flow of material within the plant, up-to-date yield figures, and even the efficiency of an individual employee on the deboning line). Such systems require multiple inputs and sensors (e.g., weighing stations, colour, pH, fat content measurements, amount of connective tissue in a specific cut, etc.). One of the biggest advantages of having real-time information is the reduced cost associated with increased efficiency and minimized waste. It is interesting to mention that in the past the further processing industry has made significant advancements with programs such as the Least Cost Formulation Program, which is used to formulate multiple products from a variety of incoming raw materials. Some of the first programs were introduced in the 1970s when mainframe computers appeared on the market. Today, many computers, software programs, and some robotic operations are seen in the primary processing area that was previously a labour intensive area. In the future it is expected that more control

systems will be introduced to help the industry; all will have to be based on sound meat science principles.

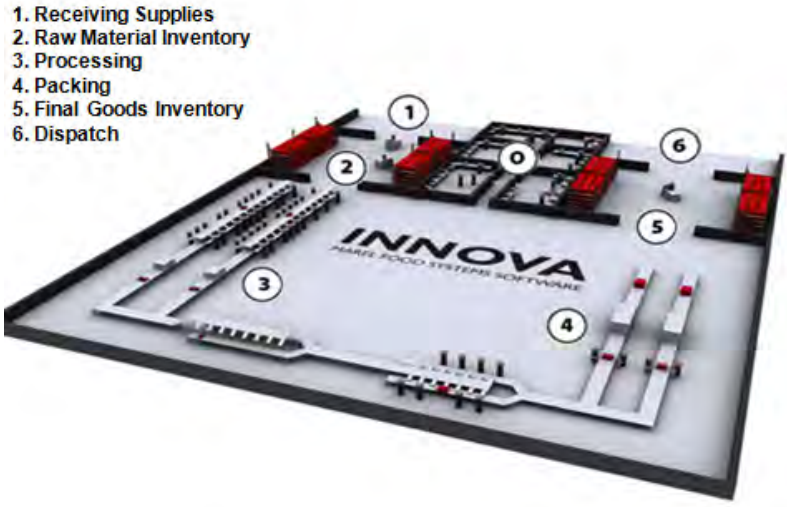


Figure 1.5.1 Integrated computer control – a software program to control an entire processing plant. The system can also be used for traceability of meat cuts.

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2

GLOBAL PERSPECTIVE

2.1 Introduction

Meat consumption is popular all over the world. As a result of population growth and rising income levels, production of poultry/red meat and other protein sources has steadily increased over the past 50 years (Fig. 2.1.1). One of the first observed changes when income rises in developing countries is a shift from a cereal based diet to a diet higher in meat. Poultry meat is gaining popularity because of its competitive price (a result of good feed efficiency; to be discussed later in the chapter), short growing period, positive nutritional image, and very few religious restrictions.

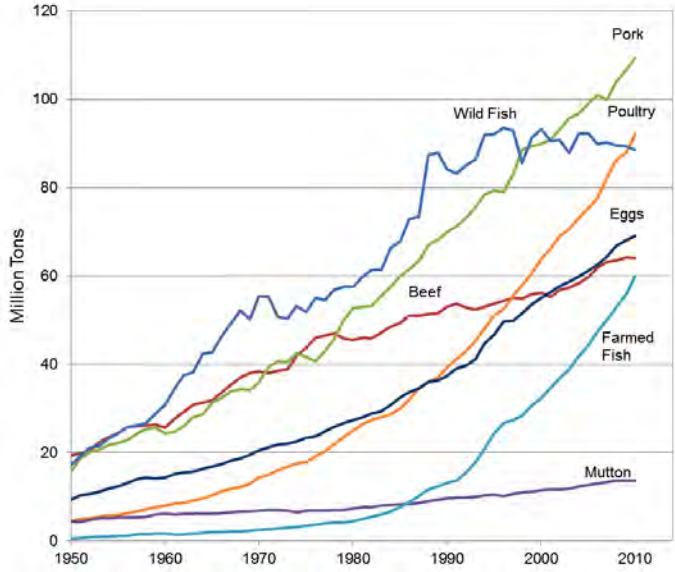


Figure 2.1.1 World meat production by type, 1950-2010.
Redrawn from FAO (2013).

Figure 2.1.1 shows the increase in consumption in all meat sources, including poultry, which has been a major contributor. It is expected that by 2020 poultry meat production will surpass production of all other meats including pork (FAO, 2013). This projection is based on the development of new mega poultry growing complexes in countries such as China, Russia, and India where population growth is expected to be highest. Currently, a substantial proportion of poultry production (Fig. 2.1.2) is done by a few large, specialized, international companies who most often use a vertical integration model (i.e., the same company owns multiple components along the supply chain such as the hatchery, feed meal, growing operation, processing plant, and distribution). This model helps to increase efficiency and maximize profit.

This chapter focuses on current and projected consumption of different meats with poultry as an example (explaining the major reasons for the tremedous increase in poultry meat production over the past few decades).



Figure 2.1.2 Poultry meat can be prepared and presented in many shapes and forms. Showing here BBQ chicken wings, oven roasted chicken breast filet and turkey nuggets. Photo Barbut and Jinde.

2.2 Poultry Meat Consumption

As indicated above, poultry meat is popular around the world but consumption varies by country/region (Figs 2.2.1 and 2.2.2). This is true for all meats, and in the poultry market there are major differences in consumption between countries such

as Brazil and the USA (where 44.4 and 41.0 kg meat/capita/year are consumed, respectively) and China and India (where 11.1 and 2.0 kg meat/capita/year are consumed, respectively). Consumption differences are the result of factors such as income level, availability, tradition, and eating habits (Swatland, 2010). It is beyond the scope of this chapter to discuss these differences in detail, but the reader should be aware that factors such as tradition and religious restrictions can play an enormous role. For example, in countries like Israel and Saudi Arabia pork meat is unacceptable due to Jewish and Muslim regulations, respectively.

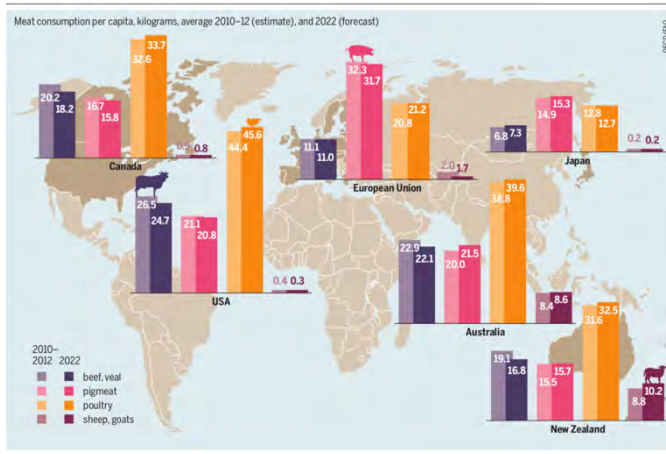


Figure 2.2.1 Demand in the rich world is satiated.
Data from OECD-FAO (2013) plotted by Anonymous (2014).

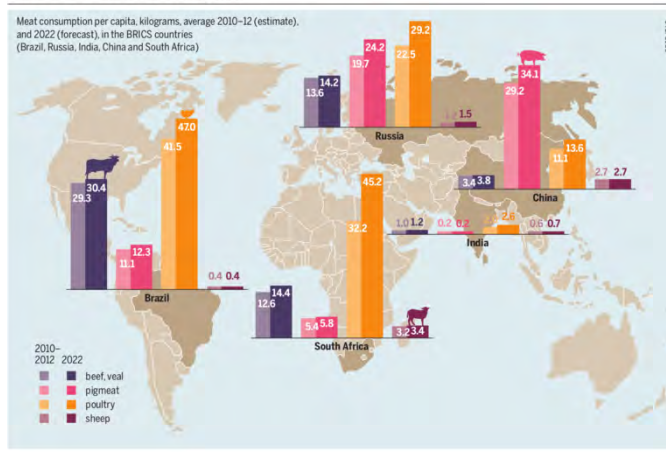


Figure 2.2.2 Demand in the developing world is rising steeply.
Data from OECD-FAO (2013) plotted by Anonymous (2014).

Total global poultry meat production has increased by almost 400% over the past 50 years. Figure 2.2.3 illustrates the increase expressed as ready to cook meat (i.e., after feather removal and evisceration). It is expected that within the next 10 years it will increase by another 25% (or a 500% increase since 1960). This projection is based on the world's population increasing by 1 billion people, especially in the developing countries (85% of the increase is expected in Asia and Africa).

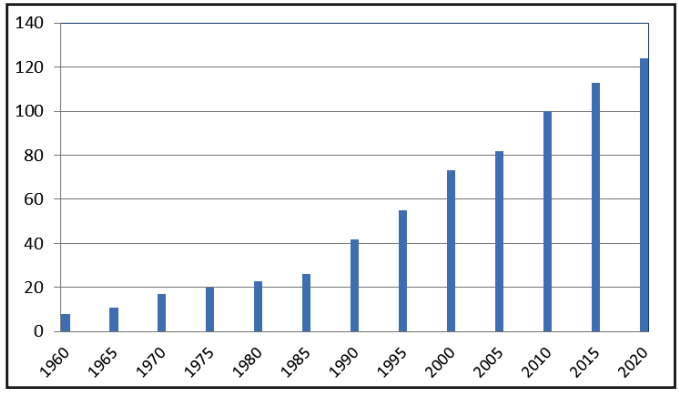


Figure 2.2.3 World total poultry meat production (million metric tons of ready to cook meat). Data from OECD-FAO (2013).

Table 2.2.1 first shows the expected increases in meat consumption around the world, and then breaks down the information by developed and developing countries. Overall meat production (beef, pork, poultry, lamb/mutton) is expected to grow from 295 to 350 million tons within the next decade (18%), but the relative proportion of poultry meat will be much higher than beef and pork (24% versus 12% and 15%, respectively). It is clear that most of the expected growth in meat consumption will occur in developing countries; expected increases of 31% in poultry, 22% in beef and 20% in pork. This is large compared to the expected increases in the developed countries; 16%, 5% and 6%, respectively. The growth reflects both the expected increase in per capita consumption and the rise in income. In developed countries consumers have enough income to purchase all/most of the meat that they would like to consume. By 2020, per capita poultry and red meat consumption in developing countries is still expected to be lower than in developed countries but the balance is changing every year.

Table 2.2.1 Expected changes in the world's meat production (in million tons of carcass weight and per capita consumption in kg) over the next decade. Data from OECD-FAO (2013).

		Calendar Year						Change %
		2012	2014	2016	2018	2020	2022	
WORLD BEEF Production	(kt cwe)	66 891	67 955	70 066	72 438	74 440	76 531	12
PORK Production	(kt cwe)	109 793	113 963	118 146	121 172	123 965	126 731	15
POULTRY MEAT Production	(kt rtc)	103 257	110 519	115 388	120 001	124 289	128 669	24
TOTAL MEAT Per capita*	(kg rwt)	33.7	34.1	34.6	35.1	35.4	35.8	6
DEVELOPED COUNTRIES BEEF Production	(kt cwe)	29 482	28 743	29 424	30 112	30 609	30 876	5
PORK Production	(kt cwe)	41 903	42 085	43 383	43 585	44 009	44 499	6
POULTRY MEAT Production	(kt rtc)	42 330	43 743	45 309	46 694	47 875	49 078	16
TOTAL MEAT Per capita*	(kg rwt)	65	64.8	66.1	66.8	67.4	67.8	4
DEVELOPING COUNTRIES BEEF Production	(kt cwe)	37 219	39 211	40 642	42 326	43 832	45 655	22
PORK Production	(kt cwe)	67 890	71 878	74 763	77 587	79 956	82 232	20
POULTRY MEAT Production	(kt rtc)	60 927	66 776	70 079	73 307	76 414	79 592	31
TOTAL MEAT Per capita*	(kg rwt)	25.9	26.7	27.2	27.7	28.1	28.6	10

*Per capita consumption expressed in retail weight (rwt). Carcass weight to retail weight conversion factors of 0.7 for beef and veal, 0.78 for pigmeat and 0.88 for both sheep meat and poultry meat. Total meat also includes sheep meat (values for sheep meat production not presented here).

2.3 Improvements in Meat Production

The meat industry has seen major improvements in the genetics, health, husbandry and processing segments. Table 2.3.1 shows the significant gains associated with growing broiler breeds selected for faster growth rate. In 1925 it took, on average, 112 days to grow a broiler to market weight of 2.5 lb. In 2010, however, it took only 47 days to get to a weight of 5.70 lb and in 2014 some processors in the US and elsewhere could get to 6.20 lb in the same amount of time or could grow the birds for 40-42 days and get a smaller broiler. Figure 2.3.1 shows more details about changes in the average broiler's growth rate and the number of days required to reach a body weight of 2.27 kg (5.0 lb). As shown, time to grow the same size bird was decreased by nine days between 1998 and 2013. The figure also shows seasonal differences in growth rate.

It should be noted that in the 1920s chickens were grown in small backyards and the same breed was used for both egg and meat production. Later on, when the industry started to grow and specialize, egg and meat production breeds emerged and farmers began to specialize in one or the other. For example, today one can find farms so specialized that they only grow pullets for laying stock. Modern farms are usually fairly large and house a few hundred thousand birds.

Selection for more efficient meat producing breeds has also resulted in improved feed efficiency (kg feed required to produce 1 kg of meat gain) from 4.70 to 1.92 (Table 2.3.1). In addition, developments in veterinary medicine and breed selection for those less susceptible to some of the major poultry diseases have helped reduce mortality rates from 18% to 4%.

These improvements along with innovation/modernization in the primary processing sector (Barbut, 2010) and in agriculture in general (e.g., growing more corn/soy per acre) have resulted in consumers paying less today for poultry meat than they did 25 years ago. An example from the US shows that on a 2010 dollar basis (i.e., using 100 as an index for 2010), deboned chicken breast meat would have been 130 in 2005, 150 in 2000, 200 in 1995, 310 in 1990 and 330 in 1985.

Table 2.3.1 Improvements in poultry meat production from 1925 to 2010. Data from National Chicken Council (2014).

Year	Market age	Market weight	Feed to meat gain	Mortality %
	Average days	lbs, live weight	lbs feed / lbs broiler, live weight	
1925	112	2.50	4.70	18
1935	98	2.86	4.40	14
1940	85	2.89	4.00	12
1945	84	3.03	4.00	10
1950	70	3.08	3.00	8
1955	70	3.07	3.00	7
1960	63	3.35	2.50	6
1965	63	3.48	2.40	6
1970	56	3.62	2.25	5
1975	56	3.76	2.10	5
1980	53	3.93	2.05	5
1985	49	4.19	2.00	5
1990	48	4.37	2.00	5
1995	47	4.67	1.95	5
2000	47	5.03	1.95	5
2005	48	5.37	1.95	4
2010	47	5.70	1.92	4

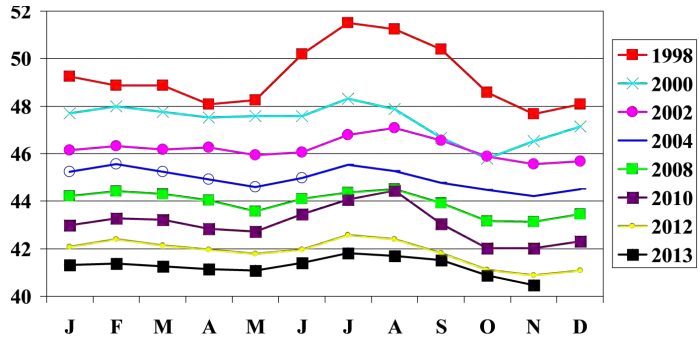


Figure 2.3.1 Broiler growth rate – days to get to 2.27 kg (5.0 lb) during different months of the year (January to December) in the US. From Donohue (2014).

Figure 2.3.2 illustrates the conformational changes of a broiler carcass raised in 1970 and in 2008. As can be seen in Table 2.3.1, average body weight increased from 3.6 to 5.7 lb (i.e., about 50%), but it should be noted that the proportion of breast meat has also increased. The data shown in Figure 2.3.3 illustrate the increase in percent yield of broiler meat in the US from 1997 to 2013. Table 2.3.2 shows other parameters that demonstrate the continuous work of breeders, farmers, nutritionists, veterinarians, and meat processors in improving yield.

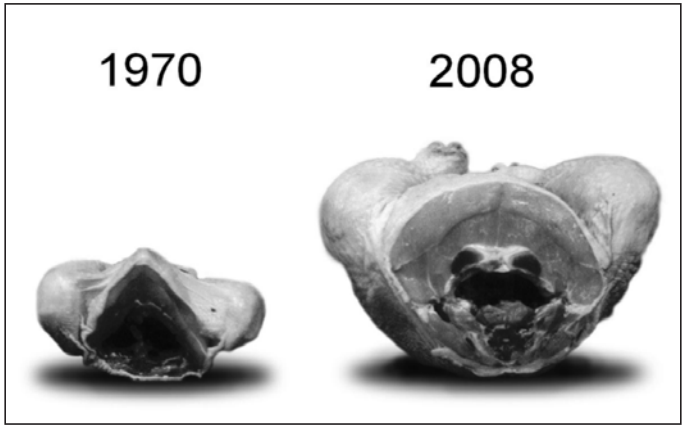


Figure 2.3.2 Cross section of a broiler carcass showing the breast area and its proportion in a 1970 and a 2008 broiler. Source unknown.

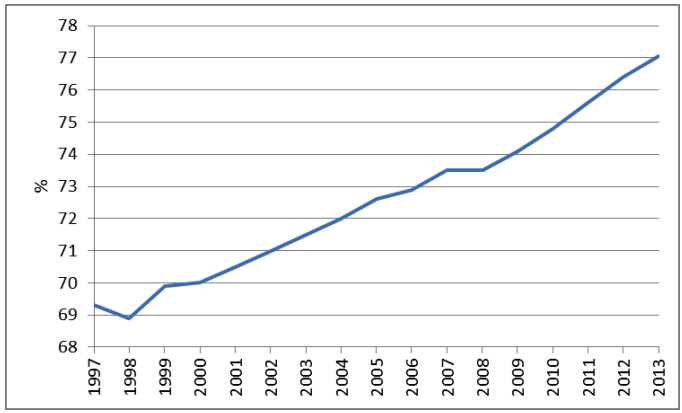


Figure 2.3.3 Percent yield of broiler meat as a portion of carcass weight without giblets (WOG) in the US from 1997 to 2013. Data from Donohue (2014).

Table 2.3.2 Changes in relative percentage of various portions of broilers in US. Data from Donohue (2014).

	1995	2005	2013
Live weight (lb)	4.8	5.8	6.0
Front half (live)	35.0	40.0	43.5
Front half (without giblet)	51.5	55.0	57.0
White meat	15.0	20.0	23.0
Wings	7.5	7.5	8.0
Leg Quarter	13.0	12.5	13.0

2.4 Changes in Meat Consumption Patterns

As already indicated poultry consumption differs by country (Figs 2.2.1 and 2.2.2). Additionally, Table 2.4.1 presents information about the common types of poultry consumed around the world and provides information about typical weights and market ages. To help the reader, translations of major terms used in the poultry industry are provided in Table 2.4.2.

In this section an example from the US market will be used to show changes in meat consumption patterns over a 50 year period. Table 2.4.3 shows changes in red meat, poultry and fish consumption. Overall, there has been a 15% increase in meat consumption; however, the proportion of poultry meat has dramatically increased from 23% in 1965 to 50% in 2010 while red meat has decreased from 72% to 50% during the same period. This is the result of various factors including price, nutritional image, and availability of further processed products (see Section 2.3). The latter especially has expanded significantly since 1960, when a limited selection of poultry products was available on the market (e.g., most sausages were made of red meat). It was in this period that the industry started to introduce new products such as hot dogs, frankfurters, and luncheon meats (Barbut, 2002). Later, in the 1970s, the introduction of the chicken nugget was a tremendous boost to the poultry industry. Subsequently, introductions such as turkey ham (see Chapter 13) and pre-portioned poultry has helped to increase consumption and has opened the door for more cut up portions as a result of a few fundamental changes that influenced the market. The first was increased consumer demand for more convenient packages with specific cuts/portions. The big change between marketing whole birds versus cut up parts and further processed products can be seen in Figure 2.4.1. In the 1960s, 85% of the market consisted of whole birds, whereas in 2013 they represented less than 10% because consumers today are willing to pay for the convenience of smaller portions with bone and skin already removed (see Chapter 9). Another factor that helped to change the market was the conscientious decision of the poultry industry to move consumption from seasonal sales (e.g., turkeys before Thanksgiving and Christmas) to year round sales. This also required introducing smaller packages (e.g., single deboned turkey breast, drumstick) instead of just whole birds.

Table 2.4.1 Common types of poultry produced around the world.

Poultry	RTC* weight (kg)	Age (weeks)
Chicken		
Broiler/Fryer	1.3 – 2.1	6 – 7
Roaster	3.0	8
Rock Cornish Game	0.6	3 – 4
Hen/Stewing Fowl	1.1	> 52
Cock or Mature Rooster	2.2	> 30
Turkey		
Broiler Hen	4.2	10
Young Hen	7.0	16
Young Tom	12.5	17 – 18
Spent Breeder	11.0	> 52
Duck		
Broiler or Fryer	2.5	7
Geese		
Mature	5.0	12 – 16
Guinea		
Mature	1.5	12
Pigeon	0.4	4 – 5
Quail	0.15	7
Ratite		
Ostrich	55.0	40 – 55
Rhea	62.0	44 – 48
*Ready-to-cook weight (which excludes feathers, blood, digestive tract, head and feet).		

Table 2.4.2 Names and terminology used in the poultry industry. First three columns based on information from the French Meat Industry Center (2000).

English	French	German	Spanish	Russian
poultry	volailles	Geflügel	aves	домашняя птица
hens	poulet	Hähnchen	gallina	куры
cock	coq	Hahn	gallo	петух
turkey	dinde	Pute	pavo	индейка
goose	oie	Gans	ganso	гусь
duck	canard	Ente	pato	утка
quail	caille	Wachtel	codorniz	перепел
partridge	perdrix	Rebhuhn	perdriz	куропатка
feather game	gibier a plume	Federwild	caza con pluma	пернатая дичь
cuts	découpes	Teilstücke	cortes	разделка туши
giblets	abats	Innereien	menudos	потроха
leg	cuisse	Schenkel	muslo	окорок
drumstick	pilon	Schenkeule	pata	голень
wing	aile	Flügel	ala	крыло
breast	blanc	Brust	pechuga	грудка
meat	viande	Fleisch	carne	мясо
neck	cou	Hals	cuello	шея
tail	croupion	Bürzel	rabo	гузка
skin	peau	Haut	piel	кожа
liver	foie	Geflügelleber	higado	печень
heart	cour	Herz	corazón	сердце
gizzard	gesier	Kaumagen	molleja	мускульный желудок

Table 2.4.3 Changes in meat consumption (lb per capita) in the USA from 1965 to 2015. Data from National Chicken Council (2014).

Year	Beef	Pork	Chicken	Turkey	Total meat	Fish and shellfish
1965	74.6	51.8	33.7	7.5	175.2	10.8
1970	84.6	55.8	40.3	8.1	194.2	11.8
1975	88.2	42.9	39.0	8.3	183.9	12.2
1980	76.6	57.3	48.0	10.3	195.1	12.5
1985	79.2	51.9	53.1	11.6	199.1	15.1
1990	67.8	49.7	61.5	17.5	199.0	15.0
1995	66.6	51.8	69.5	17.7	207.7	15.0
2000	67.7	51.2	78.0	17.4	216.1	15.2
2005	65.6	50.0	87.1	16.7	221.0	16.2
2010	59.6	47.8	83.7	16.4	208.9	15.8
2015*	53.6	47.1	85.0	16.0	202.8	16.2

*2015 Estimated. Total meat column also includes some other smaller amounts of meat (e.g. sheep)

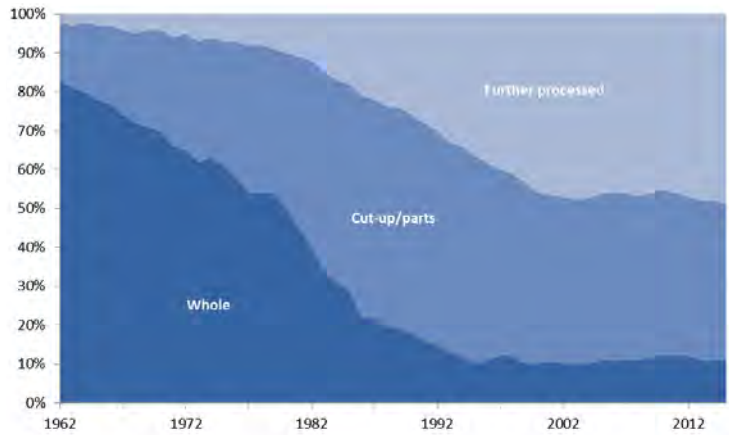


Figure 2.4.1 Changes in marketing whole broilers, cut up parts, and further processed products in the USA from 1962 to 2012. Data from National Chicken Council (2014).

The changes in the proportion of poultry sold via retail grocery stores versus fast food and food service outlets can be seen in Table 2.4.4. The proportion of grocery store sales has decreased from 75% to 56% and people today buy much more prepared food at restaurants/food service outlets compared to 1970. Today supermarket chains are also competing in this market segment and offer a prepared food counter with many items (e.g., rotisserie chicken, baked potatoes, steamed vegetables).

The US market represents one of the largest poultry markets in the world and is used here as an example to show how market forces can contribute to price fluctuation. In 2011, broiler feed cost $325 per ton. It increased to $380 in 2012 and then decreased to $296 in 2013. These changes were the result of weather conditions that affected crop yields, market forces (e.g., production of biofuel from corn), and other factors that can have a huge impact on profit margins. This cycle actually drove some small and medium sized companies out of the market. Overall, such big changes affect the poultry and other industries around the world.

Table 2.4.4 Changes in market share of different segments in the USA from 1970 to 2010. Data from National Chicken Council (2014).

Year	Market share (%)			Wholesale value of broiler products shipments from plants ($ Billions)
	Retail grocery	Fast food	Other foodservice	
1970	75	15	10	2.5
1980	71	19	10	6.0
1990	59	21	20	15.0
2000	59	21	20	29.8
2010	56	25	19	47.5

Some statistics to illustrate the size of the US current market are provided below (NCC, 2014):

a. 1.2 billion bushels of corn and 0.5 billion bushels of soybeans used for broiler feed
b. ≈ 9 billion broilers produced
c. ≈ 50 billion lb of live weight
d. ≈ 37 billion lb of ready to cook product
e. 300,000 direct employees
f. 200,000 indirect employees
g. $50 billion of product shipped
h. $70 billion in consumer expenditures

2.5 Automation in Processing Plants

In addition to improvements to aspects of growing birds (e.g., feed efficiency, growth rate, reduced mortality), the industry has also shown significant progress in the area of primary processing. As outlined in Chapter 1, line speed in broiler plants has increased from 3,000 birds per hour in 1970 to 13,500 in 2015. This has been the result of increased automation and mechanization. Table 2.5.1 provides some values for the industry where birds processed per man-hour has increased from 208 in 1994 to 310 in 2013. This 50% increase in productivity has contributed to reducing the relative price of chicken (see discussion in Section 2.3). This, together with increasing line efficiency from 95.5 to 98.3% (Table 2.5.1), has been an important factor in making the industry more competitive.

During the past 20 years, the industry has also experienced interesting changes in the amount of water used for processing each bird. The example in Table 2.5.1 refers to the US where water chilling is the main method of chilling poultry (as compared to air chilling or spray chilling more commonly seen in Europe; see Chapter 5). Overall, the introduction of HACCP and later more stringent requirements for pathogen reduction (see Chapter 6) resulted in a substantial increase in water use around 1998. However, since then there has been a steady reduction as the industry learned how to better manage the water while still reducing the number of pathogens (see Chapter 15).

In conclusion, the poultry industry has become much more competitive over the past 50 years and it is expected that poultry will become the number one meat source around the world.

Table 2.5.1 Increasing the average number of birds processed per manhour (primary processing, without giblet recovery) in the US plants, line efficiency, and amount of water used per bird during primary processing. From Donohue (2014).

Year	Bird per man hour	Line Efficiency (%)	Water per bird (Gallon)
1994	208	95.5	6.0
1995	212	95.3	6.0
1996	218	95.3	6.0
1997	217	95.7	6.4
1998	200	94.9	7.1
1999	210	95.2	7.1
2000	219	96.5	7.1
2001	222	96.8	7.2
2002	230	97.3	6.9
2003	240	98.0	6.9
2004	245	97.7	6.8
2005	257	97.6	6.9
2006	275	98.2	6.8
2007	275	98.0	6.5
2008	278	97.9	6.1
2009	278	98.3	6.2
2010	287	98.2	6.3
2011	305	98.5	6.4
2012	307	98.3	6.2
2013	310	98.3	6.4

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3

STRUCTURE AND MUSCLE PHYSIOLOGY

3.1 Introduction

The bird body has a unique structure as compared to mammals and other species because it has been adapted for flight. This includes not only wings but also the development of a light skeleton as well as air sacs that move air in only one direction through the lungs. The development of feathers and skin without sweat glands are other unique features. In this chapter, the basic overall structures of major meat producing poultry (chicken, duck, turkey, geese, pigeon) will be presented as well as the basic overall skeletal structure and muscle layout. Later, the discussion will focus on the tissue types that compose the carcass: connective, epithelial, nerve, and muscle.

Muscle structure and contraction will be described in greater detail as a basis for understanding meat quality aspects and their effects on post-slaughter changes during rigor mortis, deboning, packaging, and storage. Overall, muscle tissue represents the major edible part of the animal that is important to both meat processors and consumers. The differences between white and red muscle fibers (related to white and dark poultry meat) will also be highlighted as well as meat quality issues that can be traced to handling live birds. Two examples are pale, soft, and exudative (PSE) meat related to pre-slaughter stress and cold shortening, which is related to fast cooling during rigor mortis.

3.2 Body and Bone Structure

As indicated above, the body shape of a bird is adapted for flight and is aerodynamic to minimize airflow resistance when flying. The overall structure of a chicken skeleton is shown in Fig 3.2.1 and is typical of many avian species, although the relative size of certain body parts may vary depending on the bird's living environment. In the case of a chicken, the legs are fairly developed (Fig. 3.2.2) and adapted for walking since ancestors of the domestic chicken (jungle

fowl) lived in jungles or open spaces where standing, walking, and running represent a major proportion of total activity. The wings can be used for flying but just for a short duration to escape from predators. Thus, the wings of a chicken are not as developed as those of a migratory duck. The breast muscles that support the wings are fairly developed and even more so in the meat-type birds that have been selected for heavy musculature, especially breast muscles. The names of the different parts are shown in Figure 3.2.2.

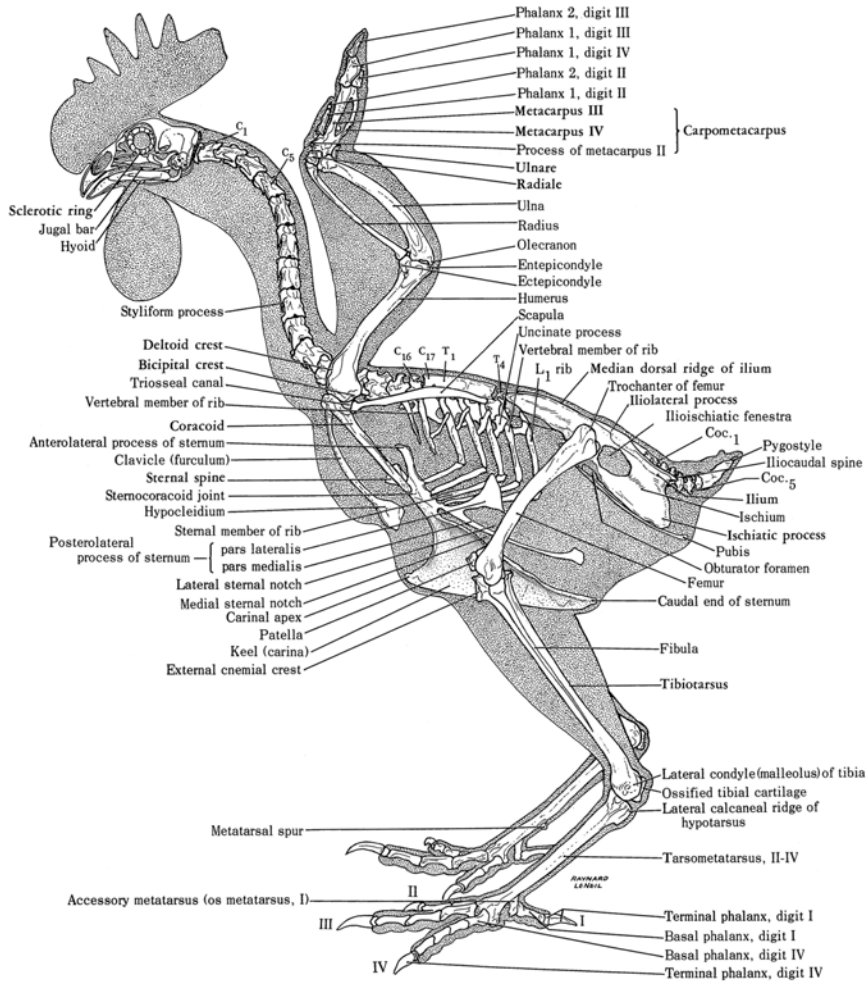


Figure 3.2.1 A lateral view of the skeleton of a Leghorn chicken. Abbreviations: C., cervical vertebra; Coc., coccygeal vertebra; L., lumber vertebra; T., thoracic vertebra. From Lucas and Stettenhiem (1972).

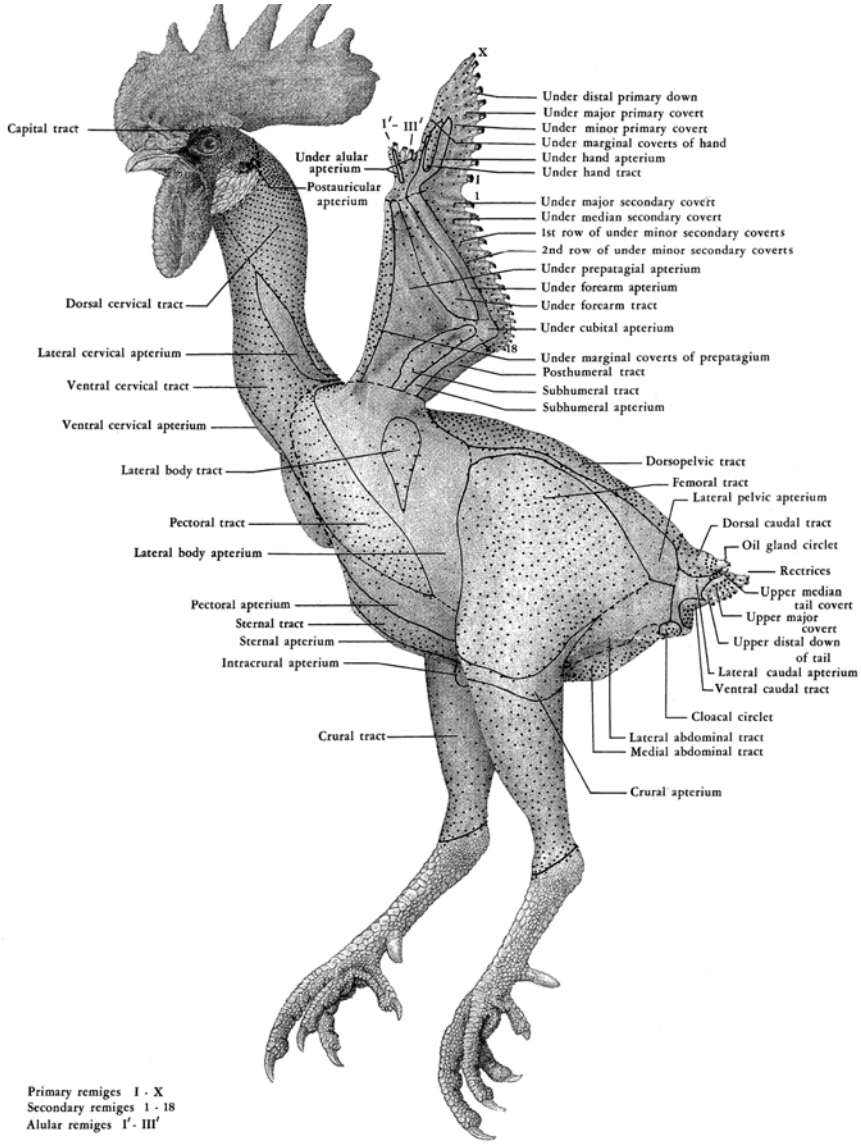


Figure 3.2.2 Left lateral view of the chicken showing the different regions. Abbreviations: reg(s)., region(s); s., synonym. From Lucas and Stettenhiem (1972).

In ducks (Fig. 3.2.3), the feet are adapted for swimming by a web between the toes that serves as a paddle. The beak is wide and has evolved to fit a marsh-type environment where it strains water and can catch small fish.

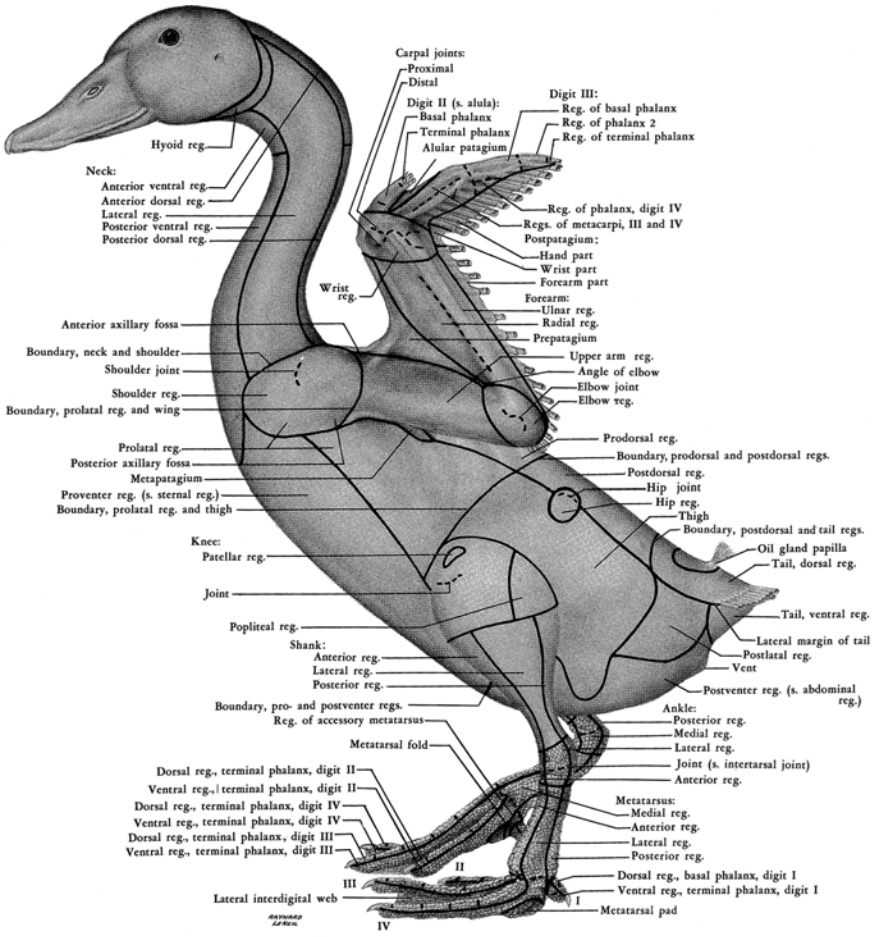


Figure 3.2.3 Lateral view of the White Peking duck showing the different regions. Abbreviations: mar., margin; reg(s)., region(s); s., synonym. From Lucas and Stettenhiem (1972).

In domesticated turkeys (Fig. 3.2.4), intense selection for heavy musculature has resulted in an almost flightless bird. The legs and toes of chickens and turkeys are structured to allow walking and perching on branches as opposed to swimming as in ducks and other waterfowl.

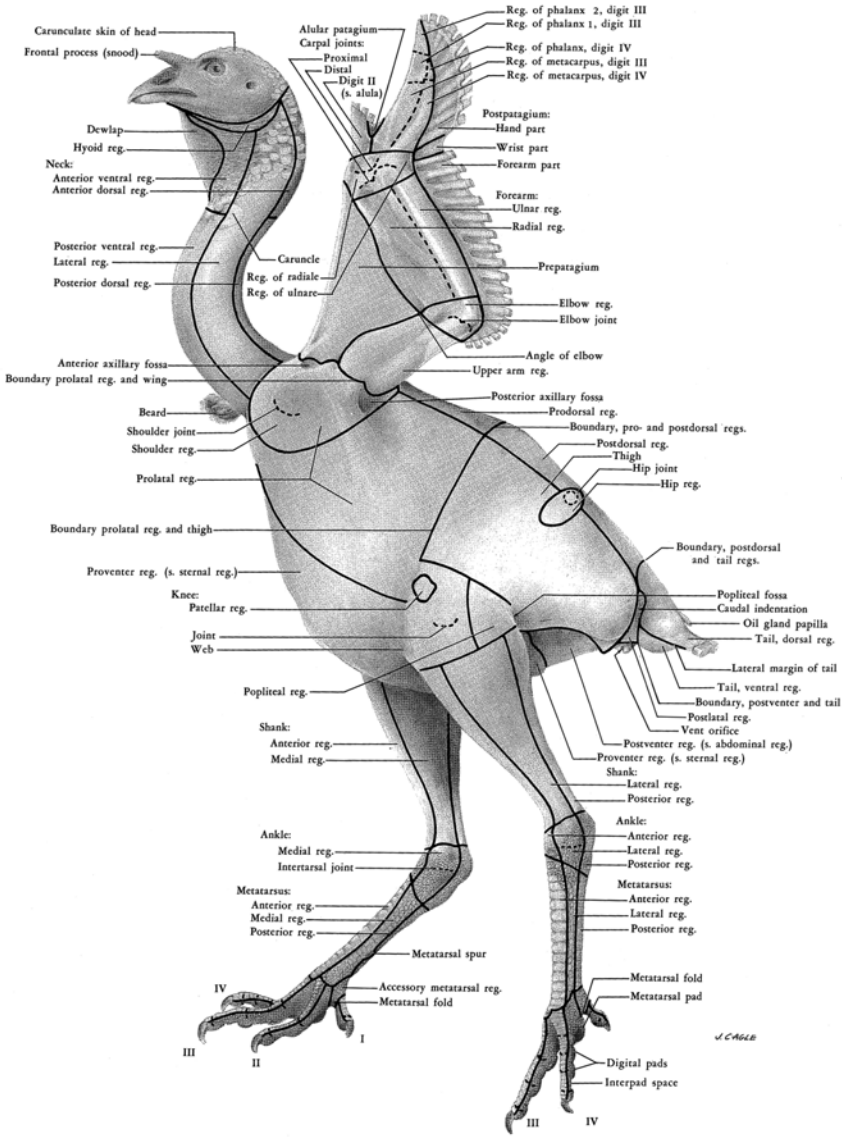


Figure 3.2.4 Lateral view of a turkey showing the different regions. Abbreviations: reg(s)., region(s); s., synonym. From Lucas and Stettenhiem (1972).

In pigeons, large wings relative to body size are used for long distance flying and gliding (Fig. 3.2.5).

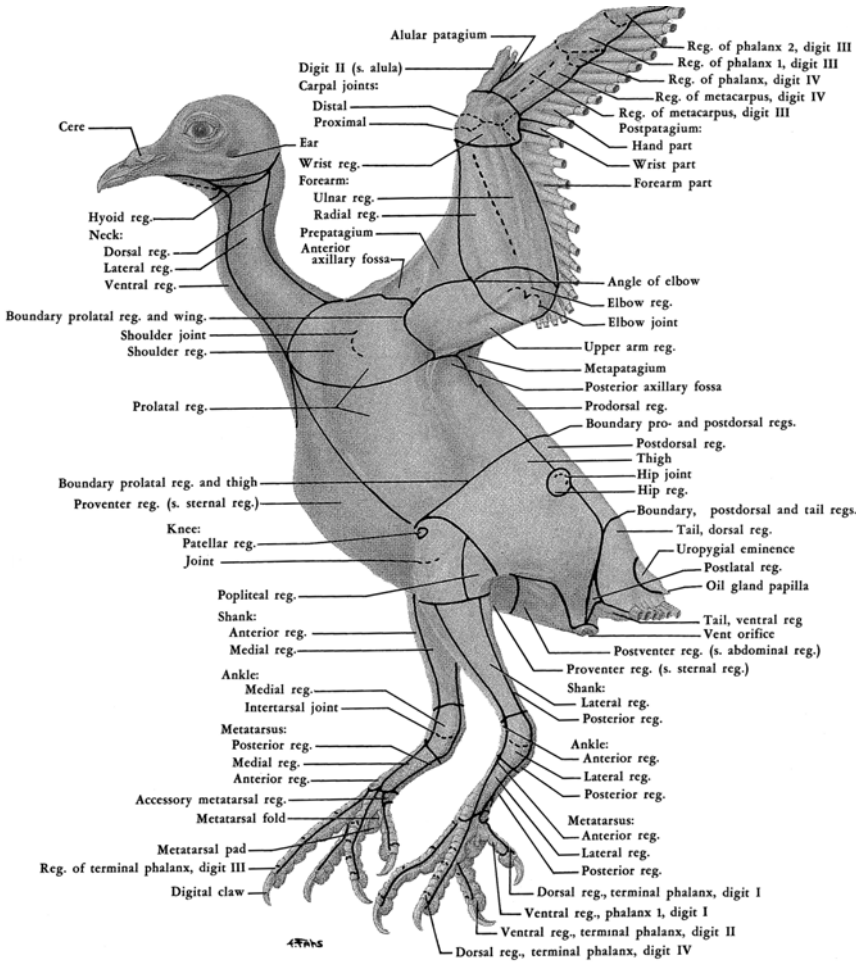


Figure 3.2.5 Lateral view of the common pigeon showing the different regions. Abbreviations: reg(s)., region(s); s., synonym. From Lucas and Stettenhiem (1972).

It is interesting to note that the overall bone structure of a bird's wing resembles the basic bone structure of limbs in mammals; however, major evolutionary modifications have occurred to allow flying.

An additional point worth mentioning is that the number of vertebrae in the axial skeleton varies both between and within bird species; the neck of a chicken can have 16 or 17 vertebrae (Lucas and Stettenheim, 1972). The respiratory system

of birds is unique (Fig. 3.2.6) because oxygen rich air flows efficiently through the lungs and air sacs in only one direction. This is different from the mammalian respiratory system where airflow is bidirectional. There are nine air sacs in the domestic chicken: single clavicular sac, two cervical, two cranial thoracic air sacs, two caudal thoracic and two abdominal air sacs (Grist, 2004). Overall the air sacs are extensions of the bronchi and some connect to the larger long bones to form the pneumatic bones (i.e., makes the bones lighter and this is advantageous during flight).

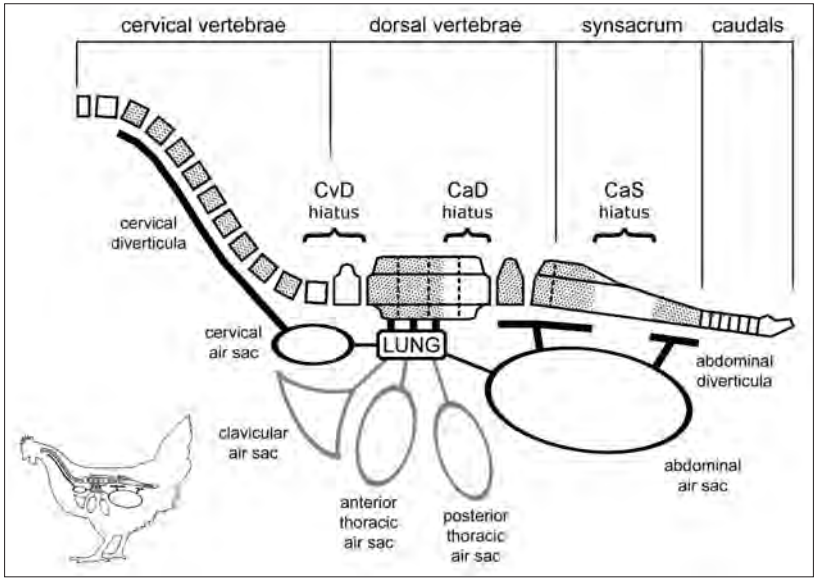


Figure 3.2.6 Respiratory system (lungs and air sacs) in chicken. From Wedel (2009). With Permission.

There are four major tissue types in animals that are related to embryonic development. They include the connective, epithelial, nervous and muscle tissues.

3.3 Connective Tissue

Connective tissue provides a supporting frame (skeleton) to connect and hold different parts of the body. It consists of bones, ligaments, connective tissue covering muscle bundles and fibers, adipose tissue, and blood. The tissue responsible for building bones and cartilage is called "supportive connective

tissue" because it provides strong structural support. Tissue that surrounds muscles, muscle bundles and fibers is called "connective tissue proper". The two types of supportive connective tissue show a number of similarities in their composition and functionality. Usually, both consist of few cells and a lot of extracellular substance. The tissue can range from very soft to very tough such as bones that contain embedded fibers and mineral crystals (calcium salts). In bones, the extracellular substance is tougher than in other connective tissues such as cartilage, where the extracellular substance is more rubbery and soft.

Blood and lymph nodes are also part of the connective tissue system. Blood especially has a large proportion of extracellular material in which cellular components are suspended (cell component usually represents about 40% of total blood volume or even lower in some fast growing breeds). The red blood cells, also known as erythrocytes (i.e., which have a distinct nucleus), transfer gases such as oxygen from the lungs to the body and carbon dioxide from the body to the lungs. The white blood cells, leukocytes, are part of the body's defense system against infections.

Connective tissue proper – consists of fibers with special helix structure of the collagen molecule which provides both strength and elasticity (Fig. 3.3.1). Tropocollagen molecules are the basic structural units of the collagen fiber. They are composed of three α chains that form a triple helix. There are about a dozen types of collagen molecules that have different functional properties and, accordingly, can be found in different locations in the body. The different types of collagen result from at least 20 different α chains that can be combined in different ways to form the triple helix. During filament assembly, the tropocollagen molecules are aligned longitudinally, end to end, and laterally in a slightly overlapping stagger as shown in Figure 3.3.1. This unique spacing and overlapping of tropocollagen molecules results in a collagen fiber that has a striated appearance (Aberle et al., 2012). Not all types of collagen form fibers. Type I and III form large and fine fibers, respectively, Type IV is non-fibrous and forms a chicken wire-like sheath that surrounds individual muscle fibers (basal lamina), and Type V and VIII form microfilaments. In general, the number of collagen fibrils within a muscle depends on its expected load, stress, and activity. Another factor that contributes to overall strength is the formation of intermolecular cross-linkages among the collagen fibrils. In young animals, there are few cross-linkages but as the animal ages the number increases and the bonds become more difficult to break.

Elastin is another major connective tissue protein with a different structure. As compared to collagen, it has a rubbery texture and its fibers can be easily stretched before returning to their original length. Elastin is commonly found in ligaments and arteries and provides structure to certain organs.

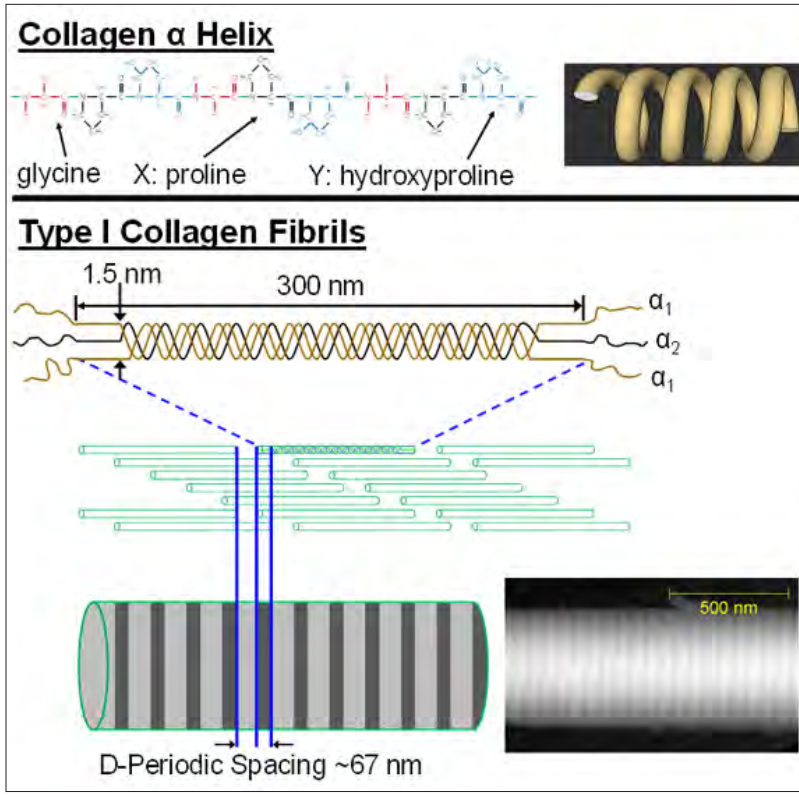


Figure 3.3.1 Microstructure of a collagen fibril which shows how the fibril, participating in muscle movement, can stretch. A striation pattern is seen at 64-67 nm intervals due to the parallel layout of the tropocollagen molecules. The striation can be seen after negatively staining a sample with heavy metals and viewing with an electron microscope. Note: collagen has a relative high content of the unique amino acid hydroxyproline, which can be also used to quantify the amount of collagen in muscle food. From http://www.iupui.edu/~bbml/boneintro.shtml.

Connective tissue proteins usually represent about 1.0% of the total muscle composition. In the meat industry the amount of connective tissue is commonly assessed by the quantity of hydroxyproline, an amino acid that is unique to collagen. Older animals are known to have tougher meat because of increased cross-linking in the collagen fibers. Both processors and consumers should know that collagen can be broken down by exposure to heat, especially prolonged, moist heat that can break some/all of the cross bridges and eventually turns collagen into gelatin. Some of the collagen becomes soluble during cooking (starting melting point ≈ 67°C). As exposure time and temperature increase, more collagen will be converted into gelatin, which becomes apparent when the meat cools and its juices

have a jelly-like consistency. Elastin, on the other hand, cannot be broken down by heat. Therefore, areas high in elastin should be either discarded or tenderized by mechanical means (needles or small blades).

Bones are also part of the connective tissue. An illustration of a chicken skeleton is shown in Figure 3.2.1. The bird skeleton is unique because, although it provides great strength, it is relatively light (i.e., important for the flying bird) as compared to the heavy bone structure needed to support a red meat animal. Bone is an active tissue where building and degradation occur all the time. It consists of an organic matrix and inorganic salts. The former contains the collagen fibers and the so-called ground substance that consists of proteins and sugar complexes. The latter is primarily made up of calcium salts (calcium phosphate and calcium carbonate), which form crystals deposited within the collagen fibers of the organic matrix. The structure consists of bone cells distributed within the matrix and arranged in small cylindrical elements called lacuna (Fig. 3.3.2). These structures form a network of canals between the cell cavities that are important in delivering cell nutrients.

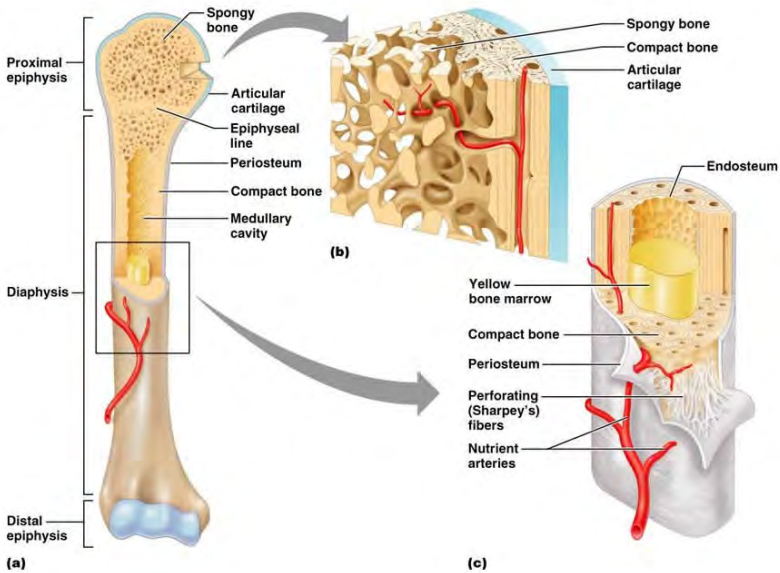


Figure 3.3.2 Overall structure of a long bone. http://classes.midlandstech.edu/carterp/Courses/bio210/chap06/lecture1.html.

The overall structure of a bone (e.g., ulna, femur) is shown in Figs. 3.3.2 and 3.3.3. The long shaft, called a diaphysis, is filled with marrow while the outside consists of a hard, compact bone structure consisting of an organic matrix and inorganic salts. Both ends of the bone, called epiphyses, are enlarged to allow sufficient surface area to connect with other bones via a cartilage-mediated medium. The epiphyseal growth plate is a region underneath the epiphyseal cartilage that separates the diaphysis and epiphysis and is the region responsible for bone elongation (see review by Howlett et al., 1984). The central hollow part of the bone contains the bone marrow that produces new red blood cells. As indicated above, bone tissue a dynamic system in terms of calcium deposition and withdrawal. For example, the laying hen is used as a research model to study osteoporosis in humans because of the fast calcium turnaround during the laying period. Bone growth can be a challenge in fast growing breeds. Summers et al. (2013) have reviewed problems that can occur during the growing of meat and egg type birds.

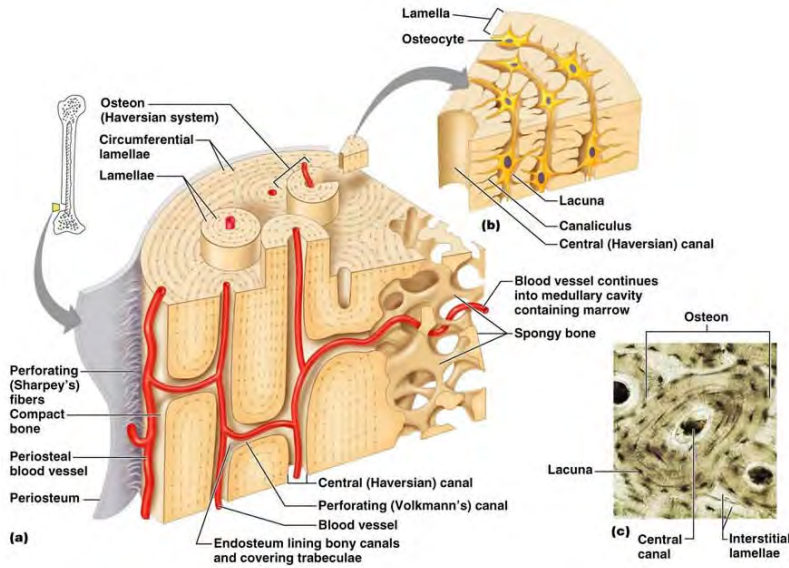


Figure 3.3.3 Structure of a long bone and its microstructure. http://classes.midlandstech.edu/carterp/Courses/bio210/chap06/lecture1.html

Cartilage is another connective tissue that has a strong structure and is used to connect and support different skeletal elements. Cells within cartilage are called chondrocytes and are found in clusters located in small cavities within the extracellular material. The interlacing collagen forms a delicate network of cartilage. Cartilage can differ in the relative amount of collagen fibers and extracellular material. This results in the formation of cartilage with different properties, of which there are three main categories. The first is hyalin cartilage, which is found between individual vertebrae, on the surfaces of joints and bones, and on the dorsal tips of vertebrae. The second type is fibrocartilage, which is found in tendons and within joint ligaments. Fibrocartilage has numerous collagen fibers and can resist repetitive stress. The third type is elastic collagen, which consists of a number of branched elastin fibers that provide elastic characteristics.

Adipose tissue consists mainly of cells and functions to protect sensitive organs (cushioning), store fat (energy) and insulate parts of the body. Adipose tissue is the main means of energy storage for the animal and is used in response to certain needs. For example, migrating birds can largely increase of their adipose tissue mass just before migration. Adipose tissue is usually found enclosed in areas surrounded by a sheath of collagen fibers. Young adipose cells are called adipoblasts. After they mature and fill with fat, however, they are called adipocytes. Adipoblasts grow from 1-2 μm to a size of up to 100 μm by accumulating small lipid droplets that fuse to form a large fat globule. Adipose tissue development is related to age of the animal and the amount of available nutrients. In young animals, the first fat deposit usually appears in the visceral area. Later, subcutaneous fat (under the skin) is developed, followed by a limited amount of intermuscular fat that is deposited in between muscles. As compared to red meat animals, poultry is fairly unique because intramuscular fat, also known as marbling, does not appear in certain locations (breast fillets/*Pectoralis* muscle). In any case, the adipose tissue has a fairly dynamic metabolism, meaning that stored lipids are constantly mobilized (i.e., when a bird lays an egg, it needs to mobilize a large amount of nutrients which includes fat, calcium, etc.).

3.4 Epithelial Tissue

From an embryonic development standpoint, epithelial tissue is designed to serve as the interface between the body and the outside world. Hence, it consists of the skin and the lining of the digestive system. It also contains some other specialized components that will be described below.

The skin (Fig. 3.4.1) serves as a protective layer that prevents microorganisms from entering the body and protects the body from environmental stresses such as drying. It also protects the body against mechanical damage and serves a major role in insulation and heat regulation. In general, the two major parts of the skin are the epidermis, which is the ectodermal portion, and the dermis, which is the mesodermal portion. A unique structure of poultry skin is the feathers (Fig. 3.4.2), which are a complex derivative of epithelial tissue. Feather size varies greatly with the longest tail feathers of a roaster being about a 1,000 times longer than the feathers on its eyelids (Lucas and Stettenheim, 1972).

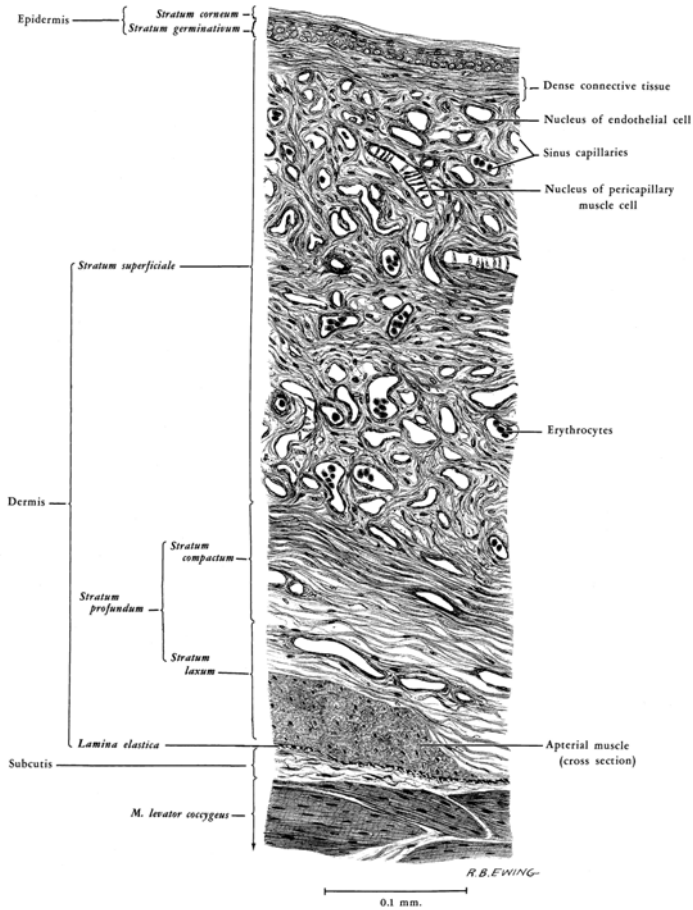


Figure 3.4.1 Structure of the skin section stained with hematoxylin and eosin. Abbreviation: M., *Musculus*. From Lucas and Stettenhiem (1972).

The predominant feathers on a bird's body are called contour feathers and are composed of a shaft with plates or vanes on either side. The feather develops in a follicle (Fig. 3.4.3) and both the follicle and its feather are tubes of modified integument that have a gradient from dermis to keratinized, highly flattened epidermis. The wall of the follicle appears to be drawn upward in some way by the sheath of the growing feather. In a full-growth feather the epidermis of the follicle has a single layer of germinative cells, which are low cuboidal cells that contain large nuclei (Lucas and Stettenheim, 1972). Animal skin has pigmented cells that contain melanin that can make it appear darker. The overall colour of poultry skin, however, is also determined by plant pigments that are absorbed from the diet and deposited in the skin (e.g., xanthophyll in corn can make the skin appear yellow; see discussion in Chapter 16).

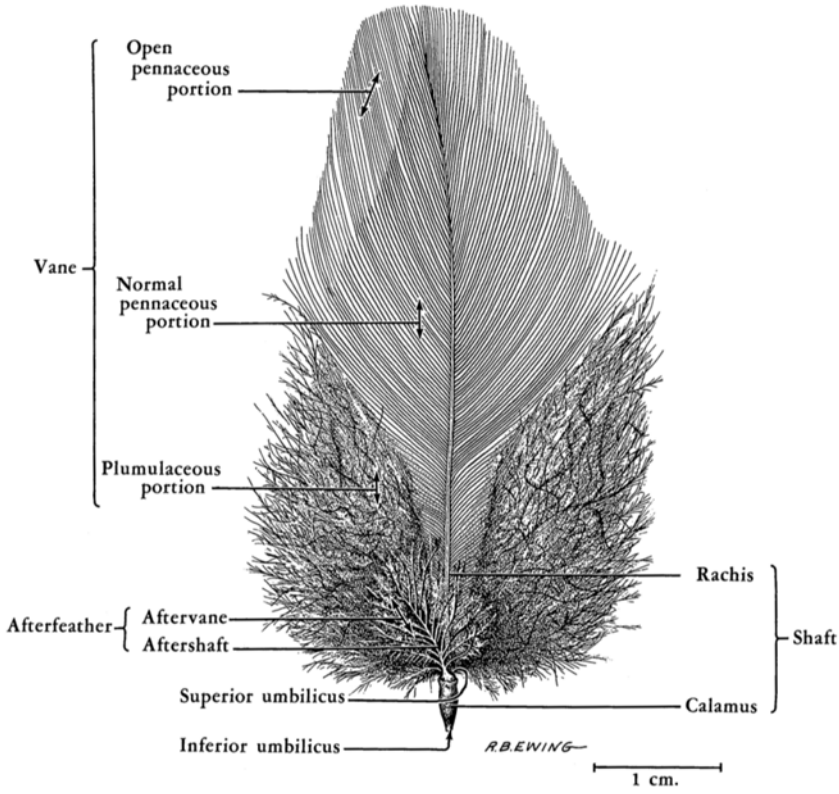


Figure 3.4.2 A structure of a feather from the middle of the dorsal tract of a White Leghorn chicken. From Lucas and Stettenhiem (1972).

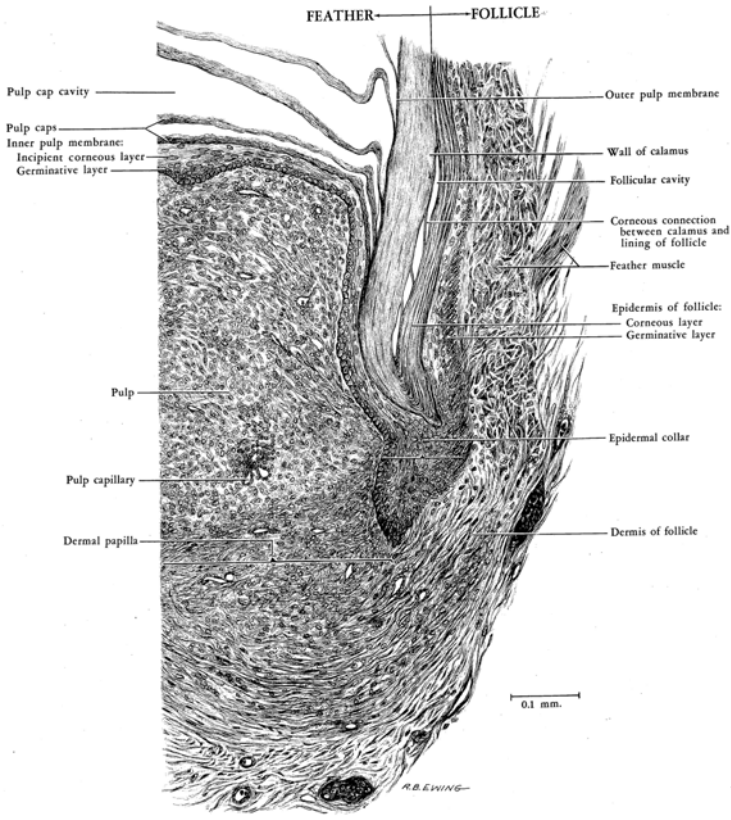


Figure 3.4.3 A microscopical section through a feather follicle of a White Leghorn chicken. From Lucas and Stettenhiem (1972).

Epithelial tissue is commonly characterized by cell shape and the number of cell layers (Fig. 3.4.4). Epithelial cells are usually laid down with little extracellular material. Cell shape can vary from elongated, columnar-type cells to very thin, flat cells called squamous cells. In addition, cuboidal cells also form single or multiple layers on external or internal surfaces of the body.

Other organs that contain epithelial tissue are the lining of the digestive system, liver, and kidney. In organs such as the liver and kidney, the cells secrete different enzymes than those of the digestive system, where they absorb nutrients from the gut and are usually columnar in shape to increase the number of cells in contact with food and make nutrient absorption more efficient.

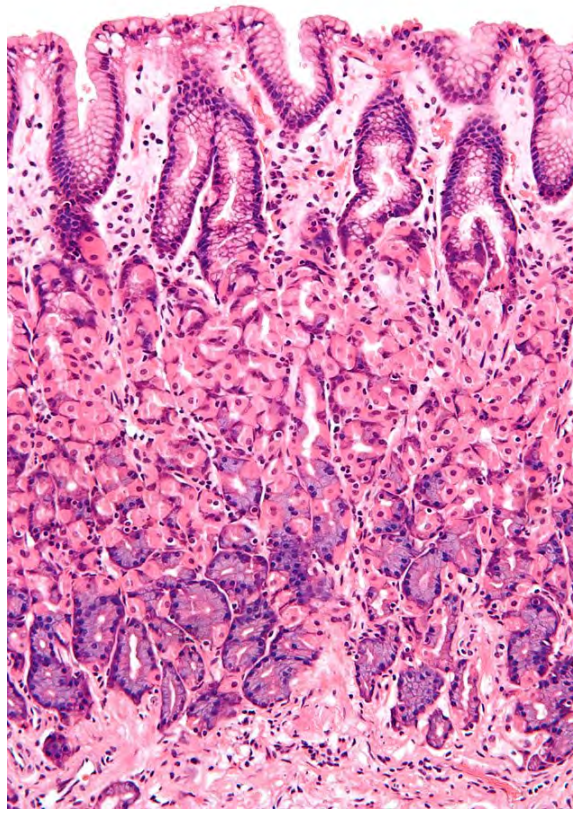


Figure 3.4.4 Classification of cells found in epithelial tissue is based on their shape. Showing here columnar epithelium cells lining at the top of the gut wall, as these many cells can efficiently absorb nutrients. The skin on the other hand has usually flat thin cells for protection. From http://en.wikipedia.org/ wiki/Simple_columnar_epithelium.

3.5 Nervous Tissue

Nervous tissue serves as the communication system within the body. While it represents a small part of the edible meat (usually less than 1%), understanding its structure is essential to understanding muscle contraction (discussed later in the chapter), post-mortem changes, and meat quality issues. The two main structural components are the central nervous system (brain and the spinal cord) and the peripheral system that consists of the nerve cells that reach all parts of the body.

The nerve cell, or neuron (Fig. 3.5.1), is the basic building block of nervous tissue and has a distinct structure consisting of a cell body with an elongated fiber-type structure called an axon. A nucleus is found within the polyhedrally shaped cell body. A few short branched structures called dendrites come out from the body. Motor neurons are those that reach muscle fiber and have a long, single axon that branches when it reaches the muscle. The junction points are called the motor end plates, or neuromuscular junctions (i.e., one nerve reaches a number of muscle fibers and triggers them all concurrently). The action potential, an electrical pulse of about 80 mV that goes from the cell body through the axon to the motor end plates, is transferred to the muscle or other nerves (i.e., their dendrite portion) via a synapse, which is a physical gap between the two cells or structures. Therefore, a chemical transmitter called acetylcholine is used, in most synapses, to convey the message across the gap (e.g., to the muscle). It should be noted that within the brain and other locations, other chemical messengers are used. Certain toxins can block acetylcholine and cause serious problems to the animal. An example of a serious toxin that is of importance in the food industry is the toxin produced by *Clostridium botulinum* (see Chapter 15).

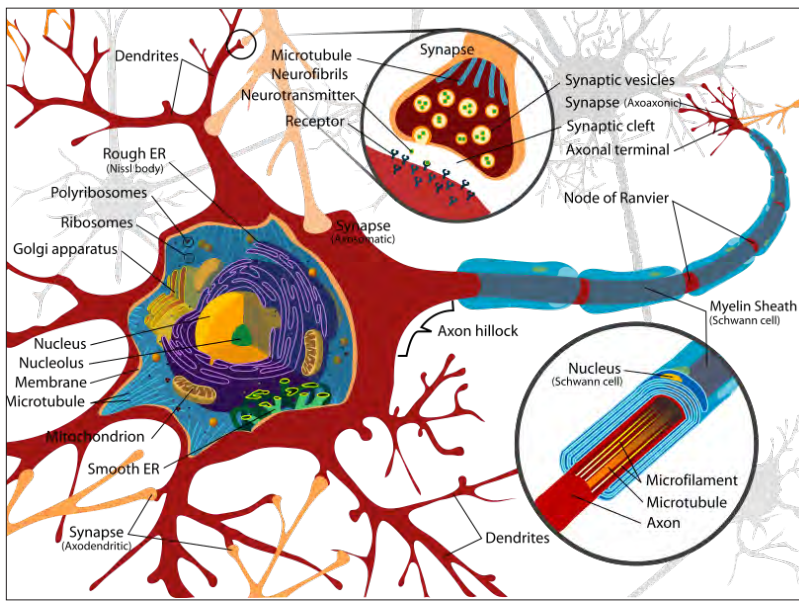


Figure 3.5.1 A schematic drawing of a neuron with motor end plates. From http://en.wikipedia.org/wiki/File:Complete_neuron_cell_diagram_en.svg

In the muscle, nerve trunks consisting of a group of axons can be observed as fine silvery lines because they are covered with a sheath of dense connective tissue. This arrangement helps protect the axons and provides strength to the structure. Small, peripheral nerve fibers are covered with Schwann cells that help speed up the electrical pulse going through the nerve whereas large fibers are often covered with a myelin sheath which is coming from the Schwann cells. Therefore, nerve fibers are commonly referred to as myelinated and non-myelinated fibers.

3.6 Muscle Tissue

The skeletal muscles of a chicken are shown in Figure 3.6.1. They range in size from small muscles (e.g., those that control the eye lids) to very large muscle (e.g., flight muscles). Muscle tissue is considered most important in terms of poultry meat consumption and therefore will be described in detail. So-called white and dark meat in chickens and turkeys represent breast and leg meat, respectively. However, in the migratory duck, the breast meat appears red due to its high myoglobin content, as will be explained later in the chapter.

Muscles are used for various functions in the live animal. The shape and structure is designed to allow for the performance of a specific task ranging from locomotion (flying) to pumping (heart muscle for circulating blood), to moving food along the digestive tract. These three major activities are related to the three types of muscles found in the body: skeletal (movement), cardiac (pumping blood) and smooth (involuntary activities).

a. Skeletal Muscle – Skeletal muscles are mostly voluntary muscles that the animal can either partially or fully control. These muscles are anchored by tendons to bones and are used to move and maintain posture. Although posture control is often maintained as an unconscious reflex, the muscles responsible react to conscious control as well. These muscles comprise 40 – 50% of the average body mass of an adult bird. The muscles range from very large muscles such as the leg muscle (*Biceps femoris*) and flight muscle (*Pectoralis major*), to very small muscles such as those that control eye movement.

Skeletal muscles are also known as striated muscles because of their striated appearance when viewed under a light microscope. As seen in Figure 3.6.2, striations are the result of the repetitive microstructures in the fibers' building blocks (sarcomeres) and their components.

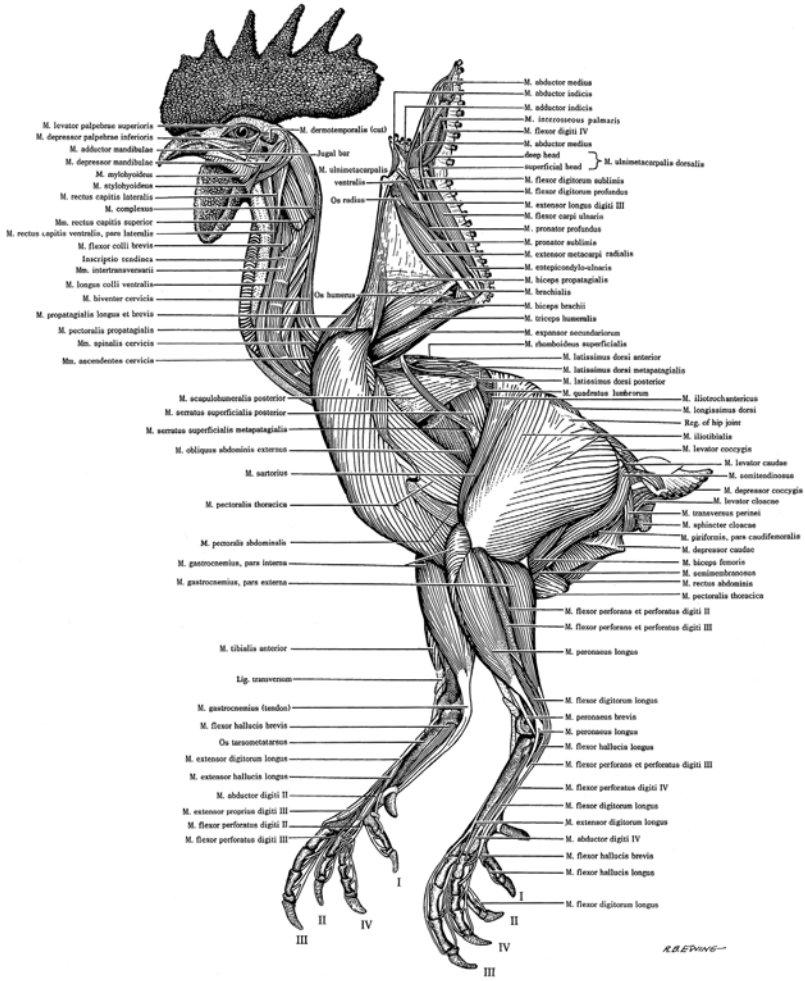


Figure 3.6.1 Lateral view of the superficial musculature of a single comb White Leghorn chicken. Abbreviations: *Lig., Ligamentum; M(m)., Musculus*(i); Reg., Region. From Lucas and Stettenhiem (1972).

Figure 3.6.2 also shows a schematic diagram of whole muscle that is broken down into its components. A large muscle such as the *Pectoralis major* is composed of numerous muscle bundles covered by epimysium. Each muscle bundle (Fig. 3.6.2) is separated from the others by a connective tissue layer called perimysium. As previously indicated, connective tissue provides structural organization,

anchors the different components, and transmits the power generated by sarcomere contraction. Blood vessels and nerves can also be seen in a cross section of the muscle. They supply energy to the active muscle and control its movement.

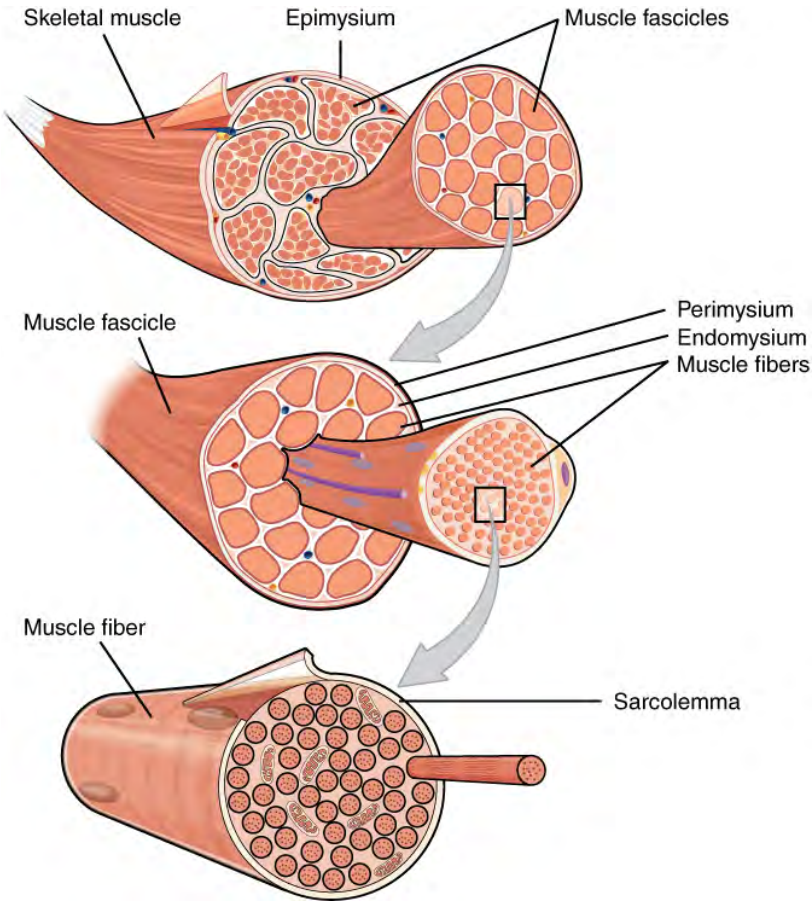


Figure 3.6.2 Schematic diagram showing skeletal/striated muscle structure, starting from a cross section of a whole muscle (size range 0.1 to 0.5 m), including the different layers of connective tissue, going down to the muscle fascicle/bundle, and muscle fiber. A single striated myofibril is coming out from the muscle fiber. It contains the many sarcomeres (smallest contracting unites of the muscle; size range 1.5 to 4.0 microns). Their structure is shown in Figure 3.7.1. They contain the thick and thin filaments with a unique stacked arrangement that produces the light and dark striation of skeletal and cardiac muscles. From http://commons.wikimedia.org/wiki/File:1007_Muscle_Fibes_%28large%29.jpg.

The muscle bundle is composed of smaller muscle fibers that are covered by a thinner layer of connective tissue called endomysium. Skeletal muscles have elongated fibers that are usually multinucleated (Fig. 3.6.3), which seems to permit better control over these long cells. Each fiber consists of numerous myofibrils (Fig. 3.6.2) that have myofilaments inside them forming the sarcomeres. The dark area in a stained muscle preparation is the result of thin and thick filaments overlapping and is called the anisotropic or A-band. Within the A-band is an area without thin filaments that is slightly lighter in colour and is called the H-zone. The area with only thin filaments is referred to as the isotropic or I-band. Sarcomeres are connected through a "backbone" called the Z-line. During muscle contraction, the thick filaments slide toward the Z-line and shorten the sarcomere which causes movement, as will be explained later in the chapter.

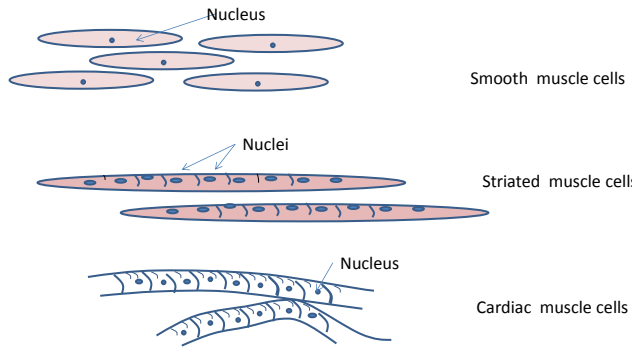


Figure 3.6.3 Smooth, striated (skeletal), and cardiac muscle cells.

b. Cardiac Muscle – Cardiac muscle is an involuntary muscle over which the animal has no direct control. The cells have a striated appearance like a skeletal muscle, but have only one or two nuclei per cell (Fig. 3.6.3) and have a dark red colour as a result of its extensive blood supply. The average length of the cell is about 50-100 μm, and its width is about 15 μm. Cardiac muscle has a unique rhythmic contraction that is triggered by the sinoatrial node and that starts early on in embryonic development. The heart is controlled by the sympathetic and parasympathetic nervous systems, which are partly outside the central nervous system.

Another unique structural characteristic of cardiac muscle is that the fibers run in a mesh-like pattern and are branched. This allows the heart chambers to contract (reduce volume), and pump blood forward. Microscopic examination reveals unique structures called intercalated disks that appear as dense lines, at regular intervals, along the longitudinal axis of a cardiac fiber. They provide a cohesive link between the fibers and facilitate the transmission of contraction force from one fiber to the other.

c. Smooth Muscle – Smooth muscle cells are part of the involuntary systems in the body (i.e., the digestive system, the walls of arteries, and parts of the reproductive system). The fibers have a single, centrally located nucleus and are relatively long and narrow with an average length of a few hundred μm and a diameter of 3-12 μm (Fig. 3.6.3). This muscle does not have a striated appearance like skeletal and cardiac muscle because the repetitive structure of the sarcomere is not as well organized, hence the name smooth muscle. In terms of layout within the body, some areas show different layers of smooth muscle. For example, in the digestive system, a cross section reveals smooth muscle layers that are positioned both perpendicular and parallel to the cut surface. This allows the digestive system to both decrease the gut diameter and elongate to move food down the tube-like structure.

White and Red Fibers – Skeletal muscles can also be divided based on fiber type. In the poultry meat industry there is a difference between white and dark meat. White meat refers to breast muscle from chickens/turkeys, whereas dark meat refers to the leg meat. This classification is based on the overall colour of the meat, which is generally relative to the proportion of red and white fibers within the muscle. Most muscles contain a mixture of red and white fibers; very few muscles are composed of all white or all red fibers.

Red, white, and intermediate fibers have different functions and therefore have different proportions of certain sub-structures (e.g., mitochondria) and metabolic rates (Table 3.6.1). It should be pointed out that these differences are judged on a relative scale and variation can exist within each characteristic. Intermediate fibers (not described in the table) have intermediate characteristics. Muscles with a high proportion of red fibers are used for long term activities such as supporting the skeleton in an upright position. Because of their unique metabolism they are less easily fatigued.

Table 3.6.1 Relative comparisons between red and white muscle fibers in poultry.

Characteristic	Red fiber	White fiber
Myoglobin (conc.)	high	low
Colour	red	white
Contraction speed	slow	fast
Mitochondria (number)	high	low
Mitochondria (size)	large	small
Glycogen content	low	high
Clycolytic activity	low	high
Lipid content	high	low
Oxidative metabolism	high	low
Fiber diameter	small	large

A constant oxygen supply is important and, together with a high proportion of enzymes involved in oxidative metabolism, the fibers can function for extended periods of time. They also have a higher myoglobin (see structure in Chapter 16) content, which results in a darker/redder appearance. Compared to the white fibers, red fibers contract at a slower rate but have the capacity to operate for a longer period of time. The presence of more and larger mitochondria, as well as higher lipid content, allow the fibers to generate energy on site and contract for a longer period of time.

On the other hand, white fibers have less myoglobin and a lower oxidative activity compared to red fibers (Table 3.6.2). Glycolytic metabolism, which predominates in white fibers, can occur with or without oxygen, i.e., aerobic or anaerobic metabolism, respectively. Muscles with relatively high content of white fibers show lower capillary density since they do not rely on fast nutrient transfer. White fibers contract more rapidly and in shorter bursts compared to red fibers and they are more easily fatigued. In some of the active, wild-type birds, such as ducks and geese who fly long distances during their migration, the breast muscle appears red because of the higher proportion of red fibers (i.e., the muscle can operate for a few days while the bird crosses a large body of water).

Table 3.6.2 Total heme, myoglobin, and hemoglobin content in chicken muscles. From Kranen et al. (1999).

Muscle	n	Total heme	Hemoglobin	Myoglobin
		(mg/g)		
Heart	9	3.75 ± 0.64^{a}	2.67 ± 0.65^{a}	1.08 ± 0.41^{a}
Adductor	8	1.39 ± 0.31^{b}	0.83 ± 0.21^{b}	0.56 ± 0.17^{b}
Pectineus	8	0.10 ± 0.04^{e}	0.09 ± 0.04^{d}	0.01 ± 0.00^{c}
Sartorius	6	0.79 ± 0.12^{c}	0.67 ± 0.11^{b}	0.12 ± 0.02^{d}
Pectoralis	10	0.24 ± 0.04^{d}	0.24 ± 0.04^{c}	ND

$^{a-e}$ Per parameter, means with no common superscript differ significantly as analyzed by t test ($P < 0.05$).
Values are means ± SD of the numbers (n) of samples indicated.
ND = not detectable.

3.7 Muscle Proteins and Muscle Contraction

3.7.1 Muscle Proteins

The physical structure of muscle is mainly comprised of proteins made of amino acid chains. Muscle proteins represent 18 - 20% of lean muscle weight whereas water is about 75% and fat 5%. Muscles contain over 50 different proteins but there are about five present in major proportions. Table 3.7.1 shows the three major protein groups based on their water and salt solubility (Asghar et al., 1985). Proteins can also be grouped in other ways but for meat scientists this is the most common division. In the lab, protein separation is achieved by homogenizing a piece of lean muscle tissue (e.g., 1:1 meat to water) in a high speed mixer/homogenizer. The homogenate is then placed in a test tube and centrifuged to separate the aqueous phase, which contains the water soluble proteins (Table 3.7.1; sarcoplasmic proteins). After decanting the aqueous top layer, a salt solution (commonly using 0.6 M sodium/potassium chloride) is added to the bottom layer, mixed well (or homogenized), and centrifuged. This separates the salt soluble proteins into the top layer (Table 3.7.1; myofibrillar proteins) and the non-soluble proteins into the bottom layer (Table 3.7.1; stromal proteins).

Table 3.7.1 The major proteins in an average muscle divided into three groups according to their solubility (see text) and their relative percentage in the wet muscle (based on 19% total protein).

Group	Protein	%
Sarcoplasmic		(5.5)
	Myoglobin	0.2
	Hemoglobin	0.6
	Cytochromes	0.2
	Glycolytic enzymes	2.2
	Creatine kinase	0.5
Myofibrillar		(11.5)
	Myosin	5.5
	Actin	2.5
	Tropomyosin	0.6
	Troponin	0.6
	C-protein	0.3
	α-actinin	0.3
	β-actinin	0.3
Stromal		(2.0)
	Collagen	1.0
	Elastin	0.05
	Mitochondrial	0.95

a. Sarcoplasmic Proteins – Distributed within the cellular fluid (i.e., sarcoplasm), they consist of myoglobin (the oxygen carrying molecule that gives this fraction its distinctive red colour; see structure in Chapter 16) as well as different enzymes. Sarcoplasmic proteins represent about 30% of the muscle's proteins.

b. Myofibrillar Proteins – These proteins are the building blocks of muscle and are also known as contractile or cytoskeletal proteins. The main proteins are myosin and actin (Table 3.7.1), which make up the thick and thin filaments, respectively. More detailed description on their structure and function can be found below. Overall, this group represents about 55% of the muscle proteins.

c. Stromal Proteins – Neither water nor salt soluble, these proteins comprise about 12% of muscle protein. The two major proteins are collagen and elastin, which are part of the connective tissue. They form structural components such as membranes that surround cells, muscle bundles (Fig. 3.6.2), ligaments, and tendons and they cushion joints by providing an intermittent material.

The following section briefly describes the major myofibrillar (salt soluble) proteins involved in muscle contraction, their unique structure, and their three-dimensional arrangement.

a. Myosin – Myosin represents the largest proportion of myofibrillar proteins (45%) and forms the thick filaments in muscle. It is an elongated, rod-shaped protein (Fig. 3.7.1) with a very high molecular weight of around 450,000 Daltons. The structure has two heavy and two light chains, which can be separated when myosin is subjected to a specific proteolytic enzyme activity. The heavy chains consist of the myosin heads, and the light chains consist of the tails. The heads possess a unique ability to split adenosine triphosphate (ATP) molecules into adenosine diphosphate and phosphate ($ADP + PO_4$), which generates the energy needed for contraction. During contraction the heads form cross bridges with the actin molecules while using energy to change their orientation and cause movement (described further below).

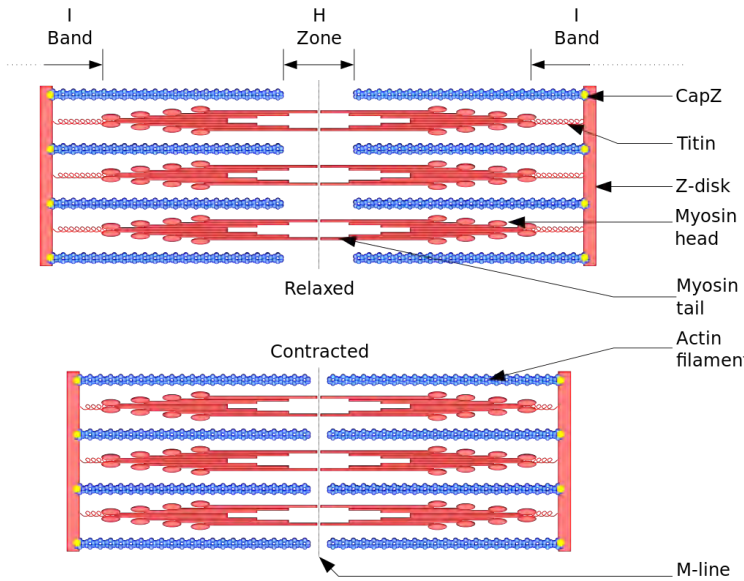


Figure 3.7.1 The microstructure of the major proteins participating in the sarcomere structure (smallest contracting unit) and muscle contraction. Thick filaments made by the myosin protein. Thin filaments made by actin, troponin and tropomyosin. The titin protein which connects the thick filaments to the Z-disk. From http://de.wikipedia.org/wiki/Muskelkontraktion#/media/File:Sarcomere.svg

b. Actin – Actin is the building block of the thin filament. It has a lower molecular weight of 42,000 Daltons and consists of two chains of F-actin that are formed from individual G-actin molecules (Fig. 3.7.1). The formation of the double helix in the thin filament takes place at a specific salt concentration, which favors the formation of the chain.

c. Tropomyosin – This protein is wrapped around thin filaments (Fig 3.7.2) and is a rod-like protein that surrounds the helical structure of actin. It constitutes about 5% of the myofibrillar proteins. There is one tropomyosin molecule for every seven actin molecules. Overall, it "lies" alongside the actin molecule and is positioned in the groove of the helical structure of the actin double helix.

d. Troponin – Troponin is another protein that is wrapped around the thin filament. It is a globular protein and constitutes about 5% of the myofibrular proteins. It is also present in the groove between the two actin filaments, where it "lies" within the tropomyosin strands. The troponin units are positioned in a repetitive pattern along the actin filament (Fig. 3.7.2). Overall, there are three types of troponin molecules:

- Troponin C – binds Ca^{++}
- Troponin I – inhibits ATP
- Troponin T – binds tropomyosin.

3.7.2 Muscle Contraction

Muscle contraction, and the movement it produces, is the result of a complex chain of events. This section provides an overview of the steps and processes involved. However, the reader should be aware that there are many textbooks devoted entirely to muscle contraction and that although we know a lot about the subject we certainly do not understand it all. While numerous individuals have received a Nobel Prize for their work in this area, more discoveries are expected. Muscle movement is the result of thousands to millions of sarcomeres (the smallest contractile unit) moving in unison to produce tension. During this process, stored chemical energy (from the food we eat that has been stored as high-energy bonds in the form of adenosine triphosphate - ATP) is converted into physical movement.

The Sliding Filament Theory is currently the most comprehensive theory used to explain muscle movement and is based on how the thick myosin filaments slide between the thin actin filaments towards the Z-lines (Fig. 3.7.2). During this process, one can measure a shortening of the sarcomeres and a conversion of energy rich ATP into ADP.

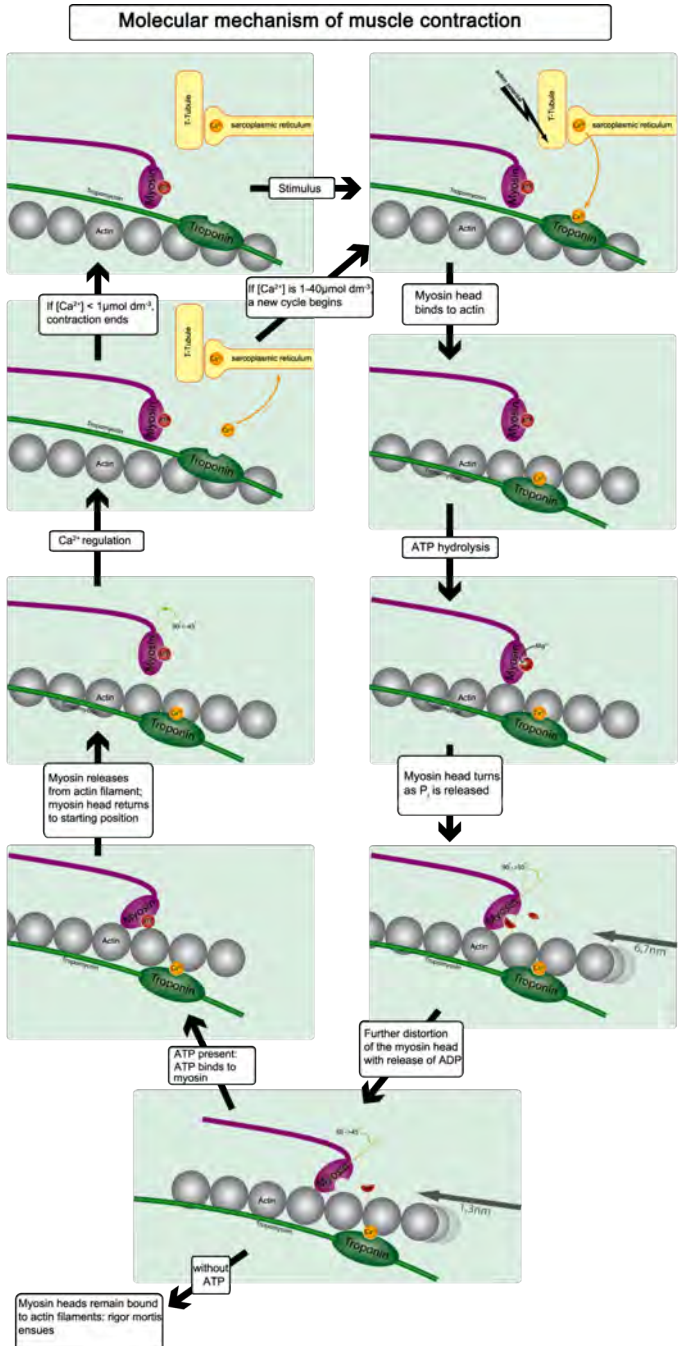


Figure 3.7.2 Illustration of the sliding filament theory. From http://de.wikipedia.org/wiki/Muskelkontraktion#/media/File:Muskel-molekular.png

As mentioned earlier, the myosin heads have a site capable of splitting the ATP, thereby releasing the energy needed to bend or twist the heads so they can pull the myosin molecule towards the Z-line (Pollack, 1990). The trigger for this process comes from the brain and is transferred via the nervous system (Fig. 3.5.1). The signal travels through the nerve by depolarizing the membrane, which quickly changes the internal electrical potential from about -80 mV to +20 mV. During the rest time, the cell establishes and maintains a potential difference (also called the resting action-potential) between the inside and outside of the cell. This is achieved by three mechanisms which include: active pumping of the Na^+/K^+ ions out of the cell, selective permeability to prevent entry of the Na^+, and using large anion proteins trapped on the inside of the cell membrane. When a message is passed through the cell, there is a quick reverse of the electrical potential (also called depolarization). The polarization change takes about 1 millisecond before the original resting potential is restored. The entire event from resting potential to the next resting potential is called Action Potential (i.e., depolarization, repolarization, hyperpolarization).

When the signal arrives at the nerve ending (Fig. 3.5.1; motor end plates), the message is transferred across the synaptic gap to the muscle by the neurotransmitter acetylcholine, which is released from the nerve ending and causes the muscle cell membranes to depolarize. This chemical messenger is broken down very quickly by the enzyme acetycholinesterase to prevent continuous signaling. Electrical depolarization in the muscle cell membrane is transferred to the myofibrils via a special arrangement of T-tubules within the sarcoplasmic reticulum, which causes a calcium release and a chain of events that result in muscle contraction (Fig. 3.7.3). The individual steps of the contraction process are outlined below:

a. calcium is released from the sarcoplasmic reticulum's terminal cisternae into the sarcoplasm
b. free calcium is quickly bound by troponin-C
c. tropomyosin translocates to uncover actin binding sites
d. actin and myosin molecules form cross bridges (Fig. 3.7.2)
e. the myosin head is energized via myosin-ATPase activity, which converts ATP $\rightarrow$ ADP + Pi
f. the repeated formation and breaking of cross bridges results in sliding of the thick filaments towards the Z line and, hence, sarcomere shortening.

During the relaxation phase:

a. signal from the nerve diminishes
b. the sarcolemma and T-tubules are re-polarized, preparing them for the next signal
c. the calcium pump in the sarcoplasmic reticulum actively resequesters calcium
d. cross bridges are broken and cannot reform
e. the tropomyosin molecules cover the actin binding sites
f. passive sliding back of the filaments as the sarcomeres return to their resting state.

An illustration of these steps is shown in Fig. 3.7.3.

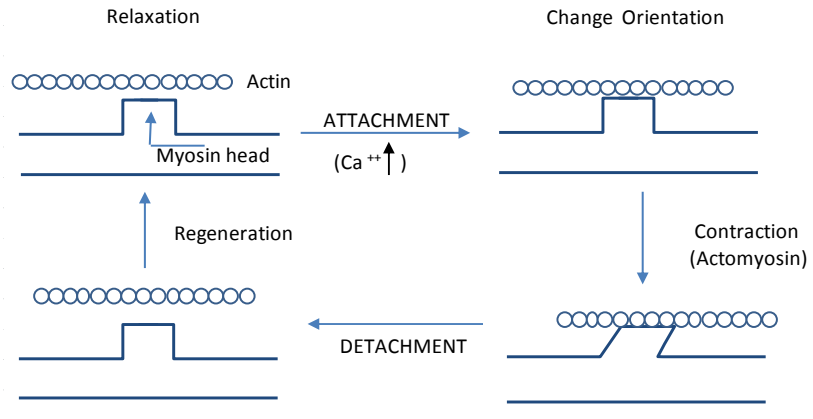


Figure 3.7.3 A schematic illustration of the steps involved in muscle contraction.

Overall, calcium concentration in the sarcoplasm controls muscle contraction. During rest, the concentration of free calcium is below 10^{-8} moles/liter and when calcium is released it increases to around 10^{-5} moles/liter. This causes the troponin-C to bind calcium, which in turn triggers movement of the tropomyosin-troponin system away from the myosin binding sites on the actin molecules. During relaxation, calcium is resequestered and its concentration goes back to around 10^{-8} moles/liter.

3.8 Rigor Mortis Changes and Meat Quality

The sections above described the structure and mechanism of muscle contraction in living tissue. In the living animal, organs work in harmony and the internal environment is kept within a very narrow range of temperature, pH, oxygen, and CO_2 concentration through a process called homeostasis. The body employs thousands of nerve sensors sensitive to physical pressure, temperature, gas concentration, blood pressure, etc., to collect data about external and internal conditions. This information is processed and corrective actions are taken as needed (e.g., fluffing the feathers, running to find a shelter, increasing breathing rate to get rid of heat, etc.).

When the animal is slaughtered and bled, oxygen and nutrient supply to the muscles is stopped and many homeostatic mechanisms are disrupted. Stress conditions prior to slaughter also affect homeostatic conditions, which can later influence meat quality. Stress can arise from activities such as catching the birds, loading, transportation, unloading, and immobilization. Immobilization of poultry, which refers to rendering the bird unconscious, is usually the first step in the process. In most countries, regulations require the use of humane immobilization methods to minimize animal pain and distress at subsequent slaughter. Electrical stunning and controlled atmosphere stunning (CAS; by CO_2, Argon) immobilization are commonly employed (see Chapter 8). A proper immobilization method should also focus on reducing stress, such as wing flipping before and during stunning, in order to minimize hemorrhages in the muscles and incidences of broken bones. The next step after stunning is known as exsanguination or bleeding. This step represents the beginning of the major changes seen during the post-mortem phase. Blood removal is required as an excessive amount of blood left in the muscle will result in an overall dark appearance or dark spots. Usually, around 40-50% of the total blood volume is removed (Chapter 5) and the remainder is contained within the vital organs. This occurs because the peripheral blood vessels constrict when the blood pressure drops in an attempt to maintain blood pressure. Blood removal stops communication between muscles and vital organs. In the living, healthy animal, oxygen is shuttled from the lungs to tissues via red blood cells. Once the oxygen supply is cut off, the normal aerobic tricarbocylic acid (TCA) cycle stops (Fig. 3.8.1) and energy metabolism switches to an anaerobic pathway to provide the muscle with energy. It should be remembered that such anaerobic pathways can only be carried out in the living cell for a certain period of time. In living tissue, lactic acid is produced (i.e., via an anaerobic metabolism pathway) and then must be transported to the liver to be resynthesized into glucose or to the heart where it

is broken down into water and CO_2 via a specialized enzyme system (Aberle et al., 2012). When circulation stops, lactic acid accumulates in the muscle until most of the glycogen stored in the muscle (about 1% of the resting muscle weight) is depleted or until the pH becomes too low for glycolysis enzymes to operate.

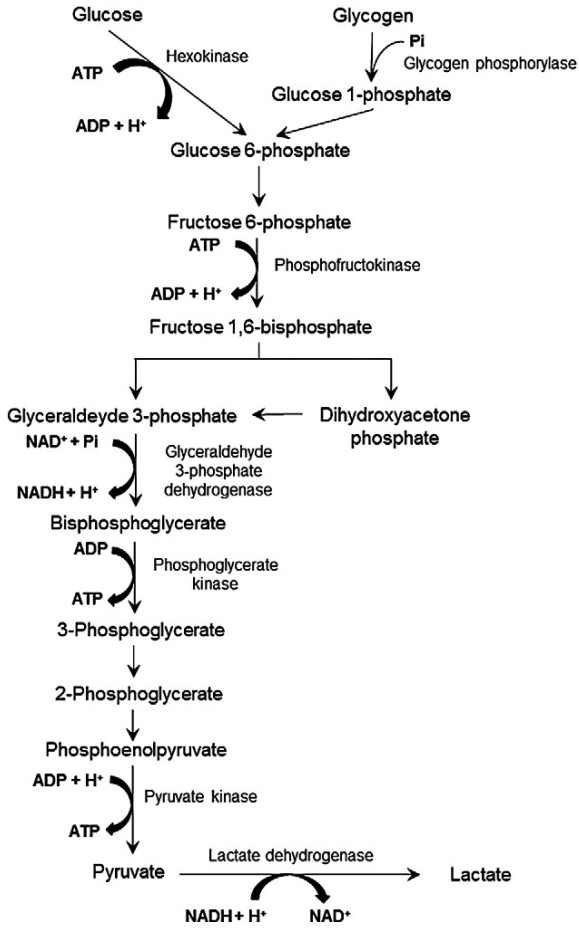


Figure 3.8.1 Aerobic tricarbocylic acid (TCA) cycle stops. From Scheffler et al. (2011).

pH decline during post mortem (Fig. 3.8.2) and its final, lowest point, called the ultimate pH, can vary between different meat producing animals. In poultry pectoral muscle, the drop in pH occurs more than twice as fast as it does in beef and pork (Aberle et al., 2012). The rate and ultimate pH can have major effects on meat quality and colour development. A normal pH reduction pattern is shown by the middle line in Figure 3.8.2. This represents a gradual decrease from the neutral pH of the living breast muscle to about 5.8. In some animals glycogen storage has been depleted prior to slaughter (e.g., due to extended activity or struggling). This results in low lactic acid production, and the pH drop will be minimal and the ultimate pH will stay high. The resulting meat is known as dark, firm, and dry (DFD). The dry appearance results from a high ultimate pH, which is further away from the isoelectric points of the muscle proteins and, therefore, exhibits higher water holding capacity (see Chapter 13). On the other extreme, the meat's pH can drop very quickly at the beginning of the post-mortem process, which results in the so-called pale, soft, and exudative (PSE) meat (Barbut et al., 2008). In this case, a rapid drop in the pH within the first hour, while the meat temperature is still high (e.g., >35°C), can cause protein denaturation. The partially denaturated proteins cannot hold water very well and the surface appears wet, hence, exudative meat. The colour of the meat is pale as a result of more light reflected from the looser muscle structure as compared to the tight structure of the DFD meat (Swatland, 2008).



Figure 3.8.2 Rate and extent of pH decline during post-mortem of chicken breast muscle.

Rigor mortis, which means "stiffness of death" in Latin, follows the depletion of energy from the muscle, and results in its temporary toughening. This state does not take place immediately after slaughter, but rather a certain time afterwards (Fig. 3.8.3). It occurs due to the gradual depletion of glycogen and other energy sources such as creatine phosphate within the cell. Dunn et al. (1993) suggested that when the muscle pH drops below 6.3, calcium can no longer be efficiently sequestered by the sarcoplasmic reticulum. As a result, cytoplasmic calcium concentration starts to rise, exposing more myosin sites to actin. In the presence of ATP the muscle starts to build some active tension (as explained by the sliding filament theory) and consequently becomes less extensible (onset of rigor mortis). When all the energy sources have been depleted, the actomyosin cross-bridges (between the thick and thin filaments; Fig. 3.7.2) can no longer be separated and the muscle becomes inextensible with a stiff texture and the muscle has developed full rigor. The time between slaughter and the onset of rigor mortis is called the delay-phase. This is seen in Fig. 3.8.3 as the initial low tension force. After a certain period of time, the muscle becomes flexible again (decline of the curve seen in Fig. 3.8.3) as a result of proteolytic enzymes that slowly breakdown the sarcomere components. Some of the major structural changes during the so-called aging process include the degradation of the Z-line (leading to fragmentation of the myofibrils and the connective tissue) and degradation of individual proteins such as titin, nebulin and desmin (Scheffler and Gerrard, 2007; Scheffler et al., 2011). The proteolytic enzymes responsible for the degradation fall into two major categories: calpains and cathepsins. These enzymes vary in their calcium requirement for activation. Calcium is released from the sarcoplasmic reticulum and mitochondria during postmortem aging. Since the enzymes are activated by calcium, calcium infusion has been suggested as a way to improve tenderness. This actually works and is used more in the red meat industry where tough meat is a bigger problem. Experiments have also shown that chelating the calcium ion inhibits these enzymes and delays tenderness development.

The rate of pH decline is significantly affected by post-mortem temperature and so it is a critical factor in obtaining high quality meat. At high temperature, pH decline is very fast. The combination of high temperature (>35°C) and low pH values will cause protein denaturation, particularly affecting myosin (Bilgili et al., 1989; Scheffler et al., 2011). An optimal temperature for the post-mortem process is between 15-20°C. Muscle temperature reduction should commence as soon as possible after slaughter to also help control microorganism growth. On the other hand, reducing the temperature too quickly to below 5°C can cause meat tenderness problems in poultry meat (Dunn et al., 1993). Temperature reduction to sub-zero temperatures, prior to the completion of rigor mortis, results in a condition known as thaw rigor. This is caused by a severe muscle contraction that

takes place during thawing, and is triggered by an excessive calcium release from the sarcoplasmic reticulum into the sarcoplasm (Aberle et al., 2012; Bilgili et al., 1989). Such a severe contraction of the muscle structure pushes water out of the meat and toughens the muscle. An unrestrained muscle (i.e., dissected and not attached by ligaments to bones) with this condition can shorten by over 50% of its original length after thawing. A microscopic examination of such muscles reveals a severe contraction of the sarcomeres and almost the complete disappearance of the I-band.

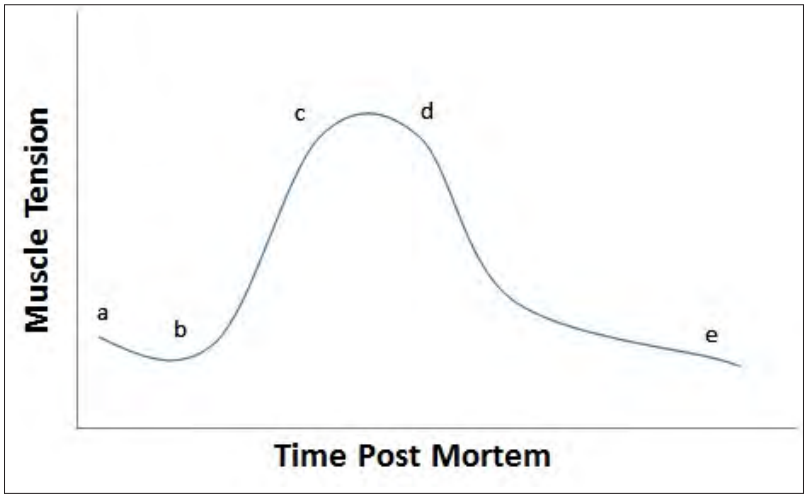


Figure 3.8.3 Development of rigor mortis expressed as muscle tension over time. The regions represent: delay time a-b; development of rigor mortis b-c; full rigor development c-d; and rigor resolution d-e. Time for each section depends on factors such as specie, degree of exercise prior to slaughter, stunning method and temperature. Adapted from Aberle et al. (2012).

Cold shortening is a less severe shortening that can occur when the temperature is reduced below 5°C but above freezing prior to the onset of rigor mortis (i.e., in the presence of ATP). The condition is more common than thaw rigor and damage to the muscle is less severe; however, it can still cause significant toughening and moisture loss problems.

Increasing the muscle temperature above 50°C (higher than normal body temperature), during the rigor process will also result in excessive shortening known as heat rigor. This is the consequence of rapid ATP and creatine phosphate depletion. However, this problem is not commonly seen in the meat industry.

The information presented above is used to illustrate the point that conditions before and during rigor can have major effects on meat quality. This includes maintaining an adequate temperature during the rigor mortis process to prevent shortening and/or toughening of the muscle. It is commonly suggested that the temperature be kept at 18 ± 2°C so it is above 15°C, but still lower than body temperature (≈39°C for broilers). Since the rigor process in poultry is much faster than in beef (1-3 hrs vs. 12-24 hrs, respectively. Note that the 1-3 hrs applies to processes which include electrical stimulation as described below. If no electrical stimulation is used, the range is longer and can be 3-8 hrs), poultry carcass chilling in modern processing plants starts about 30-60 min after slaughter and reaches 5-15°C (see Chapter 5) when rigor is completed or almost completed.

Electrical stimulation can be used after slaughter to speed up the rigor process and overcome some of the problems associated with pre-rigor deboning that might be encountered during rapid chilling. Originally, the process was developed for the red meat industry to allow accelerated processing (i.e., deboning the meat at an earlier stage compared to non-electrically stimulated carcasses). The process includes passing an electric current through the carcass and triggering muscle contraction by stimulating the nervous system (Sams, 1999; Aberle et al., 2012; Barbut, 2014). Such contractions deplete the energy within the muscle and cause a rapid onset of the rigor mortis process. High voltage applied during bleeding of chickens can induce excessive muscle contraction. This can cause physical damage to the sarcomere structure by tearing off some of the sarcomeres, which can actually add to the tenderization effect of electrical stimulation. However, one should be careful not to damage the muscle structure too much. Electrical stimulation of defeathered carcasses at a moderately high level can eliminate risks of rupturing the sarcomeres but accelerate ATP depletion to an extent that allows for filleting at 3.5 hrs post-mortem without the risk of getting tough meat (i.e., this is actually a common process used by the poultry industry). Besides accelerating the rigor mortis process and allowing deboning at an earlier stage (see Chapter 9), electrical stimulation can also be helpful in preventing or minimizing cold shortening problems (Sams, 1999). As mentioned in Chapter 1, the use of electrical stimulation for poultry is becoming very popular because it makes the deboning of broiler meat within 3.5 hrs possible on the line. Additional discussion on the procedure and the equipment used can be found in Chapter 5.

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4

LIVE BIRD HANDLING

4.1 Introduction

Compared to the total growing period, transporting live birds from the farm to the processing plant is a relatively short operation. To move them, however, the industry is faced with several challenges as birds have to be gathered, loaded, transported, and unloaded in new unfamiliar environments to the birds. Some of the challenges include harvesting the birds, feed withdrawal, and temperature variations during transport. If poorly controlled, these factors can result in downgrading and decreased meat quality. The following chapter describes current methods for catching and transporting birds to the plant, and has an emphasis on procedures involving mechanization and automation steps (Fig. 4.1.1) that increase efficiency, reduce human contact, and lower stress on the birds. A discussion on manual versus mechanical catching and loading is provided, as well as ways to monitor and reduce stress during transportation (e.g., minimize elevated temperature and relative humidity levels in a covered truck, cold stress).

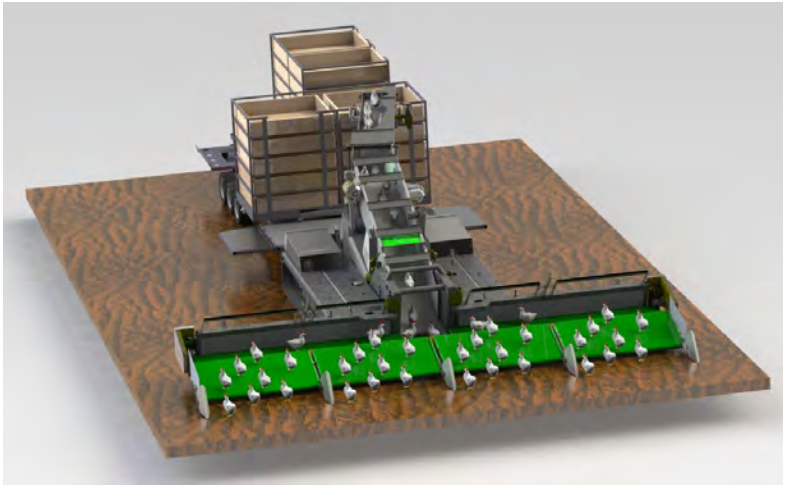


Figure 4.1.1 A mechanical loader that can be used in the barn to gently move birds to crates. See text for more discussion. Courtesy of CMC.

4.2 Harvesting – General

Gathering and moving a large number of birds from the growing farm to the processing plant can be a challenge in terms of logistics, animal welfare, and scheduling. Modern barns commonly house 20,000 to 30,000 broilers, depending on the size of the bird and the stocking density. Commercial barns are often 25 m wide × 250 m long. In the case of turkeys, a barn usually holds 5,000 to 15,000 birds, again depending on factors such as their size (larger toms are usually grown separately from the smaller hens), temperature conditions. Most meat type birds are raised on litter made out of wood shavings or other plant materials, which can affect the method and equipment that can be used to gather the birds inside the barn. Broilers are usually marketed at 6 to 8 weeks of age at a live weight of approximately 2.0 to 4.5 kg and turkeys are marketed between 13 to 23 weeks at a live weight of 5.0 to 20.0 kg (see Chapter 2). In both cases the larger birds are usually used for cut up and/or further processing while the smaller birds are sold whole and/or to food service operations.

Prior to catching and loading, the barn is prepared by raising the watering and feeding devices that are commonly suspended from the ceiling. This provides an area free of obstacles for the catching crew or the mechanical harvesting tractor. The feed withdrawal procedure is very important as it has a big influence on the quality and weight of the birds received at the plant (e.g., too much feed in the digestive system will result in contamination of the birds during processing, while a long time off feed will result in a weaker intestine and more rupturing during the evisceration process). Usually feed withdrawals of 8-12 hrs for broilers and 6-10 hrs for turkeys are recommended, as will be discussed in more detail later in the chapter.

Another factor that can improve loading is dim lighting. Therefore, birds are loaded at night or when the barn's lights are turned down. This helps calm the birds and also results in less feed consumption.

4.3 Manual Harvesting

Most poultry around the world are caught and loaded into cages or modules by hand. Kettlewell et al. (2000) suggested that the "ideal" way to pick up birds with respect to animal welfare is by the sides, but this method is not commercially feasible due to the high catching rate required. Instead, broilers are picked up by the legs in order to achieve a reasonable catching rate from the litter floor. Recent

welfare guidelines include a description of how birds should be caught and loaded (National Chicken Council, 2005; National Turkey Federation, 2004). The Royal Society for the Prevention of Cruelty to Animals (1999) stated "Chickens should be caught individually by grasping both legs, just above the feet". The guidelines also indicate that, if birds are carried in groups, care must be taken to ensure they can be held comfortably without distress or injury, and the carrying distance must be kept to a minimum. In large barns, a loading crew of 7 to 10 people catch and crate the birds at a rate of 7,000 to 10,000 per hour. In theory, it is possible to catch and crate the birds by hand with virtually no damage to the birds. However, Kettlewell and Mitchell (1994) and others have described that this job is physically demanding, which makes it difficult to maintain the attitude and concentration required to carefully pick up birds throughout an 8-hour shift. Assuming a catcher is expected to catch at least 1,000 broilers/hr and each bird weighs approximately 2 kg, during an average 8-hour shift an employee may lift 6 to 16 metric tonnes of broilers. Management sometimes has to deal with absenteeism, low morale, and employee turnover. It is the management's responsibility to train and motivate employees to ensure proper bird handling. A significant amount of damage can be inflicted on the birds if the job is not done correctly and the workers' motivation is simply to complete the job in the shortest possible time. Common types of trauma in broilers associated with lifting birds by one leg and potentially rough handling are dislocated femur (particularly in case of heavy birds), dislocated wing joints, and fractured/broken bones (Gregory and Austin, 1992)

There are different approaches to employing a catching crew ranging from employing a permanent crew to hiring people off the street for a single assignment. The former provides more training and incentives to do the job right, which usually compensates for the extra salary required. An early report suggested that leg, wing, or breast bruising may occur on as many as 25% of the broilers processed in the US and as many as 20% of some flocks in the UK (Lacy and Czarick, 1998). In order to keep injuries to a minimum, clear guidelines should be established and enforced by farmers, catching supervisors, and processors. Overall, it can be difficult to assess all but gross injuries during loading, as the operation precludes easy inspection of the birds at the farm after they have been loaded. It is possible to ascribe retrospectively any injury or downgrading which may have occurred at the farm, but this is usually detected during unloading and after plucking rather than at the farm (Kettlewell et al., 2000; Barbut et al., 1990). Colour of the bruise is often used as a general/fast indication of the bruising time, but it is not always very accurate measure, so whenever possible histology should follow.

4.4 Crates and Containers

The industry uses three major types of containers to transport poultry to the plant: a) loose crates (plastic, wood, metal), b) fixed crates on a truck (usually metal), and c) large modular containers (plastic and/or metal) that are brought into the barn.

a. Loose crates are the oldest type of transport container. They were initially made out of wood and later from metal wire. They are still common today, but are often made of plastic and they come in varying sizes (Fig. 4.4.1). A small size crate (e.g., 80 × 60 × 30 cm) can hold about 12-15 broilers. Loose crates are easy to handle and can either be taken into the barn during loading or birds can be carried out of the barn during manual loading. In other scenarios, crates can be placed on a palette and moved by a tractor. Birds are placed into the crates through an opening at the top. The opening can be of different sizes, but if it is too small there is a chance for physical injury, especially to the wings (Kettlewell et al., 2000). Overall, the crate system offers a flexible, low equipment cost approach to manual loading and transportation of birds to the processing plant, but manual labour required is higher than in the other systems. A further discussion on the importance of ventilation during transport and the possible development of micro environments (e.g., hot zones) on the truck is found later in the chapter.



Figure 4.4.1 A crate for transporting poultry. From:
http://agriculturalsupply.co/index.php?main_page=product_info&products_id=1521

Unloading the crates at the plant can be done manually or by a conveyor system, which moves them to the shackling line where birds are removed from the crates. Care should be exercised as to not hurt the birds and damage their wings, etc.

b. Fixed crates are built into a truck and are an integral part of the trailer. In that case the birds have to be brought to the truck either manually or with a loader (Fig. 4.4.2). The crates on the truck are usually arranged in two banks; each covers half of the truck's width. The number of crates depends on the size of the birds (e.g., chickens, turkeys). A common crate arrangement for broilers is eight layers of 12 crates each, or 96 crates total. The loading is done from each side of the trailer and requires that the birds be carried or walked from the barn and then either loaded directly or passed to another person positioned on the truck to allow filling of the upper level crates. In the case of turkeys, a conveyor system (loader), is commonly used to move the heavy birds to different crates by moving and elevating the end of the belt. Turkeys can usually walk on the conveyor belt (Fig. 4.4.2 shows a system for turkeys) while broilers tend to sit. According to the manufacturer, the system can handle 1,000-2,000 heavy turkeys per hour. It should be noted that the system is also used to move pullets from the growing farm to the egg laying farm. Relative to moving hens, Kettlewell et al. (2000) observed that there was a much lower level of injury moving pullets. This is in part due to the higher tolerance of pullets to handling and transporting as compared to laying hens, which are more prone to osteoporosis. In any case, care should always be taken to reduce injury and equipment should be kept in good shape (e.g., no place for wing catching, no sharp corners). At the processing plant trucks are unloaded close to the shackle line with the help of hydraulic platforms that assist the unloading crew in reaching the birds at the different levels.

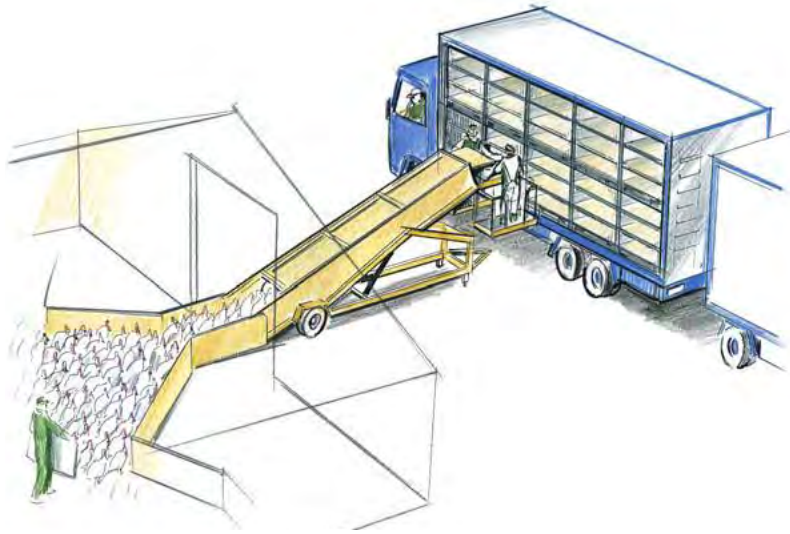


Figure 4.4.2 Schematic drawing of a mechanical loader used for placing poultry on a fixed cage truck.

c. The large, movable, modular drawer/crate system is the most mechanized system on the market today. It relies on large containers that require mechanical handling both off and on the truck (Fig. 4.4.3). This system represents a fundamental change from the small and fixed crate systems, where mechanization and improved welfare are taken into consideration. There are two basic modules: loose drawer and tipping. The loose drawer module has a number of plastic drawers positioned within a metal framework. The number of drawers depends on the size of the birds (e.g., a typical size for broilers is 1.2 m wide, 2.4 m long, and 0.3 m high). This is designed for a capacity of about 25 birds, each weighing 2 kg. The stocking density can be adjusted to accommodate weather conditions and bird weight. The crates are moved by a forklift into the barn and positioned where needed. A manual collection rate of 1,000-1,500 birds per man hour is expected. A large opening at the top helps to minimize injury and stress to the birds during both loading and unloading. At the processing plant the modules are unloaded onto a conveyor belt that transfers them close to the shackling line where the birds are removed by hand or the modules are tipped and the birds slide out (see Chapter 8 for an illustration of a tipping system coupled with a controlled atmosphere stunning system). In the tipping type the module is tilted and birds are transferred onto a moving conveyor belt so that the birds can easily come out of the crate (Kettlewell et al., 2000).



Figure 4.4.3 A module crate system used to transport birds from the farm. Note the large opening for loading. When a tier has been loaded, the overhead half-floor is pulled forward. Courtesy of Stork Corp.

Many factors affect final product quality of the meat. Bruising and injury during harvesting and transportation are very important and should be avoided as much as possible as they cause unnecessary and costly trimmings and downgrading. For a fixed crate system, Barbut et al. (1990) demonstrated that a well maintained truck, with wire doors, resulted in significantly lower downgrading than an older, poorly maintained truck with board doors. The latter resulted in higher incidences of half wing trim, bruised drums, and breast scratches (Table 4.4.1).

Table 4.4.1 Effect of truck type on the percentage of turkey downgrading. See text for further explanation. From Barbut et al. (1990).

Cause of downgrading	Type of truck						
	Wire cage			Board			Significance of difference
	Min.	Max.	Ave[1]	Min.	Max.	Ave[1]	
	---------- (%) ----------						
Wing trim	1	16	7.27	0	22	7.40	NS
Half-wing trim	4	18	10.03	3	23	12.26	$P < 0.05$
Bruised drumstick	0	19	1.83	0	7	2.44	$P < 0.05$
Breast scratches	0	2	.10	0	3	.22	$P < 0.05$
Drum thigh trims	0	1	.07	0	1	.04	NS
Back scratches	0	10	1.33	0	11	1.48	NS

[1] Values are the average of birds from 28 trucks; 100 turkeys per truck.

The wire door-type cages (130 cages on the truck; 1.12 × 1.20 × 0.43 m per cage) were well maintained (e.g., no sharp objects, broken wires) and the doors completely blocked the opening (i.e., closed right to the floor of the cage). In the board door-type cages (140 cages on the truck; 0.95 × 1.02 × 0.33 m per cage), maintenance was not as good and incidences of trapped wings were observed (corrected after the release of the study's results). In order to separate the damages resulting from bruising on the farm versus bruising on the truck, the authors used histology to study bruised tissues. Samples were obtained after the birds had been scalded (i.e., skin exposed to 52-55°C) as they entered the inspection/trimming station. Thin samples (5µm) were stained with hematoxylin and eosin and the presence and number of macrophages, pigment, cells, and debris within macrophages were used to determine the age of bruises/scratches. Very fresh bruises/injuries from the unloading step contained no macrophages. Loading and transportation-damaged tissue contained few macrophages. Farm-damaged tissue contained a small to moderate number of macrophages, many of which had engulfed pigment, cells,

and debris. The histology study was useful in developing a set of photographs to train employees to record injury history data on the processing line. Generally, bruises that were bright or dark red with a good demarcation line were less than 19 hr old, which indicated a fresh injury.

4.5 Mechanical Harvesting

As already indicated, live bird harvesting is one of the least mechanized processes in the broiler production chain. However, this is gradually changing as more automation is introduced. Over the past 40 years, a number of systems have been developed, of which some totally failed while others slowly progressed to commercial systems.

A description of several of the systems that were not commercialized (moving mats and vacuums) is provided below as these systems can be used to learn a lot about the overall process. This is followed by a description of two systems currently used by the industry.

a. A built-in conveyor belt was developed in Georgia in the early 1970s. It consisted of a mechanized growing, harvesting, and transporting system. A permanent, recessed conveyor belt was built into the barn's concrete floor. During catching, the birds were mechanically herded onto the recessed belt using large paddles that rolled on metal tracks. The herding device was also equipped with lights and horns to help move the birds. The conveyor belt carried the birds out of the barn to a short, inclined conveyor that lifted them into a transport truck. Overall, the system was too complex and was never adopted in commercial practice.

b. A collecting mat system was developed in Europe to remove the birds from the barn. Mats were laid down in sections of the barn's floor a few hours prior to catching. Later, the mats and the birds on top of them were pulled from the barn one at a time and the birds dropped into stackable crates. The system required a lot of manual labour for placing the mats and was not developed further. In addition, the process was most likely impractical due to differences in barn design around the world (e.g., length, width, slope of the barn's floor).

c. A large foam rubber paddle loader with a self-propelled harvester was developed in Northern Ireland in 1980. The system caught the birds with large foam rubber paddles that rotated down on top of the birds and pushed them onto a conveyor belt that carried the birds to a loading platform and deposited them into modules. The modules were made up of a series of layered compartments

that were carried on the back of the machine (i.e., this last part is similar to one of the currently used systems). The loading platform was equipped with a weighing device that indicated when a crate was full (also used today in some systems). The whole assembly was mounted on a powered vehicle, which manoeuvred inside the barn through almost any type of litter. Overall, the equipment proved to be too slow, unreliable, and costly to maintain (Kettlewell and Turner, 1985).

d. A pneumatic vacuum system (i.e., can be described as a large vacuum cleaner) was developed around 1980 where birds were suspended in air as they passed through a tubing system (the feathers helped to prevent or reduce bruising). The birds were caught by hand, placed in a funnel-like aperture, and pulled through tubing by suction into cages positioned on the truck. The operator directed the stream of birds into the cages. According to Kettlewell and Turner (1985), the system did not work well and problems were encountered when birds were placed in the funnel too quickly, which resulted in malfunction and unacceptable injuries to the birds.

e. A second generation vacuum-based system was developed by a Dutch company. The self-propelled machine had a pick-up head about 2.5 m wide that could swing back and forth thereby extending the catching area to 5-6 m. Broilers that came in contact with the pick-up head were exposed to gentle suction that lifted them onto a conveyor belt and transferred them to a cage-filling device.

f. A tined fork system was developed to herd birds to one corner of the barn and then scoop them off the floor with a large tined fork. The fork was attached to a small, front-end loader that could lift about 100 broilers at a time. Although the pick-up mechanism was reported to be effective, the procedures for transferring broilers to crates were less than satisfactory and the system did not receive wide acceptance.

Today there are two main mechanical catching systems used by the industry. They include loaders that move towards the birds and either a) place them on a moving belt, or b) gather the birds with long rubber fingers while directing them onto a conveyor belt .

a. The moving belt system was introduced at the beginning of the chapter (Fig. 4.1.1) and can be seen in more details in Figure 4.5.1. Overall, a tractor equipped with the loading device is driven into the barn and birds are moved to one area. The bottom part of the device is slowly moved towards the birds and as they step on it a belt carries them towards the centre where a second inclined belt picks them up and moves them toward the crate system. The equipment is fitted with a scale

system and/or a bird counter so each crate is filled with a predetermined weight/number of birds. Once the module is full, it is automatically moved to the back and another module is filled. The manufacturer indicates that about 10,000 birds per hour can be loaded with this system. It is currently more popular in Europe than in North/South America, but this will likely change over the next few years.

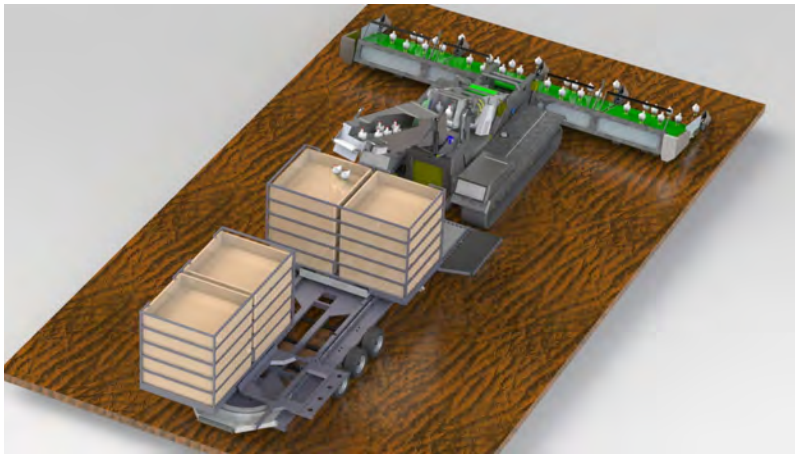


Figure 4.5.1 A complete system for loading and putting the birds into crates. The tractor has a conveyer belt that moves and counts the birds, so crates can be filled automatically. Courtesy CMC, Italy.

b. The rubber finger gathering system consists of a few soft, long, counter-rotating rubber-fingered cylinders that direct birds onto a conveyor belt (Fig. 4.5.2). The long rubber fingers are soft to prevent injury but they are also stiff enough that the birds cannot escape or flap their wings (Ramasamy et al., 2004). Once captured, birds are lifted onto an inclined telescoping conveyor belt (maximum scanning range of 24 m) that carries them to a caging system designed to fill standard dump type cages at the back of the machine. Some of the critical operating factors are drum spacing, rotation speed, and the speed at which the machine approaches the birds. The machine is designed to handle 8,000 to 12,000 broilers per hour with a crew of four people. As with other catching procedures, the operation is done at night or when the barn lights are very dim in order to prevent too much movement and/or excitement of the birds.



Figure 4.5.2 A mechanical harvesting system using long rubber fingers. Courtesy of Anglia Autoflow, UK.

The main benefits of using mechanical harvesters include improved working conditions for the catching crew, reduced labour costs, and reduced stress and injury to the birds. In the past few years, animal welfare and employee health and safety issues have received much more attention and therefore advancements in mechanical harvesters are closely watched by the poultry industry. Fifteen years ago there were only a handful of mechanical harvesters operating in the UK, each capable of harvesting 35,000 birds per day (Kettlewell et al., 2000), and few operating in the USA and Australia. Today, however, some industry estimates suggest 20% mechanical loading of broilers in Europe and 5% in North America. For turkeys the percent of mechanical loading increases to 80% in Europe and the US. In Saudi Arabia some estimates are as high as 100% mechanical catching. Overall, it is expected that the use of mechanical loaders will increase as more companies are interested in automating the process.

While there are a few older reports in the scientific literature that compare manual and mechanical loading, most available data is from equipment manufacturers (Ramasamy et al., 2004). Lacy and Czarick (1998) compared the bruising rate of manual versus mechanical harvesting and reported that leg bruising was reduced by more than 50% and there were also reductions in back and breast

bruising when mechanical harvesting was used (rubber fingered rotor machine; see Table 4.5.1). However, a slight, non-significant increase in wing bruising was also observed. Theoretically, a manual catching crew can load the birds with no injuries but in real life stress to the birds and to the people trying to catch them as well as time constraints usually result in a less than optimal situation. Duncan (1989) indicated that stress could be reduced and welfare improved by a properly designed mechanized harvester. They compared the physiological parameters of birds harvested manually to those harvested by a prototype of a rotating rubber finger harvester developed at the Silsoe Research Institute, UK. The researchers showed that the time required to return to normal heart rate and duration of tonic immobility were significantly lower in birds caught by the mechanical harvester. The study, however, did not examine the subsequent placing of birds into transport crates as such equipment was not available at the time. Duncan (1989) suggested that manual handling, whether gentle or rough, is a cause of stress since birds are not used to contact with people. Others have also indicated that direct contact with humans, especially if infrequent, is a physiological stressor to the birds. The basic method used by a mechanical harvester reduces the direct contact between humans and birds.

Table 4.5.1 Mean percentage and standard deviation of carcass bruising observed on hand harvested and a mechanically harvested (rubber finger type) broiler following processing[1]. From Lacy and Czarick (1998).

Harvesting Method	Bruising			
	Back	Breast	Leg/Hock	Wing
	---------- (%) ----------			
Hand harvested	3.5 (2.5)	1.0 (2.0)	16.5[a] (5.9)	10.5 (3.4)
Mechanically harvested	2.0 (2.0)	1.5 (1.0)	7.0[b] (3.3)	11.5 (3.0)

[1] Four samples of 50 birds each were graded by processing plant personnel for the two catching methods.
[a,b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

There are not many non-commercial cost comparisons between manual and mechanical harvesting operations. Therefore, an older scientific paper that compared the two approaches is used here. Lacy and Czarick (1998) estimated labour costs for a typical nine person manual catching crew at $215,000/yr.

Comparatively, the labour costs for a three to four person crew required to operate a mechanical harvester were estimated at $72,000/yr, which represented a cost savings of $143,000/yr. Assuming a cost of $175,000 for a mechanical harvester, the reduction in labour cost alone would pay for a harvester in less than 15 months. According to the authors, this payback estimate does not include the additional cost savings associated with reduced bruising to birds, reduced workmen's compensation claims, and reduced workers' health care costs.

4.6 Feed Withdrawal

The length of feed withdrawal can have significant effects on bird quality during processing, yield (also called live shrink), and contamination problems at the processing plant. Overall, the watering devices and feeders are removed/raised prior to loading to allow birds time to empty the food in their intestines. It is important that the intestines be fairly empty during processing to reduce the chance of faecal contamination (i.e., when the intestines are full there is a higher chance of rupture when using automated evisceration equipment as well as during manual evisceration (see also Chapter 5)). Usually, the recommended time for feed withdrawal is 8-12 hrs for broilers and 6-10 for turkeys (Buhr et al., 1998; Duke et al., 1997; Zuidhof et al., 2004). However, it should be noted that different companies use different withdrawal times, depending on factors such as the distance between the farms and processing plant, weather conditions, and history of contamination at the processing plant (e.g., variation from 6 to 14 hrs can be seen in the industry). Note that feed withdrawal time refers to the total time birds are off feed. This includes time on the farm, on the truck, and in the holding area at the plant (Zuidhof et al., 2004). The relative time of each phase is also important when considering the emptying rate of the intestine. For example, Summers and Leeson (1979) reported that it took more time for broilers to empty their intestinal contents when kept in cages as compared to broilers left on the floor with access to water. This was assumed to be the result of lower activity and higher stress levels. Similarly, birds kept in the dark are slower at emptying their intestinal contents. Buhr et al. (1998) reported that broilers exposed to light and water empty 60-70% of their gut content after 6 hrs, 80% after 12 hrs, and 100% after 18 hrs. Several companies recommend removing feed, but not water, 3-4 hrs prior to loading. If the birds are off feed for only 4-6 hrs prior to processing, the chances of intestinal content leaking onto the carcass during a process such as electrical stunning/stimulation (i.e., causing muscle contraction) are higher. On the other hand, too much time off feed (e.g., 14 hrs) is not recommended as this can result in a weakening of the intestine's strength. Bilgili and Hess (1997) reported

that the tensile strength of the small intestine decreased by 20% when time off feed increased from 6 to 18 hrs. They also reported a sex difference (female broiler intestinal strength was 15% lower than male broilers) and a seasonal effect (strength was 15% higher in winter). Overall, when feed withdrawal is too long, the microstructure of the intestines changes (e.g., villi become longer, mucus layer decreases), the gallbladder becomes longer, and the chances for bile contamination of the liver and the carcass increase.

The amount of time off feed also affects the yield/live shrink weight of the processed birds. Various studies have looked at live shrink and reported values ranging between 0.2 to 0.5% per hour, depending on bird size, age, climate, feed used, etc. Petracci et al. (2001) reported values ranging from 0.27 to 0.48%, while Buhr et al. (1998) reported 0.25 to 0.35% per hour for broilers during the first 6 hours off feed. Duke et al. (1997) indicated values of 0.2 to 0.4% for turkeys (note: heavier birds lose more weight per hour which translates to higher profit losses).

4.7 Transportation

Transporting the birds on a truck to the processing plant is a significant part of the whole operation. As birds are exposed to new conditions (e.g., climate, vibrations, social order, feed restriction) special care should be taken to minimize potential damage. Minimizing stress during transport is an important issue from both an animal welfare and meat quality perspective. Considering the large number of birds grown and transported to processing plants (e.g., over 4 billion broiler chickens in Europe) this is a major issue. Poultry raised on large farms, scattered around the country, are transported to processing plants 1-5 hrs away (some reports indicate < 2 hrs is ideal). As previously indicated, feed withdrawal and harvesting the birds results in physiological stress. Additionally, the combined effect of transportation stresses (e.g., thermal, acceleration, noise, social disruption) may range from mild discomfort for the bird to significant discomfort and death. Bayliss and Hinton (1990) reported that up about 40% of deaths of birds arriving to the plant (usually ranges from 0.0 to 0.2% of birds on the truck) in England are attributable to transport stress. Furthermore, they noted that mortality increases with journey length. The authors have also mentioned that the average broiler journey in the UK is 3 hrs or less, but that occasionally birds might be confined to the vehicle for up to 12 hrs. The same is true in North America where a so-called long journey can extend to 5 hrs and time on the truck to 10-12 hrs. Duncan (1989) used behavioural and physiological responses (heart rate, plasma corticosterone concentration, tonic immobility) to characterize the stress(es) imposed on the birds during transport. Post-transport birds had higher plasma corticosterone, which indicated

an activation of the hypothalamo-adenohypophyseal-adrenocortical axis. This was consistent with observations of an increasing heterophil:lymphoctye ratio. Transport stress was also reported to induce tissue damage, which was reflected by an increased plasma activity of intracellular muscle enzymes such as creatine kinase and others.

One of the major transportation stresses is environmental temperature. For this reason trucks may be covered during cold weather. Over the years, several studies have examined and modelled the effects of heat on metabolic rates in birds during transport (Mitchell and Kettlewell, 1998; Yahav et al., 1995; Knezacek et al., 2010). Webster et al. (1993) indicated that well-feathered birds experience thermal comfort over a narrow range of ambient temperature. They proposed that stress could be minimized by appropriate control of air flow within the truck, both in motion and at rest (i.e., minimal natural ventilation during rest/stop time). Later, Mitchell and Kettlewell (1998) completed a very comprehensive temperature modelling study that has been used to generate guidelines for poultry transportation. The result of their work is used here to illustrate ways of monitoring the so-called thermal microenvironment zones within the truck (e.g., note that today inexpensive data loggers can be used to monitor the condition on any truck and construct a database fairly quickly), measuring stress, and providing practical guidelines for operation in different geographical regions.

First the authors described a value called the apparent equivalent temperature (AET) that shows the "effective temperature" that the birds will experience. Calculated to characterize the birds' responses to quantified thermal conditions, the value takes into account temperature, water vapour pressure, and the psychometric constant. As relative humidity increases, at a constant temperature, it will be more difficult for the bird to lose heat via panting and the bird will perceive a higher body temperature (birds do not have sweat glands). The value is related to the wet bulb temperature and describes the total heat exchange between a wetted surface and the environment (e.g., a similar principle to monitoring relative humidity to control the smoke house operation, as described in Chapter 13). It should be mentioned that the influence of heat loss might be more pronounced inside a crate than on an individual bird under similar conditions in an open space.

Figure 4.7.1 shows a line going through temperature and humidity conditions yielding an AET value of 64°C (based on the physiology of the bird), which the authors indicated as the maximum value at which the birds would be comfortable. An AET of 65°C can be theoretically achieved by an ambient temperature of 65°C in completely dry air or at 22°C and in air with a relative humidity (RH) of 100%. For example, an air temperature of 40°C and 21% RH will result in the

same value. Overall, an RH of <50% is not a realistic value within the thermal core of commercial trucks, regardless of temperature. Therefore, the maximum permissible dry-bulb temperature should be 30°C. A more realistic RH range is 70-80%; therefore, truck temperature should be kept below 25-26°C with adequate ventilation that can reduce the water vapour load. By installing a monitoring system in the truck it is possible to minimize heat stress and improve the welfare of the birds. It is important to emphasize that the calculations presented here are modelled off of a stocking density of about 53-58 kg/m^2 and a transit time of about 3 hrs. These conditions compare favourably to the EU standards (EC 91/628, 1993).

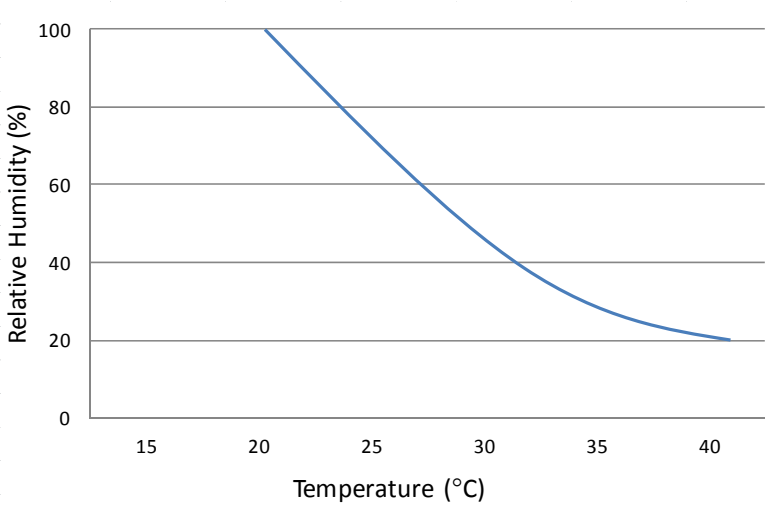


Figure 4.7.1 Dry bulb temperature and relative humidity combinations yielding an Apparent Equivalent Temperature (AET) of 64°C, the recommended acceptable upper limit for the thermal load in the core of a commercial poultry transporter. Redrawn from Mitchell and Kettlewell (1998). With permission.

In their study (Fig. 4.7.2), Mitchell and Kettlewell (1998) used a typical broiler transporter with a modular container system (1.3 × 0.7 × 0.25 m) that carries about 6,000 birds of 2 kg body weight. Stocking density was 53 kg/m^2 in each crate, which was loaded with 21-22 birds in the summer and up to 23 birds in the winter. The crates were perforated by vertical slits that were 1 cm wide and 5.5 cm apart. The truck had a solid headboard, a roof, and an open rear. Temperature and RH probes were used to continuously gather information at six locations in the truck (probes were positioned at the same level as the broilers). Outside temperature

and air speed over the vehicle during the journey were also measured. The study resulted in a 3-dimensional thermal mapping of the transport truck in the summer (curtains left open) and winter (curtains closed). During the winter months, data reveal the presence of microenvironments where there were substantial increases in both temperature and vapour density (VD; Figure 4.7.2.b).

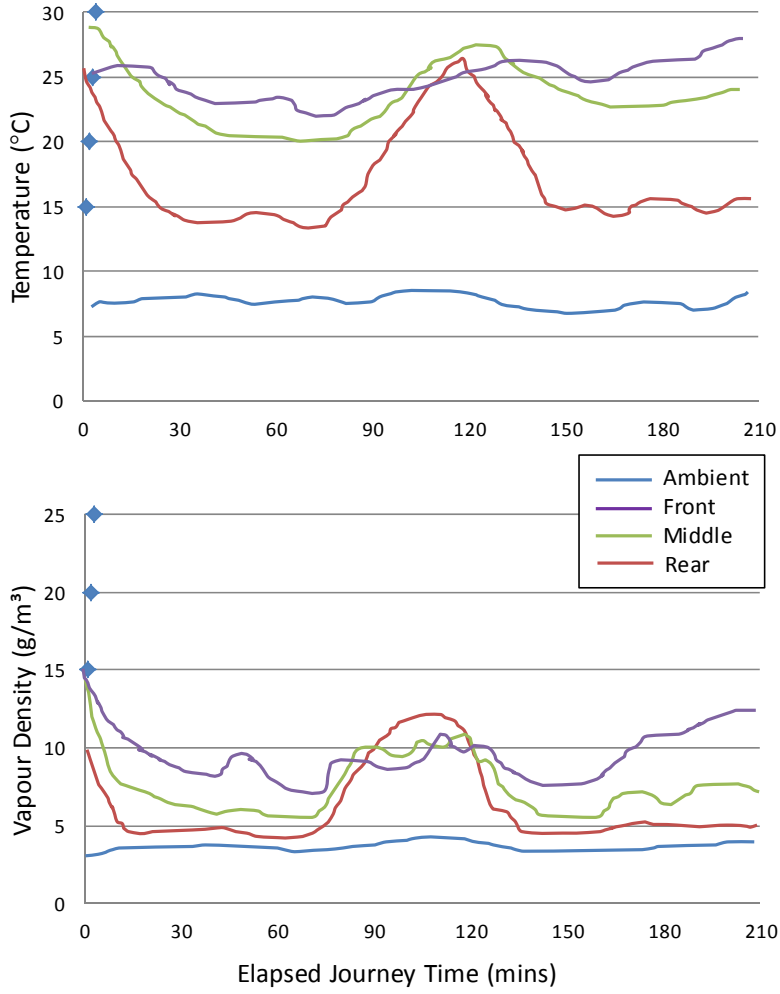


Figure 4.7.2 Variation in temperature (first) and water vapor density (second) in three locations in a poultry transporter with elapsed time during a typical winter journey (curtains closed configuration). The vehicle was stationary during mandatory "driver break" between 78 to 118 min. Redrawn from Mitchell and Kettlewell (1998).

Overall, mean temperature increased by 14.5°C and VD by 6.2 g/m^3 (Fig. 4.7.2). This indicates that when the curtains are closed, a "paradoxical heat stress" may occur within the "thermal core" even when the outside temperature is very low. During the summer, only a small gradient of 2 to 5°C was measured. Dissipation of temperature and humidity gradients and proper distribution of the thermal load within the truck should therefore be a primary objective when designing a new truck or improving the ventilation system of an existing one.

The data presented for the winter (Fig. 4.7.2) indicate that a gradient exists from the front to the rear of the truck. This "thermal core" could be seen towards the upper front of the truck where ventilation was minimal and the risk of heat stress was proportionally greater. Another very important observation was that temperature and VD substantially increased when the vehicle stopped for the mandatory driver-break (between 78-118 min). This is an extremely important point because many trucks rely on "natural ventilation" when the truck is not in motion. During transport, both temperature and VD were the highest and fairly constant in the "thermal core". Under reduced ventilation conditions (truck stopping), the summer temperatures and high VD put the birds under a higher thermal load.

Overall, the authors reported mean AET values of approximately 50°C. The maximum AET was around 60°C during the summer (curtains open) and ranged from 60-80°C during the winter (curtains closed). It should be noted that the data were derived from what they called a "typical journey"; however, under other commercial conditions, values may exceed those reported here, especially during a warmer period in spring and autumn when trucks may still run with closed curtains. The authors also conducted laboratory "in-crate" experiments to demonstrate the effect of the AET values on physiological responses associated with stress. Internal body temperature was measured and blood samples were collected at 0 and 3 hrs after simulated transport conditions (Table 4.7.1). The AET values were achieved at "in-crate" temperatures between 22 and 30°C and VDs of 10.5-27.0 g/m^3. Confinement of the birds in the crates tended to induce hyperthermia at all heat loads. At an AET of about 70°C, the hyperthermia became marked and at an AET of 80°C or more, the hyperthermia was profound and life threatening. Plasma creatine kinase increased in all groups, reflecting the physical stress of these conditions. Levels of above 1,000 IU/L resulted after exposure to all AETs above 45°C, although the response tended to be proportional to the AET. A 45-50% increase in creatine kinase, associated with AET exposures of 81.1 and 91.5°C, suggests a significant disruption of sarcolemmal integrity and therefore significant muscle damage. A significant increase in the cortical steroid secretion at AET > 70°C was also observed. The authors mentioned that this was followed by a disturbance in the acid-base balance and partial CO_2 pressure of

the blood due to thermal panting. Overall, the stress profiles suggested that AET heat loads of 45-50°C were associated with minimal or mild physiological stress. Between 50 and 70°C, stress was moderate to severe, and increasing physiological stress was associated with failure of several homeostatic systems, which could potentially increase mortality rates (catastrophic failure of thermal regulation, profound hyperthermia and collapse of vital systems). As indicated before, it was suggested that AETs > 65°C should be avoided. The authors developed a practical method for on-line, routine monitoring of the environment within the thermal core of commercial vehicles. The program uses the physiological response model to warn the driver against the risk of rising heat stress during the journey. Simple modifications such as adjusting the side curtains and/or raising the roof can be used to reduce risk of heat stress during transport. The thermal data describing the conditions within the truck (Fig. 4.7.2) show the complexity of the microenvironments present. The authors indicated that if the average metabolic rate of a 2 kg bird is 15 W, evaporating 10.5 g/h of water, then 6,000 birds would produce 90 kW of heat and 63 kg/h of metabolic water that must be dissipated by ventilation. Disturbances in air flow through the structure will cause an accumulation of heat and moisture and result in higher risk of heat stress for the birds. In addition, the consequent stimulation of thermal panting will further increase evaporative water loss (from the panting birds) and cause a vicious spiralling cycle of hyperthermia.

Table 4.7.1 Body temperature and plasma creatine kinase (CK) in broiler chickens exposed to a range of thermal loads (θ *app) for 3 hr under simulated transport conditions. Values are given as the mean ± SD (n = 10). From Mitchell and Kettlewell (1998). With permission.

	Body temperature			Plasma CK activity	
θ *app	T_0	T_1		T_0	T_1
	---------- (°C) ----------			---------- (IU/L) ----------	
45.0	41.6 ± 0.13	42.0 ± 0.25		693 ± 257	888 ± 324
58.0	41.7 ± 0.17	42.4 ± 0.29		696 ± 296	1,043 ± 432
70.4	41.5 ± 0.17	42.5 ± 0.30		652 ± 178	996 ± 241
81.1	41.5 ± 0.11	43.0 ± 0.33		830 ± 323	1,205 ± 393
91.5	41.3 ± 0.23	44.6 ± 0.33		810 ± 215	1,239 ± 410

Today, more attention is paid to truck design factors such as air spaces in the middle of the truck, air movement from bottom to top. In some trucks the roof can be elevated to increase ventilation when the truck stops or while moving on

very hot days. Roof height adjustment can also be used to facilitate loading and unloading of the module crates. The special floor design shown in Figure 4.7.3 allows better air movement without causing problems with droppings from the upper cages.

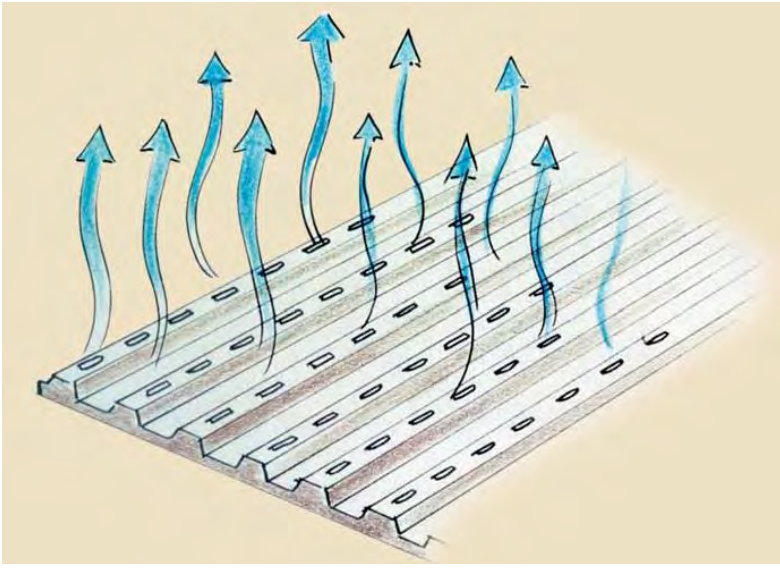


Figure 4.7.3 A design to allow adequate air flow with minimal dropping contamination (Air Flo). Courtesy of Stork.

An example for calculating air velocity was provided by Mitchell and Kettlewell (1998). They showed that when the outside temperature was 20°C and the RH was 50%, the water vapour density was 8.6 g/m^3. If moisture addition, via panting from birds within the truck, increased the RH to 90% (without any change in temperature) then the VD would increase to 15.6 g/m^3. They calculated a water addition of 63 kg/h (from the 6,000 bird truck) and indicated that keeping the humidity status quo would require an air flow of 2.5 m^3/s. This calculation assumes no temperature increase and a homogenous internal environment that may not actually exist in a commercial truck.

Knezacek et al. (2010) used thermal mapping to model broiler transportation during the cold winter in Canada (Fig. 4.7.4). Their study is used here to demonstrate the benefits of mapping in detecting and fixing problems with microenvironments. The researchers measured the temperatures using external data loggers and core body

temperature monitors on four journeys. Overall, temperature heterogeneity was found between modules on all loads with average crate temperature ranging from 11-31°C, 9-28°C, 2-26°C, and 1-16°C for journeys of 191, 193, 178 and 18 min and ambient temperatures of -7, -27, -28 and -18°C, respectively. The temperature monitoring indicated the potential for developing both hypo- and hyperthermia, showing that cold stress can occur near air inlets and heat stress in poorly ventilated areas. Passive ventilation inside the truck resulted in crate temperatures of 18 to 55°C higher than the outside temperature. By first mapping the conditions on the truck, one can start to correct the problem areas and provide more uniform conditions. Continuous monitoring during transportation can further help maintain ideal temperature, as conditions can change along the way (e.g., wind direction, truck speed, rest period). Today some trucks used to transport animals have fans located at strategic points to direct air to certain areas, this can be combined with a monitoring system to reduce/eliminate microclimate problems.

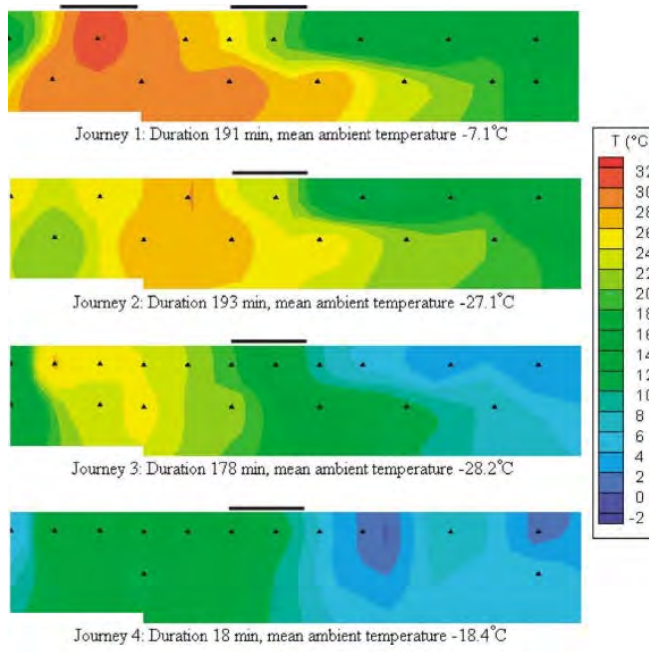


Figure 4.7.4 Interpolated temperature variations along the center of a 16 m trailer during four winter journeys. Dark dashes above each image indicate locations of open air vents. Small black triangles within each image indicate locations of temperature sensors. From Knezacek et al. (2010). With permission.

Mitchell and Kettlewell (1998) used the model they developed to compare a conventional truck with an improved truck with a modified ventilation system. The modifications were based on mathematical and physical modelling of the pressure fields surrounding the conventional truck. This was done in order to identify locations of pressure gradients that could assist in driving natural ventilation while the truck is moving. During testing the authors used a matched control, back-to-back, alternate journey protocol for identical routes on four successive days. Temperatures and RHs were recorded, as well as assessments of the physiological stress experienced by the birds on both trucks by analysing blood samples for heterophil:lymphocyte (H:L) ratio and plasma creatine kinase levels. In the standard truck, the average temperature was 28.7°C and the RH was 63% (VD of 17 g/m^3). This resulted in AET of 68.8°C, above the recommended level of 65°C, and the birds experienced physiological stress as measured by a marked elevation in the H:L ratio (i.e., was 0.97). In the modified truck, the same external climate conditions (11.7°C) resulted in an average core temperature of 22.5°C, RH of 51% (VD of 10.2 g/m^3), and an AET value of 45°C. As a result, physiological stress indicators were lower (i.e., plasma creatine kinase was 310 versus 407 IU/L in the standard truck, and H:L ratio was 0.30 versus 0.97). The experiment clearly demonstrates the physiological benefits of using physical parameters to improve truck design. The modifications also resulted in lower mortality (0.43% DOA versus 0.49% in the standard truck) and the ability to increase truck capacity by about 10% (i.e., addition of the equivalent of two more modules or about 500 broilers).

Another important reason to avoid heat stress during transport is that it may make birds more susceptible to a condition known as pale, soft, and exudative (PSE) meat. It has been reported that the incidence of PSE increases when broilers/turkeys are exposed to extreme weather conditions. McCurdy et al. (1996) showed an increase in the paleness of the breast fillets (Fig. 4.7.5) and a decrease in water holding capacity in turkey muscle transported during the hot summer months as compared to the winter. McKee and Sams (1997) also showed that turkeys exposed to heat stress (38/32°C during the day and night, respectively) for one month during their growing period showed higher paleness values, lower post mortem pH, and higher drip and cook loss compared to turkeys grown at 24/16°C. In a later study it was shown that broilers held at temperatures >18°C in the holding shed at the processing plant (i.e., just prior to slaughter) resulted in more incidences of PSE than when broilers were held at 12°C (Bianchi et al., 2006). This information underlines the extreme importance of maintaining good conditions during growing, catching, and transportation. Overall, better understanding of factors such as truck configuration, stocking density, frequency and duration of

rest periods should be of great interest to the poultry industry. A multidisciplinary approach that includes animal physiology, nutrition, mechanical engineering, and electronics would benefit the industry in improving transportation.

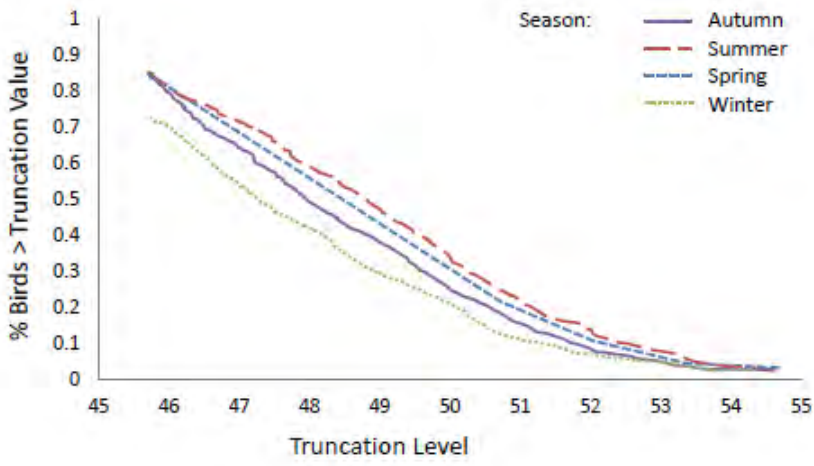


Figure 4.7.5 Truncation values showing the lightness values of turkey tom breast meat fillets during different seasons. See text for more details. Redrawn from McCurdy et al. (1996).

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5

PRIMARY PROCESSING OF POULTRY

5.1 Introduction

As the poultry processing industry has matured, dedicated large scale plants have been built around the world. As indicated in Chapter 1, automation has helped to improve efficiency and line speed. Fifty years ago, maximum line speed was about 2,000 birds/hr (bph). In comparison, modern plants with automated evisceration and cut-up lines (Figs. 5.1.1a and b) can handle 13,500 bph on a single line. In contrast, manual lines usually handle fewer birds and the output for workers is drastically lower (see Chapter 2). New technologies such as computerized machine vision are finding their way to processing plants and can be used for grading and sorting birds as well as for veterinary inspection. Some government agencies are currently evaluating this concept, which can be performed to a high degree of accuracy and can help increase human performance with this kind of repetitive task. A significant price reduction of sensors, control units, scales, and cameras has assisted in introducing computerized equipment and monitoring systems into poultry processing plants to help improve performance. Information, captured by a machine vision system (Fig. 5.1.2), can be also used to make decisions about the way each bird will be marketed (e.g., whole, cut-up), or the way it should be portioned (e.g., deboned breast, bone in thigh meat) to best match inventory available and daily market demands. One of the big advantages of such a system is that a manager can make a decision three hours before the bird gets into the cut-up department. Such in line computer systems are already available to the processor (see also Chapter 1). In the future, the use of in-line computer systems is expected to increase as is their degree of sophistication and application in traceability.

Modern dedicated poultry plants are designed to process a certain type of poultry (e.g., broilers, turkey, duck, ratite) and include slaughtering, de-feathering, evisceration, chilling, portioning, and packaging operations specified to the type of bird processed. In many cases the primary processing plant is built adjacent to a secondary meat processing plant so shipment of fresh meat is not an issue.

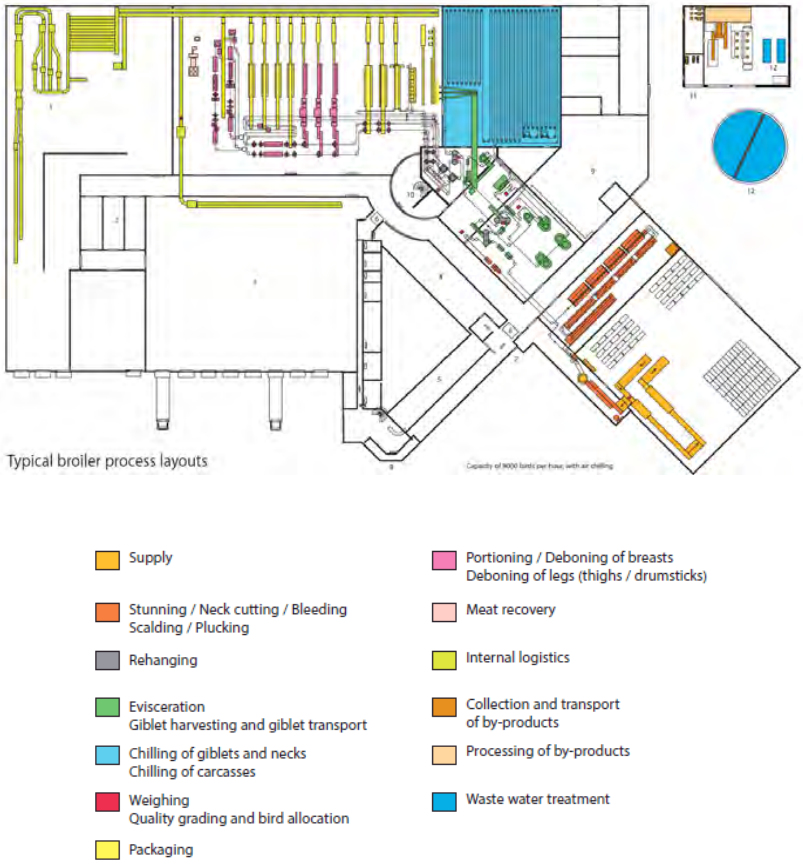


Figure 5.1.1.a Floor plan design for a broiler processing plant handling 9,000 birds per hour. Courtesy of Stork.

The steps involved in a typical poultry processing plant are illustrated in Fig. 5.1.3; modifications of this arrangement can be seen (e.g., unloading before or after stunning, a hot wax bath to remove pin feathers in a duck processing operation), but the basic steps are similar in all plants. Another diagram showing the overall process and focusing on the HACCP program is provided in Chapter 6. As will be described below, the whole operation can be automated to varying degrees depending on factors such as capital investment, local labour costs and availability, and processing volumes.



Figure 5.1.1.b Inside view of a modern poultry processing plant designed to handle 13,500 birds per hour. Courtesy of Marel.



Figure 5.1.2 Machine vision of broiler operation. Courtesy of Marel.

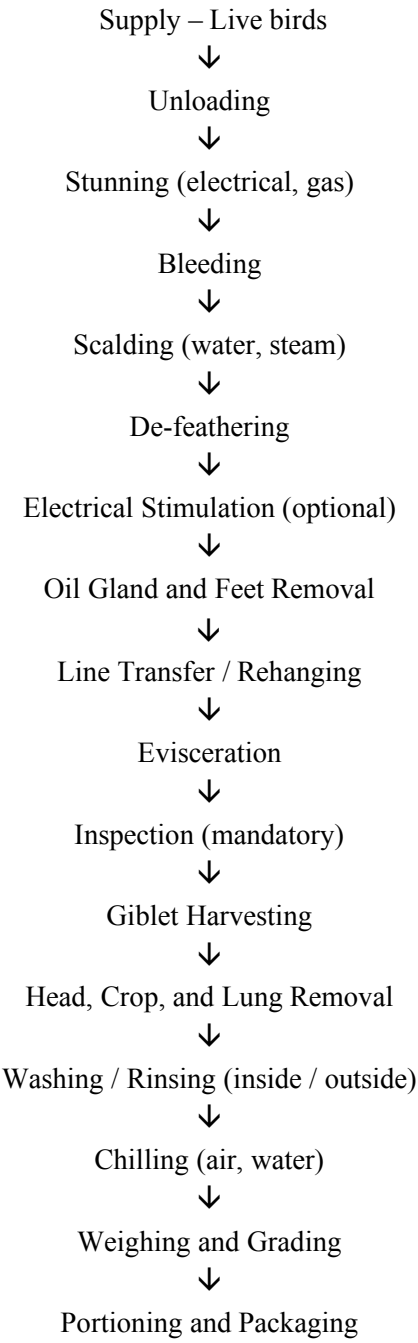


Figure 5.1.3 Typical sequence of steps in poultry primary processing.

This chapter focuses on the different steps involved in the primary processing of poultry. The microbiological and hygienic aspects of the various steps are further explained in Chapters 6 and 15. Overall, there has been a lot of development over the past half century and today more automation has been introduced in countries where labour costs are high (e.g., Western European countries). However, regions with traditionally low labour costs are also seeking increased automation as worker availability becomes a major issue (e.g., competition with other industries).

5.2 Supply – Live Birds

Birds usually arrive to the plant by truck in crates or cages (see Chapter 4). At the plant, the process starts with a bulk weighing of the birds either on the truck when it enters the processing plant or in the cages prior to unloading. The live weight is used as a basis for calculating the payment to the grower. In some places, the eviscerated weight is subtracted from the liveweight (minus the weight of the condemned birds) and, together with the grades assigned, is used to calculate the payment to the grower. When the birds arrive at the plant, it is recommended to allow them some rest time. This is especially important for birds that have been exposed to harsh environmental conditions such as extreme heat, cold, and/or a long journey. Reducing their stress level and providing time for the birds to return to their normal breathing and heart rate is very important for reducing problems on the processing line. For example, in the case of controlled atmosphere stunning (CAS), it is recommended that birds be placed in a quiet, cool area for 1-2 hrs prior to processing because factors such as breathing rate and muscle glycogen levels are crucial in preventing meat quality defects that result from convulsions (see Chapter 8 for more details).

5.3 Unloading

Traditionally, unloading the birds from the crates and placing them on the shackle line has been done manually and is still done this way in many places around the world (Fig. 5.3.1). The crates can be unloaded onto a conveyer belt, which then passes by employees who remove the birds and place them on a moving shackle line. If the crates are built into the truck, the birds are unloaded and placed directly onto the shackle line by employees who stand on a scissor lift. Automated unloading systems have also been developed and are usually part of a large modular crate system (Fig. 5.3.2). In this case, the whole module is lifted and tilted so the birds can walk onto a conveyor belt. Since this process is fully

automated, motion or light sensors are used to verify that no bird is left in the crate after tilting. If a bird is detected, the crate is tilted again and/or an alarm is sounded so an employee can come and check the crate.

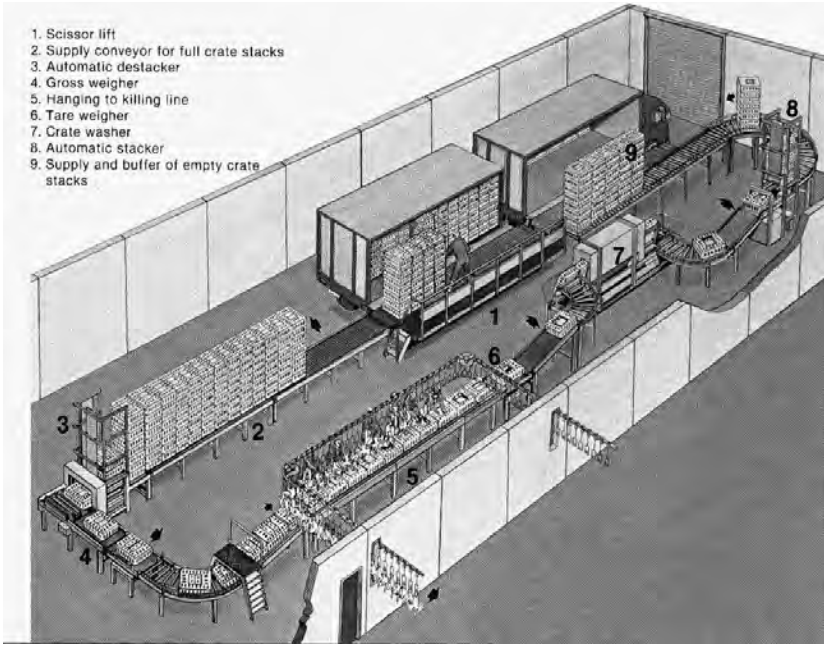


Figure 5.3.1 An example of manual bird unloading system: Courtesy of Stork.

In plants where electrical stunning is used, birds are manually placed on the shackle line. If CAS is employed, the birds are commonly unloaded onto a conveyor belt (usually by tilting. Note this step can also be done where electrical stunning is used) and then moved to the stunning area where they are stunned by CO_2, argon gas, or a mixture of gases. In other CAS systems the birds are left in their crates during stunning and are then easily removed and placed on the shackle line. Handling unconscious birds is much easier and helps reduce bruising as compared to the removal of conscious birds from crates. When birds are stunned prior to their placement on the line, birds should be moved quickly before they regain consciousness. There are some exceptions when deep and irreversible CAS or electrical stunning is used. Regardless of the unloading operation, special care should be taken to minimize bruising of the birds. Several large companies are now introducing additional measures to minimize the stress birds are exposed to during

catching, transporting, holding, and unloading. In the latter two phases measures can include showers, air conditioning, special lighting (mainly blue light, which does not excite the birds), and ventilation systems that reduce dust and decrease the noise level. Various research publications have shown that excited birds are more likely to be active, flap their wings, and get hurt during the process than relaxed birds (McEwen and Barbut, 1992).

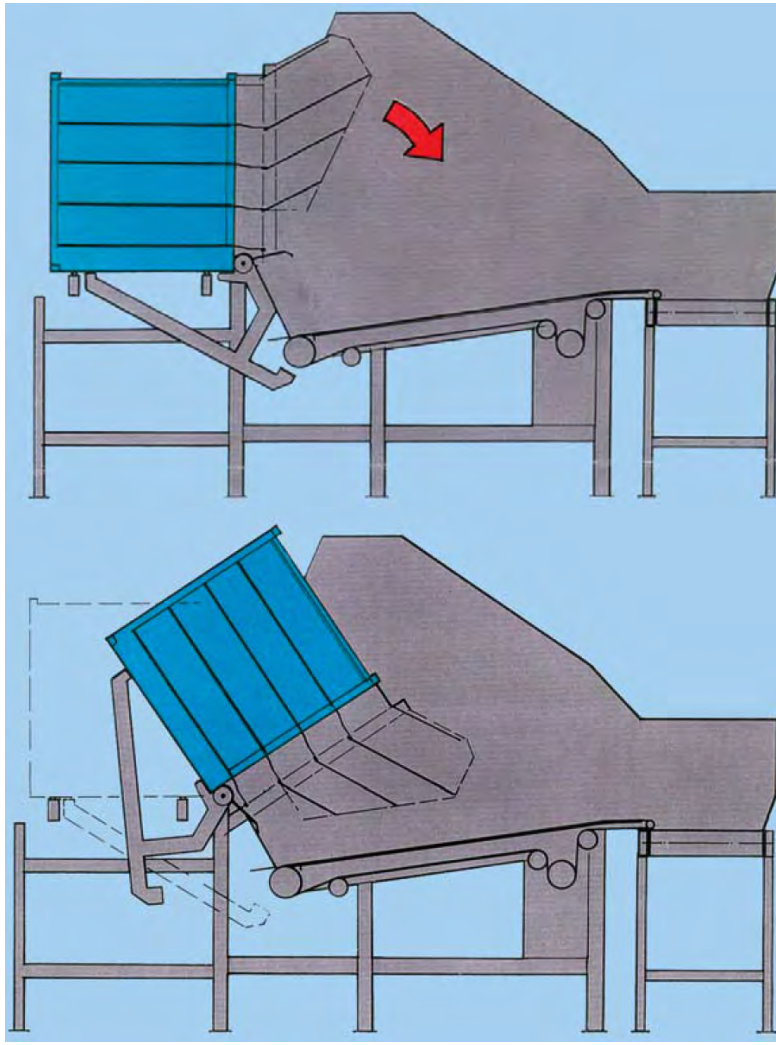


Figure 5.3.2 Automated tilting system for unloading birds. Courtesy of Stork.

5.4 Stunning

Stunning is done to render the animal unconscious prior to slaughter. When stunning is used, it can be done by an electrical current, gas, or by mechanical means. It was originally done to immobilize the animal to allow for easier and safer handling. This was especially true for large, red meat animals. More recently, stunning has been used primarily as a means of improving animal welfare by minimizing the pain and suffering associated with the process. From this point of view, stunning should result in the rapid onset of a stress free insensibility of sufficient duration to allow the animal to remain unconscious until death (Fletcher, 1999). The settings used for stunning are commonly prescribed by strict government regulations. These also include any exemptions that arise from special religious considerations (e.g., the Jewish and Islamic laws known as Kosher and Halal, respectively). More detailed information is provided in Chapter 8, which is devoted to the different methods of poultry stunning.

5.5 Bleeding

Bleeding is done by opening the blood vessels in the neck (Fig. 5.5.1). There are several ways of cutting the blood vessels in poultry: a single blade to sever one carotid artery and one jugular vein, a single or double blade to cut both carotid arteries and jugular veins, or severing one or both vertebral arteries. The so-called "Modified Kosher" is one of the most common methods and results in cutting the jugular vein just below the jowls so that the trachea and esophagus remain intact. Leaving these parts intact is important when automated equipment is later used to pull out the trachea. Other, less common methods include decapitation and a mechanical stunning that consists of piercing the brain and cutting the veins in the roof of the mouth. The "Modified Kosher" is easy to perform manually or with automated equipment and results in a good bleed out while leaving the head, trachea, and esophagus intact (Mountney, 1989). High speed automated bleeding equipment employs a railing system that positions the neck of the suspended birds in such a way that the blood vessels can be opened with precision. In the case of the traditional Kosher and Halal slaughter, only manual cutting of the blood vessels is permitted. This is done by a specially trained person who cites a blessing during the operation.

The bleed out phase can take anywhere between 2-5 min depending on bird size and type. During the process, about 35-50% of the total blood volume is removed. Considerable variation can exist between animals and flocks. Using the Modified Kosher method has been reported to result in higher bleed out than decapitation

or piercing (Mountney, 1989). Other factors affecting blood loss include pre-slaughter stress, stunning method, and the time interval between stunning and bleeding.

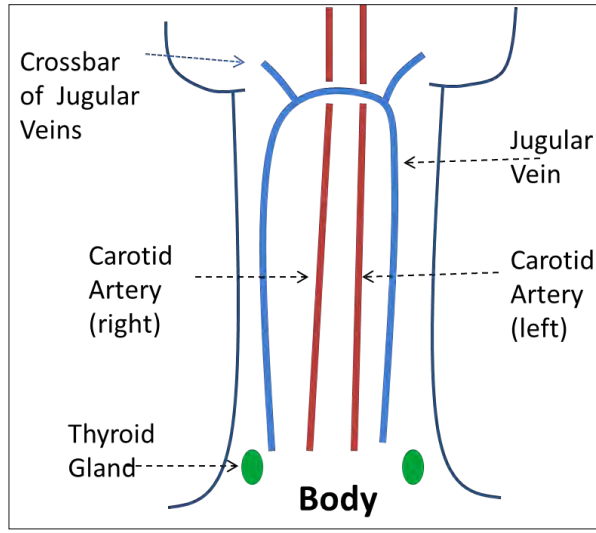


Figure 5.5.1 Ventral view of the main blood vessels in the chicken neck.

Table 5.5.1 shows some of the differences between four different stunning methods. Overall, it shows that bleed out can be significantly affected by stunning method and the length of time before the neck is cut. It is important to note that a poor bleed out can increase the prevalence of carcass downgrading due to blood spots and, in particular, engorged or hemorrhagic wing veins (Gregory and Wilkins, 1989; Raj and Johnson, 1997). The data in Table 5.5.1 indicates that the highest bleed out was achieved with high frequency electrical stunning. Fifty Hz, which is commonly used in some countries, resulted in adequate bleeding when blood vessels were ruptured 1 min after stunning; a delay of 3 min resulted in lower bleed out. A controlled atmosphere stunning with a CO_2+ argon mixture resulted in slightly less bleed out compared to the 50 Hz electric current. The bleed out was not affected by ventral or unilateral neck cutting methods; however, delayed cutting resulted in lower values. In the argon stunning, a delay of 3 or 5 min did not cause a significant difference. The authors concluded that CO_2+ argon stunning, as compared to 50 Hz electrical stunning, provided satisfactory results. See additional discussion on gas stunning in Chapter 8.

Table 5.5.1 Results of stunning treatments on bleed out. Adapted from Raj and Johnson (1997).

Treatment	Time until neck cut (min)	Method of cutting	Bleed out (g/kg)
			Mean (SE)
Electrical 50 Hz (120 mA)	1	V	34.2 (1.88)^{de}
		U	29.7 (1.74)^{e}
	3	V	26.0 (1.41)^{ab}
		U	28.4 (1.79)^{abc}
	5	V	29.1 (2.19)^{abc}
		U	24.8 (1.33)^{a}
Electrical 1500 Hz (120 mA)	0.3	V	36.1 (0.93)^{e}
90% Argon	1	V	31.0 (1.56)^{cd}
		U	29.8 (1.11)^{bc}
	3	V	26.5 (1.46)^{abc}
		U	29.8 (1.68)^{bc}
	5	V	30.0 (2.13)^{bcd}
		U	29.7 (1.89)^{bc}
Carbon Dioxide + Aargon mixture	1	V	30.0 (1.01)^{bc}
		U	28.7 (1.76)^{abc}
	3	V	26.1 (1.67)^{ab}
		U	28.1 (1.50)^{abc}
	5	V	26.0 (1.00)^{abc}
		U	25.0 (0.98)^{a}

V = Ventral cut, both carotid arteries and jugular veins.
U = Unilateral cut, one carotid artery and one jugular vein.
$^{a\text{-}e}$ Means without a common letter differ significantly ($P < 0.05$)

5.6 Scalding

Loosening the feathers by immersing the birds in hot water is an important step that provides for easier de-feathering. Traditionally hot water has been used but recently steam scalding has been introduced and is now being installed in various large scale operations. In a small plant scalding can be performed manually (i.e., placing and removing the carcass from a stationary scalding tank). Large plants use a continuous line where birds are submerged in a long hot water tank while suspended from a moving shackle line. The water bath can consist of a single long bath, a multistage scalding water bath system (Fig. 5.6.1), or a steam scalding system (Fig. 5.6.2). There are three commonly employed scalding schemes:

a. Soft/semi-scalding: 50-53ºC for 1-3 min, used for broilers and young turkeys.
b. Sub/medium scalding: 54-58ºC for 1-2 min, used for mature birds.
c. Hard scalding: 59-61ºC for 0.75-1.5 min, used commonly for waterfowl.

Selecting a scheme depends on factors such as the degree of difficulty in removing feathers, the subsequent chilling method (e.g., water, air), and the bird's age (Barbut, 2010; 2014). A higher scalding temperature better loosens feathers from their follicles (see histological sectioning through a broiler's feather follicle in Chapter 3) but is also harshest on the skin. In the case of hard scalding, the outer layer of the skin (see Chapter 3; skin structure and especially epidermis) becomes loose and is later removed during the plucking operation when rubber fingers are used to rub the skin. The removal of the epidermis can result in the skin becoming lighter in colour as the typical yellow pigmentation that comes from feed (e.g., corn) is lost. In some markets, however, a preference for white skinned birds mandates the use of hard scalding. Hard scalding can also be used for certain chicken parts, such as in China where a separate hot water scalder is used for feet and paws (i.e., peeling the outer skin layer is part of the traditional process). When considering the whole bird, hard scalding can result in skin discolouration if dehydration occurs during a subsequent air chilling operation. In any case, hard scalding is a common way to release the feathers from waterfowl. Generally speaking, hard scalding does not cause as much discolouration in the thick skin of waterfowl as it does in young broilers. In very young broilers even a milder treatment of medium scalding can remove part of the outer skin layer, which leaves the skin sticky; however, it will not result in excessive discolouration if the birds are kept in a moist environment (e.g., water chilling, spray chilling).

In general, soft/semi-scalding is commonly used for young broilers and turkeys because it does not damage much of the outer layer of the skin but it still allows for relatively easy de-feathering. In a water scalding tank, adequate water agitation and uniform water temperature ensure good heat penetration for subsequent feather removal. By introducing air bubbles at the bottom of the tank or using pumps to create jet streams, the water currents will force feathers to separate and not form an insulating layer (Fig. 5.6.1). To improve meat hygiene, careful scalding equipment design is required. A single gram of soil material (e.g., dirt, fecal material) attached to feathers can contain 10^8-10^9 microorganisms per gram, and it is therefore important to minimize cross contamination in this common tank.

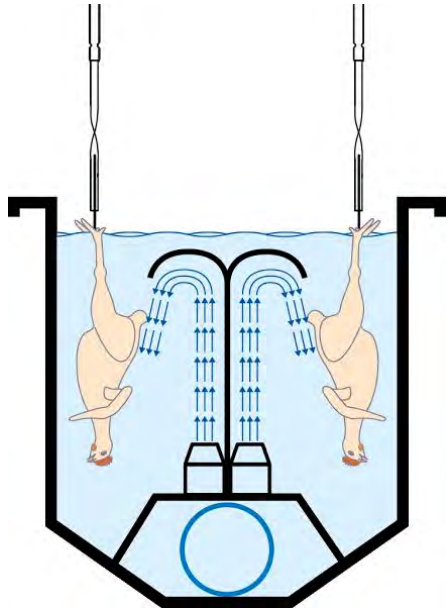


Figure 5.6.1 Hot water scalder used to loosen the feathers. A water jet system is used to improve circulation and enhance water – skin contact. Courtesy of Meyn.

Maintaining and controlling the water temperature is one of the key parameters that can control bacterial load. Another means is the use of a counter flow design whereby clean water is introduced at the exit end of the scalding tank and water flows toward the entrance where the birds are introduced. Installing a multistage scalding tank operation can further reduce contamination problems. A multistage operation can include 2 to 4 water tanks separated by transfer zones, where excess water on the birds is allowed to drip off. Carcasses are moved from an initial, more contaminated tank, to subsequently cleaner tanks while the transfer zones drippings are collected and discharged separately (see also Chapters 15 and 18; dealing more specifically with microbiology and waste water, respecitvely). The scalding operation is a high energy and water consumption process. Newer systems feature steam as the heat transfer medium (Fig. 5.6.2). A steam scalder can save up to 70% of the water used by a traditional hot water scalder, which results in large savings in both water and energy.

It should also be mentioned that in true Kosher processing scalding is prohibited. Because hot water is not used to loosen the feathers, a more aggressive plucking operation is required that can result in more skin tears.



Figure 5.6.2 A new steam scalding system showing the shackle line (top) and the strategic location of the vents for the steam discharge (sides). Courtesy of Marel.

5.7 De-feathering

Feather removal in modern plants is done by mechanical pickers/pluckers equipped with rubber fingers that rub the feathers off the carcass. In a continuous operation, this is done while the birds are hanging upside down on a moving shackle line and go in between two to three sets of drums or rotating disks covered with rubber fingers. Figure 5.7.1 shows a rotating disk design used to obtain good coverage of the bird. The de-feathering equipment is composed of many of these disks that are mounted on a special frame. The height and spacing arrangement of the disks can be adjusted to accommodate different sizes of birds. The fingers can also be mounted on drums. The fingers (Fig. 5.7.2) are made of rubber and contain different levels of a lubricating agent to control their hardness and elasticity. All chemicals used in making the fingers have to be approved for food contact; any modification should be approved by the appropriate regulatory agency. The elasticity and length of fingers vary depending on the type of bird, task required (e.g., pulling tail feathers), machine speed, etc.



Figure 5.7.1 De-feathering disks mounted on a vertical surface. The birds are moved in between disks mounted on both sides; distance can be adjusted to accommodate different size of birds. Courtesy of Stork.



Figure 5.7.2 Examples of different fingers and disk mounting for de-feathering equipment.

As indicated before, the size of the fingers and force needed depend on the type of bird, location (wing, tail) and ease of feather removal. The feather follicle distribution on a broiler is shown in Fig 5.7.3.

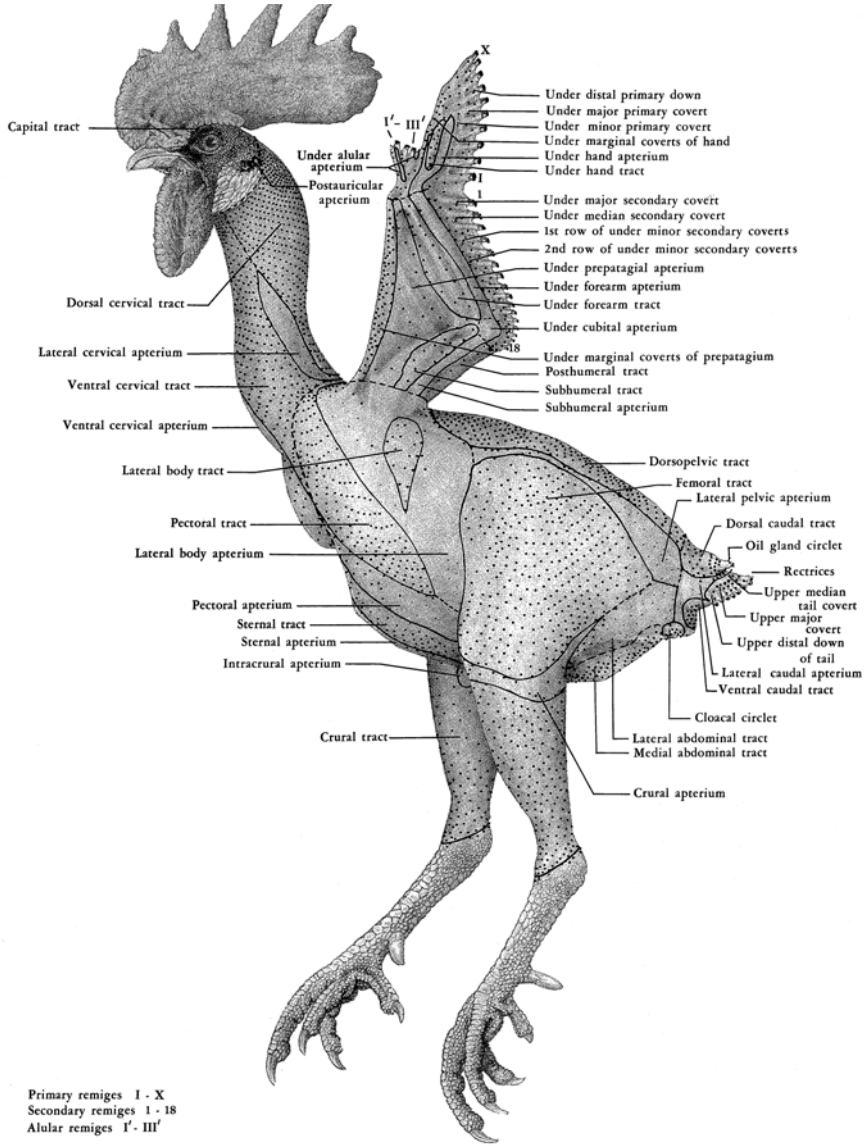


Figure 5.7.3 Feather follicle distribution in chicken. From Lucas and Stettenheim (1972).

Areas of denser feather coverage have more feather follicles. Some of the feathers are more firmly attached (e.g., wing tip) and require stronger force to remove. In order to achieve this task, the rubber fingers should be positioned closer to the carcass or additional plucker disks should be installed at strategic locations. Klose et al. (1961) reported that scalding broilers at 122°F (50°C) significantly reduced feather pulling force by about 30% compared to pulling similar feathers from a live bird. When the scalding temperature was raised to 128°F (53°C), force was reduced by about 50% and when 140°F (60°C) was used, about a 95% reduction was seen. The authors also used an anesthetic drug (sodium phenobarbital) to assist in releasing the feathers. When they measured the force reduction in live birds, they reported about a 50% reduction compared to non-anesthetized birds.

Table 5.7.1 Retention force of broiler's feathers. Adapted from Buhr et al. (1997).

		Initial post-mortem[1] (2 min)			Final post-mortem (6 min)		
Slaughter orientation	**Sample orientation**	**Feather tract**			**Feather tract**		
		Pectoral	**Sternal**	**Femoral**	**Pectoral**	**Sternal**	**Femoral**
		---------- (g) ----------					
Supine	**Supine**	425	311	618	434	338[ab]	677
	Inverted	423	363	631	424	367[ab]	649
Inverted	**Supine**	422	344	667	437	325[b]	637
	Inverted	380	366	663	405	394[a]	709
Side:							
Left		396	337	632	433	372340	667
Right		429	355	657	417		669
Pooled SEM		40	37	49	40	41	59
		---------- Probability ----------					
Source of variation:							
Slaughter-Sample orientation		0.1434	0.0524	0.2337	0.5076	0.0193	0.1570
Side		0.0557	0.2220	0.2402	0.3109	0.0515	0.9532

[a,b] Means within a column and parameter contrast with no common superscript differ significantly ($P < 0.05$), n = 4 broilers.

[1] Post-mortem 2 or 6 min after stunning and bleed out. All broilers were stunned inverted on a shackle and bled as indicated.

When they combined the anesthetic drug and scalding, there was an additional reduction below the value of the anesthetic drug used by itself for both the 50°C and 53°C scaldings. At the 60°C scalding, the difference was not so great, since scalding already resulted in a large reduction. However, the authors suggested that 60°C was too high for broilers and recommended a lower temperature. Later, Buhr et al. (1997) investigated the feather retention force in commercial broilers (Table 5.7.1). The broilers were electrically stunned (50 V alternating current, for 10 sec; average current drawn of 30 mA per bird), bled (severing both carotid arteries and at least one jugular vein), but not scalded. The results showed that the force required for feather removal was consistently greater in the femoral area than in the pectoral area, with sternal feathers requiring the least force. The carcasses were either suspended from a shackle (inverted) or placed on a table (supine). In their study, scalding was not used because "it would overwhelm the detection of minor factors such as angle of feather extraction, sampling side, stunning, spinal cord severing, or carcass orientation" that they were examining.

The feather follicle distributions in a mature turkey and in a duck are shown in Fig. 5.7.4 and Fig. 5.7.5, respectively. Overall, feather removal force is higher in turkeys and ducks than in broilers and increases as turkeys mature. Another difference is the presence of small pinfeathers in waterfowl that are very hard to remove by conventional rubber fingers. Therefore, in a waterfowl (e.g., duck, geese) processing plant, a hot paraffin bath is used to dip the carcasses after the first de-feathering operation (i.e., removal of the large feathers). The carcasses are then taken out, allowed to cool, and the hardened wax is peeled off by another set of rubber fingers. This wax is then re-melted, filtered to remove the pinfeathers, and re-used. When only minor pinfeather problems exist such as in conventional broiler processing, a singeing process (burning of small feathers) is commonly used. This is done by passing the carcass through the flame of a clean burning substance (e.g., natural gas) that does not leave any off-odours or flavours. The carcasses are then rinsed by high pressure spray nozzles while moving on the shackle line to remove any soil left after the de-feathering and singeing processes.

In a low volume operation, the de-feathering process is done in batch-type equipment where the carcasses are placed inside a large rotating drum equipped with rubber fingers. Alternatively, some operations handpick the feathers. Hand picking is also utilized if fancy feathers are to be collected for decoration, sport equipment, etc. (see Chapter 18).

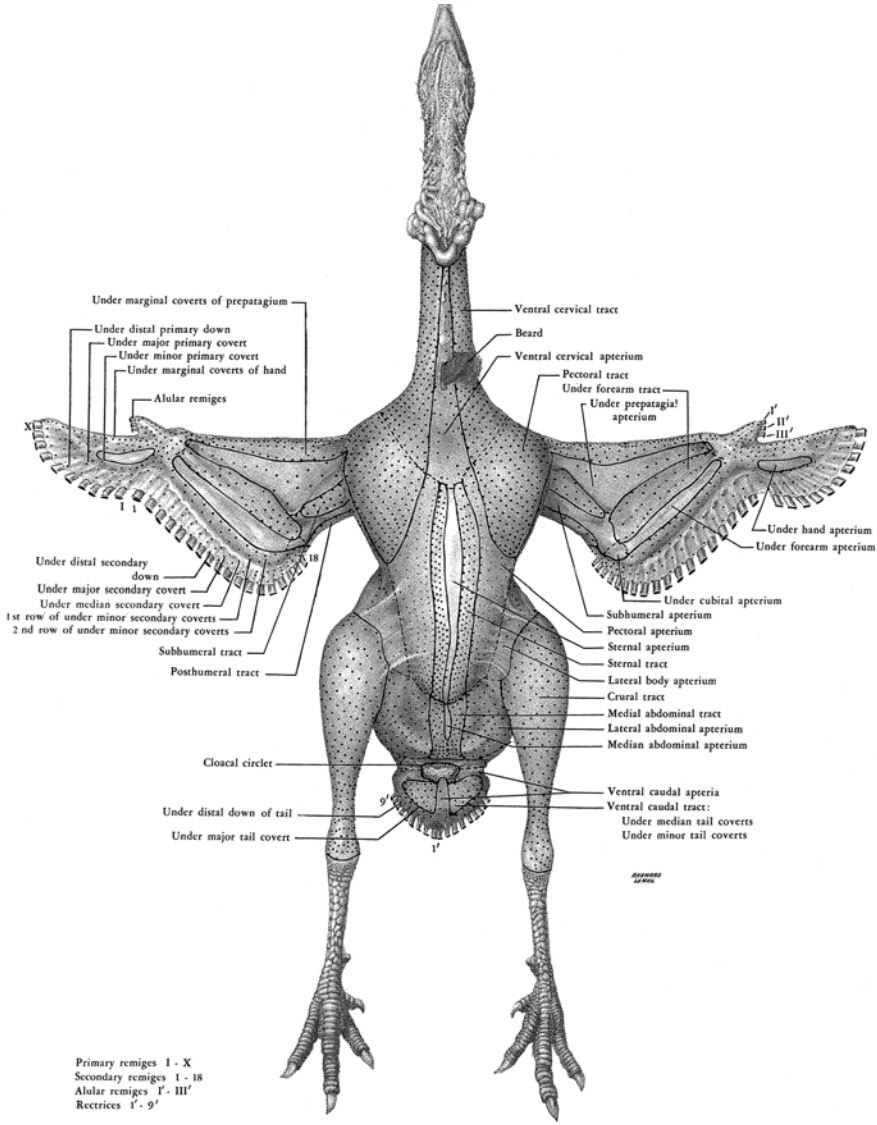


Figure 5.7.4 Feather follicle distribution in turkey. From Lucas and Stettenheim (1972).

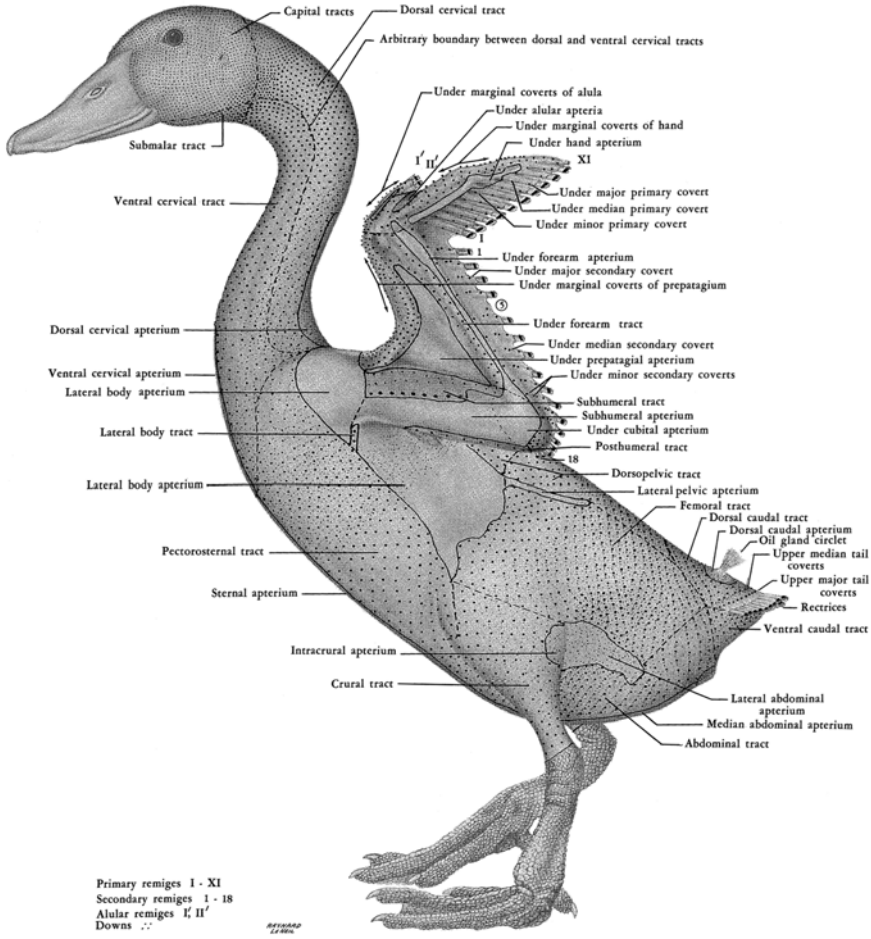


Figure 5.7.5 Feather follicle distribution in duck. From Lucas and Stettenheim (1972).

5.8 Electrical Stimulation

Electrical stimulation is an optional treatment that can be applied after either bleeding or de-feathering to trigger muscle contraction and speed up post-mortem metabolic changes (see Chapter 3 for background information on rigor mortis development). In the past, electrical stimulation has been used almost exclusively by the red meat industry but today various new poultry processing plants are using it. Originally, the lamb industry in New Zealand developed the process in order to minimize toughening associated with cold shortening. The process today also allows for the so-called "accelerated-processing" or "hot-deboning" of lamb/beef and shortens the 12-24 hr waiting period usually required for the completion of the rigor processes.

Electrical stimulation was initially tested in poultry in the early 1960s, but in the following 20-30 years did not receive much attention. A renewed interest occurred in the late 1990s when a patented process called the Minimum Time Process System was introduced. The patent described a deboning process that allowed tender meat harvest 24 min post-mortem. However, a review by Li et al. (1993) indicated that the large variation in test conditions (e.g., voltage, frequency, current, method and time of application) among researchers studying this process provided inconclusive results. In any case, the industry has showed more interest in the process and a few commercial systems have been developed. Later, Sams (1999) also reported that stimulation applied on line could provide sufficient acceleration of rigor to allow deboning right after chilling. Currently, a large portion of new poultry processing plants as well as some old ones are installing electrical stimulation in order to shorten the processing time so that tender breast meat fillets can be harvested immediately after chilling (i.e., within 3 hrs of stunning the birds). In some places in the Far East, where deboning is traditionally done 1 hr after bleeding, electrical stimulation can help (to a certain degree) reduce meat toughening. The electrical stimulation equipment is fairly similar to the equipment used for electrical stunning. The carcass is suspended from a moving shackle line and touches a metal plate (note: a saline solution is used in the stunner) through which a current is passed. Usually the equipment can deliver up to 500 V (AC) and can be set to pulse at 0.2 to 2.0 sec intervals.

5.9 Oil Gland and Feet Removal

In an automated line, oil gland removal is done by angling the birds via a set of metal bars (located along the shackle line) that position each bird such that a rotating blade can cut off the oil gland from the tail area. The cut must be precise and

remove the entire gland without damaging the underlying tissues (i.e., equipment should be adjusted when switching from large to small birds). In a small operation the oil gland is removed manually.

Feet are commonly removed by a circular blade(s) positioned along the shackle line that severs the leg at the knee joint, which has been put into position using guiding bars. It is important that the cut is done within the joint and not through a bone because bone cuts will appear dark or red in the chilled bird and, after cooking, will usually turn darker or even black. Some of the new automated leg cutters first bend the leg and then make a small incision with a stationary knife. This results in further bending of the leg, which can then be cut off at the joint with a rotating circular blade. Depending on market demand, sometimes only the foot is cut off (by cutting the hock) instead of removing the whole leg (e.g., market preference in some regions in Japan).

5.10 Transfer/Rehanging

Rehanging is done when carcasses have to be moved to another line. This can be done manually as the carcasses fall onto a sorting table, or automatically by transferring the birds right away to another line (Fig. 5.10.1). When the live birds are initially unloaded from the crates, they are placed on the line with their feet suspended from the shackle. After going through the scalding and de-feathering operations the feet are removed and the birds are re suspended from the knee joint. The transferring of birds to another line also assists in reducing contamination as semi-processed birds are moved from the dirty shackles used for the live birds to cleaner ones. The shackles used for the live birds are commonly washed before being used for the next batch. Devices for a continuous washing operation are available on the market and usually also include brushes for scrubbing.

There are different configurations for the transfer equipment. One common configuration, shown in Fig. 5.10.1, consists of a large wheel with slots for holding the birds from underneath the knee joints and then pushing them into the slots on the next line (evisceration shackles). It is important that the two lines, de-feathering and evisceration, are synchronized. This can be done by coupling the drives or establishing a buffer zone. The advantages of using automated rehanging equipment are labour savings, better hygiene (as birds do not touch each other on the sorting table), and a more homogeneous rigor mortis process. The latter is important because rehanging the birds without delay ensures that all birds are positioned at the same time interval and in the same way as rigor mortis sets in. The result is equivalent tension on similar muscles and therefore no deformation.



Figure 5.10.1 An example of an automatic bird weighing system which also includes a temporary transfer system. Courtesy of Stork.

5.11 Evisceration

Evisceration involves opening the body cavity and withdrawing the viscera (Fig. 5.11.1). The process can be done manually using a knife and scissors, semi-automatically, or fully automatically by first using a moving blade to open the cavity and a scoop-like arm to withdraw the viscera. The latter is done at high speed on lines that can process 13,500 birds per hr (Barbut, 2014). A typical carousel design is shown in Figure 5.11.2. In all cases, special care should be taken not to pierce the viscera, which would contaminate the carcass by exposing the meat to high microbial loads (e.g., 1 g of gut content may carry 10^9 bacteria). In some countries, such a contamination results in an immediate condemnation of the parts or whole carcasses exposed to the spill, whereas in other countries, moderately contaminated carcasses can be trimmed or washed.

It is important to explain the development in equipment design and layout especially when discussing the move to higher line speeds. An operation such as evisceration takes a certain amount of time, and as line speeds increase one needs more space to perform the task. For manual operations this has been resolved by lengthening the line so more people can work on the carcasses moving along the shackle line. Another alternative is to use a serpentine or a loop line (Fig. 5.11.3).

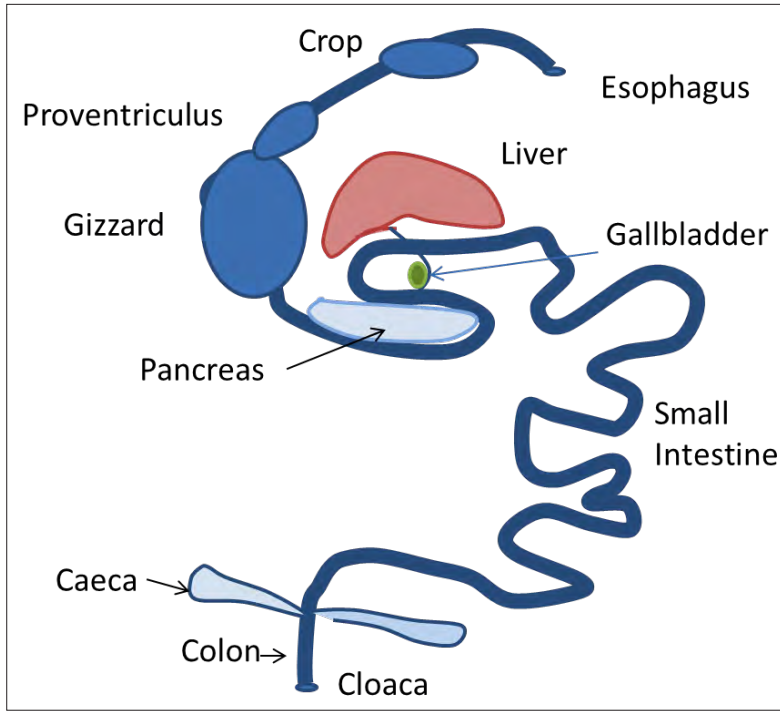


Figure 5.11.1 Digestive system in poultry. Based on Swatland (1994).

For automated procedures the poultry industry (as well as other industries), have developed loops within the line so there is additional space and time to perform a certain task. A carousel design with devices moving with the bird (Fig. 5.11.2) is currently most popular. As will be shown below, a drawing spoon is inserted at the entrance to the carousel and continues to work while the bird is moving along. Another development has been the introduction of a conical shape carousel so the birds are more spaced out at the bottom of the carousel. If needed, multiple evisceration stations/carousels (or other equipment) can be installed on the line. Overall, this is now a common design in high speed lines. It should also be noted that the serpentine type design is common in various scalding lines as the need to reduce the equipment's footprint as well as energy consumption are important drivers in the industry. In such a case the line goes back and forth within a wider scalding tank.



Figure 5.11.2 Automated equipment used for poultry evisceration. Courtesy of Marel.

In a conventional manual operation, the abdominal skin is cut open along the midline from the anterior part of the breast bone towards the cloaca. The skin around the cloaca is usually cut in a circular pattern to minimize the chance of gut contents spilling on the carcass. In recent years vacuum cleaning of cloacal content has been added to some automated equipment in order to reduce potential contamination. After, the viscera are removed manually or by a mechanical "spoon". It is interesting to read the description for a manual process from 1962:

> "The evisceration is performed by supporting the bird with one hand and inserting the fingers of the other hand through the incision in the abdomen. The three middle fingers (and sometimes the middle finger) extended, slide past the viscera until the heart is reached. They are then partly closed in a loose grip followed by a gentle twisting action, and the viscera are slipped out of the body and released" (Childs and Walters, 1962).

The same basic operation steps are used with mechanical evisceration equipment. The mechanization of the process requires precise control of the different operations. Adjusting the equipment to accommodate variations among flocks (i.e., bird size) is of great importance since unadjusted equipment can result in damaging the intestines and carcasses and causing gut spills. Since the current equipment is not designed to be self-adjusting (i.e., no sensors to gauge pressure,

or X-ray mapping of bone location), the eviscerated birds should be monitored on a continuous basis. It should be mentioned that X-ray and other mapping devices have started to appear in red meat cutting, where larger variations among animals can be expected and where line speeds are much slower (i.e., by a factor of at least 100; see discussion and figures in Chapter 1). As indicated before, a poultry eviscerating line is designed to handle only one species (e.g., chicken, turkey) and size variations are handled by raising or lowering the devices (e.g., stunner, plucker) along the shackle line.

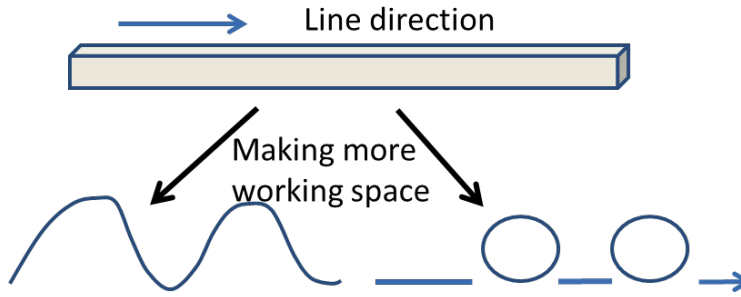


Figure 5.11.3 Illustration of "extending" workable line space.

In semi- or fully-automated evisceration lines, the first step is to cut around the cloaca using a circular rotating blade (Fig. 5.11.4). A vent cutter is placed around the cloaca by mechanical means. The blade diameter should match the size of the particular bird being processed. As indicated earlier, some of the new devices are equipped with a vacuum so the potential for fecal contamination is reduced. The cutting head is commonly rinsed after each insertion (see Fig. 5.11.4, one of the three lines reaching the device is for rinse water). The steps involved in a fully-automated evisceration process are shown in Fig. 5.11.4. Correct positioning is very important to minimize potential damage to the viscera pack and the carcass. It should be pointed out that there are different drawing spoon configurations on the market, but the main goal of the operation is the same. In some operations, the carcasses are rinsed just after withdrawing the viscera (depending on local regulations), as will be discussed later on in the chapter.

In conventional semi- or fully-automated lines, the viscera are withdrawn from the body cavity but remain attached to the body for inspection purposes. However, in some automated lines, the viscera are totally separated from the carcass after

withdrawal. This step can further improve the hygiene of the eviscerated carcasses. If the viscera pack (i.e., intestine liver, gizzard and heart) is detached from the carcass, it should be presented to the inspector together with the carcass from which it was removed. This requires precise synchronization of the two lines.

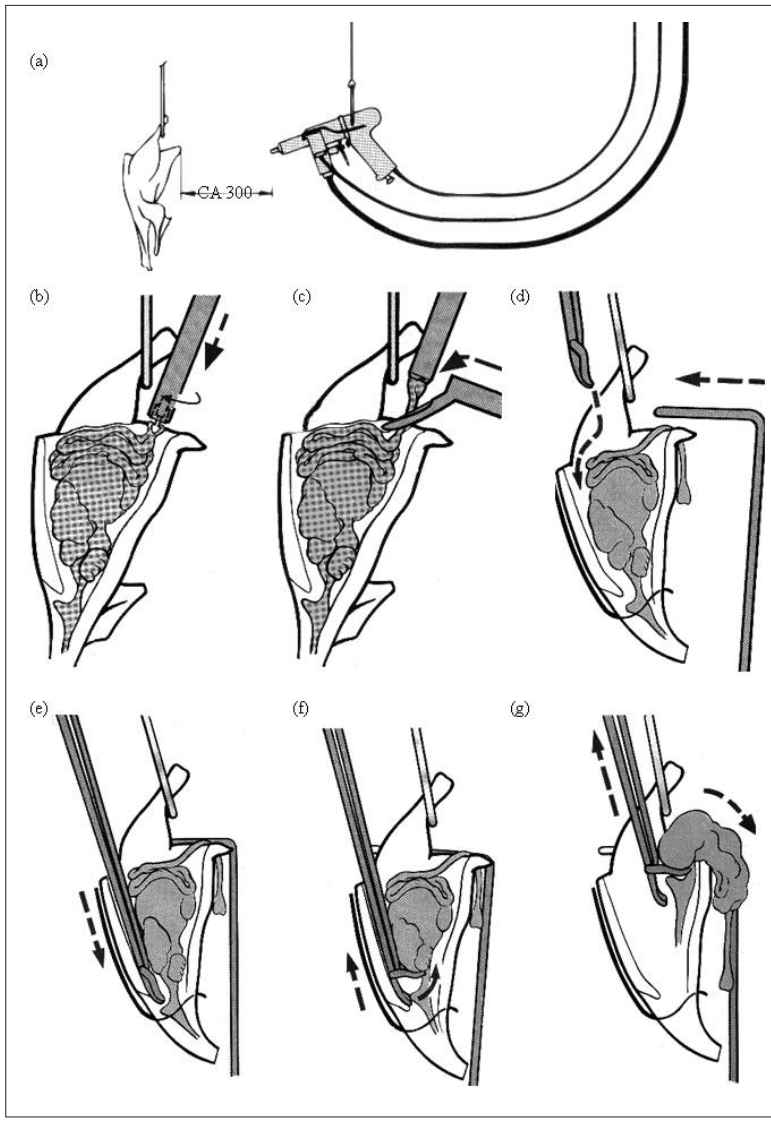


Figure 5.11.4 Schematic of unit operation used for evisceration. Shown here is a unit used for evisceration: (a) vent cutter; (b-g) steps in removing viscera. Courtesy of Stork.

5.12 Inspection

Inspection is commonly done after evisceration, as all parts are exposed at the same time. The attached or detached viscera can reveal diseases and other problems associated with the internal organs and/or outside contamination. Inspection requirements differ between countries (see Chapter 7), and the process is usually carried out by a government official. Inspection is essential to ensure that only wholesome birds that are free of disease reach the market. Some countries require individual inspection of each bird by a qualified veterinarian or government official, whereas other countries inspect flocks as a whole and only a certain number of individual carcasses. However, in the case of a wide spread disease, the inspector may choose to inspect all birds. It should also be mentioned that in some countries there is no requirement for inspection. This can cause international trade problems but not if poultry is only consumed locally. The inspection area should be equipped with adequate bright light (conditions commonly specified in the local inspection act), hand washing stations, a rake for handling suspected birds (i.e., for a more detailed inspection/trimming), and a bin for condemned birds. When individual bird inspection is required line speed should be adjusted so the inspector can check every bird. In a high speed operation, the line can also be split so several inspectors can examine the birds at once. Another alternative is using a single line with marked shackles so each inspector can be assigned certain birds (e.g., every 3rd or 4th bird; usually assigned using different coloured shackles). The carcasses should be presented in a clear way and sufficient spacing between birds should be provided. Often, mirrors are positioned such that the inspector can see both sides of the bird without touching it. An example of text from the Canadian Government Regulation is provided in Chapter 7. Computer vision systems are already available to assist and alleviate the pressure associated with examining a high speed line (see Chapter 1). However, these systems are not currently accepted for full inspection in many countries. As indicated before, a camera captures a digital picture of the carcass and compares it to a reference of a perfect carcass. After certain calculations, the system can flag any deviation as suspect and these birds are either removed from the line or are more thoroughly inspected. Several systems are already equipped with "fuzzy-logic" that allows them to "learn" as new variables are introduced. Some of the options are described in an EU supplementary document (Löhren, 2012).

5.13 Giblet Harvest

After inspection, the viscera are disconnected (i.e., if not disconnected before when special equipment is used to carry the carcass and viscera in parallel to the inspection

station) from the carcass and the giblets (liver, heart, and gizzard) are salvaged and washed in a separate line. This is an optional step, where any combination of parts can be harvested depending on market value. Previously, the process was totally manual; today, however, the process can be semi- or fully-automated. In cases where the viscera are separated to a different line for inspection (see previous section), the holder can be used as a platform for harvesting the different parts. In this case, automated equipment can be used to first remove the hearts and lungs from the hanging packs (i.e., heart and lungs at the top). This is followed by another machine that gently removes the liver, and then a module that cuts the intestines from the gizzards. Later, another unit can be used to separate the heart from the lungs. This is all done on a moving line (e.g., 12,000 packs per hour). Equipment is available for broilers, turkeys, guinea fowl, etc. The gizzard muscle (i.e., the stomach used to grind food, as birds have no teeth) is detached (manually or mechanically) from the pack, cut open, the contents are removed and the lining is peeled off. Mechanical equipment used for peeling consists of two grooved rollers (Fig. 5.13.1; right and left handed). The basic equipment is operated by a person who holds and presses the gizzard onto the rollers. The grooves/teeth catch and pull off the yellow/white lining. More automated options are also available. The gizzards are then inspected, washed and immediately chilled in order to extend their shelf lives. The hearts and livers are also inspected, washed and chilled. The giblets can be sold separately or packed in a waterproof paper bag (sometimes with the neck included) and inserted back into the eviscerated whole bird. Alternatively, parts can be sold separately (e.g., chicken livers, gizzards) or can be used by the plant for further processing.

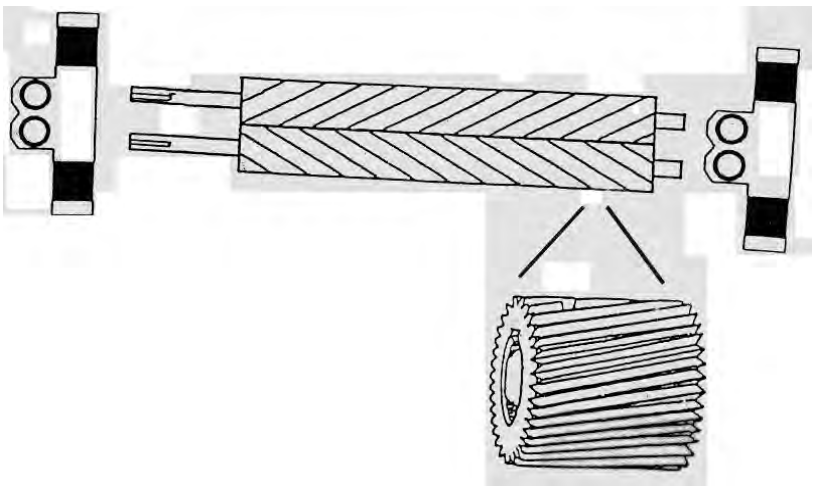


Figure 5.13.1 Illustration of rollers used for gizzard cleaning. Courtesy of DeLong Inc.

5.14 Head, Crop, Neck, and Lung Removal

The head and crop are commonly removed after inspection. However, in certain operations, one or both may be removed prior to inspection. Additionally, if the lungs were not removed during evisceration (see previous section), they have to be removed manually by inserting a rake-like device into the body cavity or by using a semi-automated vacuum gun. In high speed lines, this can require more employees than usual. The overall structure of the vacuum gun is similar to the vent cutter gun shown earlier in this chapter (Fig. 5.11.4) but it may be larger. The vacuum gun is usually attached to the plant's central vacuum system (used to transport trimmings and by-products to a central location). The equipment is commonly suspended from the ceiling by a tension cord so employees do not have to carry its weight. A fully-automated process employs the same type of equipment, but the vacuum tube is inserted by a machine after the carcass has been placed at a certain angle on a carousel as previously explained for the evisceration operation. Proper equipment adjustment is critical for obtaining a high quality product (i.e., without residues) when flock sizes change. Head removal can be done manually by using a knife. Shears operated by air pressure can be used to reduce repetitive motion injuries in workers. The mechanical shears can also be suspended from the ceiling to further improve the working conditions. Automated systems usually consist of a head puller where a guide rail first positions the head into a trough-like structure. While the carcass is moving on the shackle line, the head is pulled back and the neck is broken at the weakest point (i.e., between the atlas and the axis vertebrae). The advantage of this device is that the esophagus and trachea (windpipe) can be removed from the carcass at the same time, which saves labour. As already mentioned, care should be taken not to damage the esophagus and trachea during the bleeding operation if this method of crop and trachea removal will be used. A device to cut the neck can also be installed so the neck is separated at the shoulder area.

5.15 Bird Wash (Inside/Outside)

Various devices are used to wash the birds at different points along the processing line. They range from a simple low volume spray nozzle system to rinse the outside of the carcass after de-feathering to a more sophisticated medium/high volume water system that includes a moving shaft equipped with nozzles that is inserted into the abdominal cavity. The efficiency of the sprays in removing organic and extraneous material depends on factors such as overall coverage of the spray nozzle, spraying time, water volume and pressure used. It is important to realize that high volume and/or pressure does not necessarily provide better

washing. A common location for the washing procedure is just prior to the chilling operation. An example of an inside/outside bird wash device with multiple spray points is shown in Fig. 5.15.1.



Figure 5.15.1 An inside/outside bird washer. Courtesy of Stork.

The spray heads are positioned in such a way that debris is washed from the top down and critical areas are covered by additional spray nozzles to ensure blood and debris removal. The inside is washed by a retracting shaft equipped with high pressure nozzles that spray the abdominal cavity as it retracts. The industry has developed two methods to drain the water. The first option is draining through the neck opening (formed after removing the trachea and the crop) via a rod-type shaft with small teeth and spray nozzles that rotates while moving down and out of the neck opening. This also allows removal of any loose tissue from the neck area. The second option is tilting the carcass after spraying, which results in thorough draining of the water through the abdominal opening (created during evisceration). Different machinery variations are available depending on which draining option is desired and when the washing will take place on the line (e.g., after de-feathering or after evisceration). It is now also recognized that maintaining

a water film on the skin (by periodic spraying) while rinsing helps remove bacteria and any debris left on the carcass after scalding, plucking and/or evisceration. High pressure, low volume nozzles are becoming popular to effectively remove debris. Proper nozzle positioning (and adjusting to flock size) is very important in achieving good and efficient cleaning. Where permitted, bactericidal rinses such as chlorine and organic acids, are also used. Chlorine is one of the most commonly used chemicals and levels of up to 20 ppm are commonly employed. Bactericides, such as organic acids and phosphate dips, are sometimes used prior to chilling. See additional discussion on the different bactericides and maintaining a water film in Chapter 15.

5.16 Chilling

Regulations in most countries require that meat be chilled within a certain period of time (e.g., 2 - 6 hrs to 4°C; depending on bird size) to minimize microbial growth. In most plants thorough chilling is done prior to deboning, but in some plants carcasses are deboned before final chilling (called hot-boning or partial hot-boning). The most common methods used to chill poultry meat include immersion chilling in cold water, air chilling, spray chilling (intermittent water spraying), and combinations of the above (e.g., certain time in water and the rest in air). For immerse chilling (Fig. 5.16.1), it is common to employ long chillers (e.g., 10-50 m long) that use a counter flow of cold water, sometimes supplemented with crushed ice, to bring carcass temperatures to about 4 - 5°C within 30 - 75 min. The carcasses are placed into a trough-like structure equipped with a large diameter auger that moves the birds forward. Another design employs large paddles that slowly drag the birds forward. Parallel flow chillers (i.e., product and water flow in the same direction) and chillers with cold water/ice added along the chilling tank are still used in various plants.

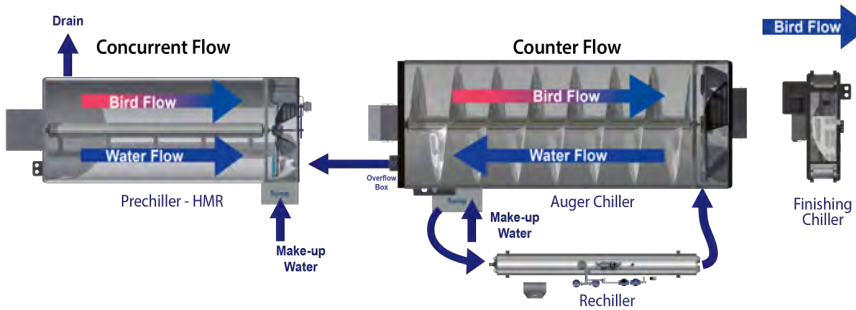


Figure 5.16.1 Water chiller system showing counter flow and a finisher chiller for possible antimicrobial treatment application. Courtesy of Morris.

However, the most common design used today is the counter-flow design where carcasses move counter to the flow of the cold clean water. This is a much more efficient way of cooling the carcasses (i.e., the coldest temperature is at the end of the tank) than the parallel flow design. This also helps to reduce the microbial load and improve the hygiene of the process. The microbial quality of the birds leaving the water chiller is usually better than those entering because the system allows bacteria to be washed away (see Chapter 15). The chilling tank length and diameter are determined by the product flow requirements where dwell time can be adjusted by modifying the auger/paddle speed. The average dwell time is 30-40 min for small to mid-sized broilers and 60-90 min for large turkeys. To increase cooling efficiency, water agitation and turbulence are used. A simple and economical way of achieving turbulence is blowing air into the bottom of the tank at various points along the line. Alternatively, a pump can be used to create water streams as described for the scalding tank. The amount of clean air (preferably from outside of the plant) and water can be adjusted so as to increase or decrease mixing. It should be mentioned that the amount of agitation could also affect the amount of water picked up by the product.

The use of a pre- and post-chiller is another improvement in obtaining a cleaner product. In the pre-chiller, water is used to chill and wash the carcasses (see diagram and additional discussion in Chapter 15). A counter-flow design helps in the gradual removal of residual blood and pieces of loose tissue attached to the product. The product is then lifted, drained, and transferred into a larger, secondary post-chiller where new clean, cold water is used to further chill the product. Ice can be added at different points, but is usually added toward the latter half of the chilling tank. The amount of water overflow in the chilling tank is regulated in some countries. For example the minimum volume required by the European Union is 2.5 liters for eviscerated birds weighing $\leq$ 2.5 kg, 4 liters for 2.5-5.0 kg, and 6 liters for $\geq$ 5 kg.

Upon exiting the chiller, the product is allowed to drain for a few minutes to remove excess water. This is done either on a perforated conveyor belt or on the next shackle line. In many countries the amount of water picked up during chilling is regulated with respect to the product's weight. For example, in the USA the maximum permitted water pickup is:

- 8.0% for chicken < 4.5 lb and turkey < 10 lb
- 6.0% for turkey 10-20 lb
- 4.5% for turkey > 20 lb
- 6.0% for all other birds types and weights

The European Union, regulations (#1538/91 EEC) are specific to chilling method and specify maximum values of: 1.5% for air chilling, 3.3% for air spray chilling, 5.1% for immersion chilling (Löhren, 2012).

Air chillers are more commonly used in Europe and some countries in the Middle East where the prices of fresh water and waste water treatment are expensive as compared to North and South America. However, it should be pointed out that air chilling is now starting to appear in North America and elsewhere. Cold air is used as the chilling medium so care should be taken not to over dry the product surface. This is usually achieved by either increasing the humidity (which also improves heat transfer), and/or wetting the product at a strategic point along the chilling process. By doing so, dehydration losses can be reduced to 0-1%. In a large plant, the setup includes an overhead railing system that goes back and forth along the chilling tunnel, which can stretch to a few km (Fig. 5.16.2).



Figure 5.16.2 Air chilling system showing overall refrigeration area. Courtesy of Marel.

There are several air chilling technologies used by the industry. The simplest is cooling birds on a stationary rack in a walk-in cooler. Air temperature, speed and relative humidity usually depend on the particular cooler setting and are not always optimized for chilling poultry. A step up uses directed air flow and allows adjustments for air speed, temperature, and humidity to achieve the optimal

chilling rate for a particular bird size and rigor mortis stage. Dedicated chilling tunnels are constructed with a single or multi-layer overhead conveyor system (conveyors run on each tier and are offset to prevent dripping on a lower tier). Air is blown over cooling elements and then circulated in different patterns around the room at a fairly high speed. Depending on the chilling tunnel capacity and volume of the product sent through, chilling can be achieved within 60-150 min. Moisturizing at strategic points is recommended over humidifying the whole room/tunnel as better control and less cross contamination can be achieved. Usually the moisturizing units are positioned on 180º corner wheels outside the main room/tunnel. An improvement of the process is called maturation chilling and includes a system that initially directs cold air into the abdominal cavity of the carcass and onto the exterior of thick parts (e.g., breast, leg). This process can shorten the chilling time and improve the efficiency of the system. However, one should be careful to avoid cold-shortening of the muscles (i.e., chilling too quickly before rigor mortis is complete, see Chapter 3). Therefore, after the initial fast cooling of the surface, the temperature is raised and air flow is reduced. One of the benefits of air chilling is reduced moisture pick up and a drier final product that usually shows no exudation (drip loss) when packaged (Huezo et al., 2007). This is appreciated in certain markets (i.e., where people are willing to pay for it). Some processors also claim that the microbial quality of the air chilled products is better than that of water chilled products, but that is not always the case (see Chapter 15 for further discussion).

Spray chilling is a hybrid between water and air chilling. Cold water is either intermittently or constantly sprayed over the product while it moves along the shackle line. The resulting moisture pick up is less than that of water chilled products, but more than that of air chilled products. Young and Smith (2004) compared moisture uptake following water and air chilling and determined that storage decreases moisture pick up by half. In that study, air chilled carcasses lost about 0.68% weight post-chill, but did not lose any more during subsequent storage and cutting. The water chilled carcasses picked up about 11.7% moisture post-chill, but only retained about 7% through storage (24 hrs at 1ºC), 6% immediately after cutting into front-halves and leg quarters, and 3.9% after cut-up and 24 hrs of additional storage (48 hrs post-mortem). Leg quarters showed higher purge than front-halves. New air chilling systems (evaporative air chilling) now incorporate a moistening system to prevent weight loss typically associated with air chilling.

Overall, choosing one chilling method over another depends on factors such as market demand, water cost and availability, electricity costs, and capital investment available. Overall, when a new plant is built (called a "green field") the processor should consult with equipment manufacturers, inspection personnel,

and consumer groups in order to make the best decision for the new operation while recognizing that the method chosen will stay in place for many years.

The use of mathematical modeling to design new chilling options or validate the operation of an existing one, has increased over the past few years. The advantages of modeling are the ability to predict the outcome and optimize the process (see additional discussion in Chapter 11 dealing with modeling of meat cooking; i.e., another example of a heat and mass transfer modeling). Figure 15.16.3 shows the heterogeneous thermal conductivity (k) and specific heat (C_p) in different areas of a broiler carcass. This information is used in the modeling to simulate the cooling rates in different areas. Figure 5.16.4 show the simulation of an air cooling process, which in this particular case shows the effect every 30 min at the beginning and later every 3 hrs.

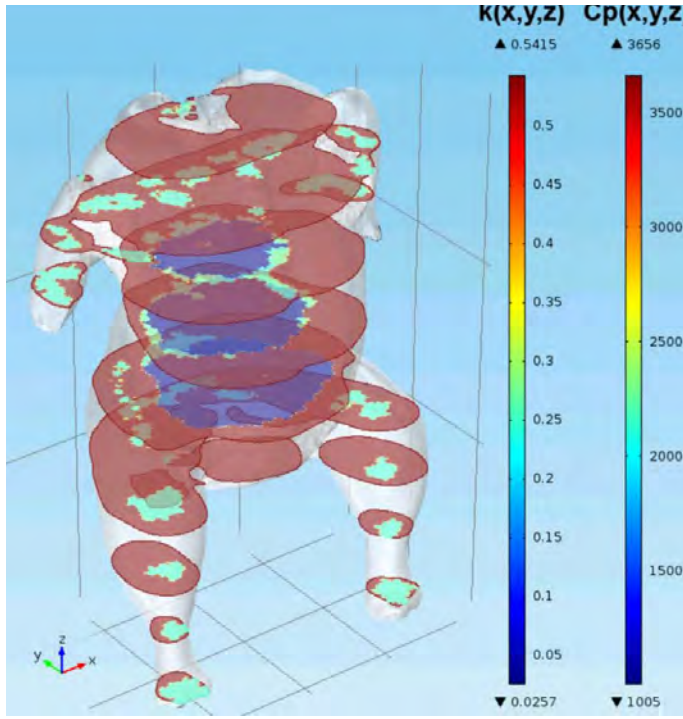


Figure 5.16.3 Slice plot of a broiler carcass showing heterogenous thermal conductivity k (W/mK), and specific heat Cp (J/kgK). From Cepeda et al (2013). With permission.

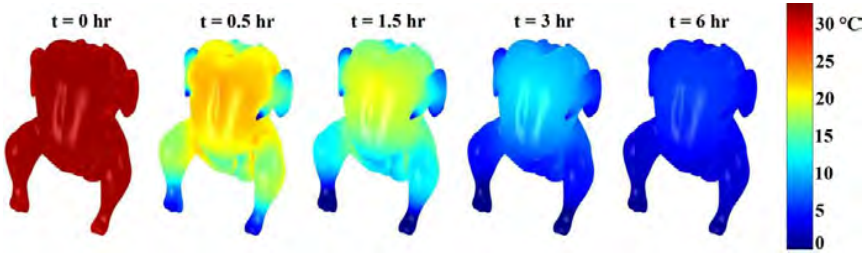


Figure 5.16.4 Simulation of air-cooling of a poultry carcass, using Comsol software. From Cepeda et al (2013). With permission.

5.17 Weighing and Grading

After chilling, the birds are weighed, graded (see Chapter 7 for more details), and either packed or deboned prior to sale and/or further processing. In most large plants, automated weighing equipment connected to a computer network is used to record the weight of each carcass/part and sort it (Fig. 5.17.1). More sophisticated computer systems can combine weight and image analysis data (previously discussed) to make a decision about the best way to market each bird (e.g., whole carcass, parts). The decision depends on input regarding price for various parts, market demands for a specific day/week, requirements for in-plant meat supply, etc. Such a process can have significant cost-savings in medium and high volume plants that process hundreds of thousands of birds per day.

Grading is done either before or after weighing. Usually, it is not mandatory but is commonly done to facilitate trade. Grading can be done by a qualified worker or with the assistance of a computerized machine vision system. See detailed discussion on grading criteria in Chapter 7. Overall, it is important to recognize that the final grade and overall meat quality can be strongly affected by the different steps described in this chapter (e.g., unloading, stunning, plucking, chilling, etc.), as well as by conditions on the farm (e.g., feeding, animal health).

Whole poultry, cut up parts or minced meat are commonly packaged in small retail packages or large combos for industrial use. The packaging material is design to protect the product form moisture loss due to evaporation, cross contamination with bacteria (e.g., on the hands of employees, consumers), dust and foreign matter, while also providing room for the processor to advertise its product (e.g., company's logo, recipes, nutritional information). See additional discussion of films' characteristics in Chapter 11.

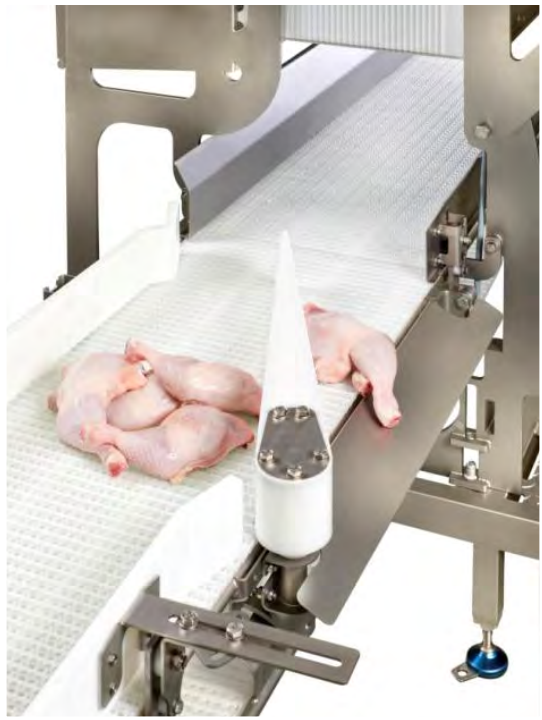


Figure 5.17.1 An example of an automated sorting station. This is done after weighing each piece on another short segment of the belt (i.e., a standalone segment equipped with a fast weighing system). The weighing station is located about 5-10 meters in front of the sorting station, so there is enough time for data processing and execution. Courtesy of Marel.

5.18 Portioning and Packing

Depending on the end use the birds can be portiond and/or packaged individually or in bulk; see Chapters 9 and 11, respectively.

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6

HACCP IN PRIMARY PROCESSING

6.1 Introduction

The Hazard Analysis Critical Control Point (HACCP) program was developed in the early 1970s at the Pillsbury Food Company while developing food for the National Aeronautic and Space Administration Program and the US Army Research Laboratory (Mortimore and Wallace, 1995). HACCP represents a scientific preventive approach to controlling and reducing hazards associated with food production. Overall, it was developed to replace the Random Finished Product Quality Control program, which could not guarantee the level of safety required for the space program. Today, implementing a HACCP program has other added benefits such as problem identification and quality monitoring at an early stage of production, which saves time and money. At the beginning, the HACCP concept was only applied to few products (e.g., low acid canned foods), but today it is used around the world for a large variety of foods and across international trade. Currently, most large food companies, supermarkets, and fast food chains use HACCP in one form or another and quite a few require that their suppliers become HACCP approved. This kind of an integrated approach has resulted in better cooperation within the industry to assure high quality and safe food products. It is important to mention organizations such as the Global Food Safety Initiative (GFSI, 2014). This is a global industry driven initiative aiming at harmonizing and providing guidance on food safety management system controls of the food supply chain. Numerous countries have mandated the use of HACCP in sections or whole food processing plants, while others have only recommended its use to create a more effective food inspection system. For a processing plant, becoming HACCP approved requires a strong commitment from management (e.g., resources, time) and the concept embraced by all employees (Yiannas, 2009). Implementing a HACCP program usually starts with putting together a team of people from different areas of the plant (e.g., engineering, production, and maintenance) who review the entire production line(s).

Overall, an effective HACCP system is one that leads to the production of safe food (free of microbiological, chemical, and physical hazards) via a systematic

approach that monitors each processing step from receiving raw materials to packaging and storing the final product. This is done through identifying the hazard and interventions to minimize risks. The following chapter will introduce the reader to the seven HACCP principles that have been internationally accepted and described in the Codex Alimentarius Commission Codex (1993) and the National Advisory Committee on Microbiological Criteria for Foods (Mortimore and Wallace, 1995). This chapter also describes a generic model related to operating a primary poultry/meat processing plant that readers can use as a template in setting up their own operation or compare to an existing program. In later chapters two other HACCP models will be introduced for ready to eat meats (Chapter 12) and breaded products (Chapter 14). The models not only illustrate the use of a HACCP plan, but also provide the reader additional information about processes described elsewhere in the book (e.g., live animal/bird handling which is discussed in Chapter 4; preservation discussed in Chapter 11; preparation of poultry products discussed in Chapter 13; microbiology discussed in Chapter 15.

Many food companies around the world have already implemented or are in the process of implementing HACCP and/or ISO 9000 programs. These companies experience tangible benefits such as legislation compliance, consistent product quality, increased product safety, and easy acceptance of performance by third party auditing. Today some of the plants aim to simultaneously implement both HACCP and ISO 9000 because the two systems are complimentary (Barbut and Pronk, 2014; Sandrou and Arvanitoyannis, 1999). It should be mentioned that there are several books specifically devoted to the technical aspects of HACCP, including books that deal with employee commitment and motivation.

6.2 The Seven HACCP Principles

1. Conduct a hazard analysis. Prepare a list of processing steps where significant hazards could occur and describe the preventive measures. There are three types of hazards:

a. Biological (B) – hazards primarily concerned with pathogenic bacteria (e.g., S*almonella enteritidis, Staphylococcus aureus, Campylobacter jejuni, Clostridium perfringens, Clostridium botulinum, Listeria monocytogenes,* and *Escherichia coli* O157:H7), viruses (e.g., the bird flu H5N1), and parasites (e.g., *Trichinella spiralis* in pork).
b. Chemical (C) – toxic substances or compounds that may be unsafe for consumption (e.g., cleaners, sanitizers, pesticides, insecticides, rodenticides, paint, lubricants, mycotoxins, antibiotics). An example

that received a lot of publicity in the poultry industry was the Belgian dioxin incident that occurred in January 1999 when a mixture of polychlorinated biphenyls (PCBs) contaminated with dioxins was accidentally added to a stock of recycled fat used in the production of animal feeds. It impacted more than 2500 farms and resulted in a major food crisis that rapidly extended to the whole country and resulted in the implementation of a large PCB/dioxin food monitoring program. The Belgian dioxin incident was due to a single source of PCB oil that was introduced into the food chain. The total amount of PCBs added to recycled fats was estimated at 50 kg, which corresponds to about 100 liters of PCB oil. The highest concentrations of PCBs and dioxins were found in poultry, particularly in the reproduction animals (hens), which showed classical manifestations of chick edema disease. Pigs were also affected but to a lesser extent and no sign of intoxication was observed.

c. Physical (P) – foreign objects that may injure the consumer (e.g., stones, wood, feathers, metal, glass, bolts, screws, plastic, knife blades, needles, hair).

2. Identify the critical control points (CCPs) in the process by using a decision tree (described in Section 6.4). A CCP is defined as a point, step, or procedure in a food production system at which control can be applied to prevent, eliminate, or reduce a hazard to an acceptable level. Examples of potential CCPs:

a. Heat/radiation process to destroy a specific pathogen.
b. Reaching and maintaining a certain pH level which prevents pathogen growth.

3. Establish critical limits for preventive measures associated with each identified CCP. A critical limit is defined as a criterion that must be met for each preventive measure associated with a CCP (e.g., raw meat to be cooked to a temperature of 72°C; see also Chapter 12). Each CCP will have one or more preventive measures that must be properly controlled to assure prevention, elimination, or reduction of the hazard(s) to acceptable levels.

4. Establish CCP monitoring requirements. Establish procedures to monitor the results of each step in the process. This involves a scheduled testing or observations of each identified CCP and its limits. The results must be documented and kept on record for a pre-determined period of time (e.g., five years). For monitoring a parameter such as temperature, a chart recorder may be used to demonstrate that a certain cooking temperature has been achieved and maintained for a specified period of time.

5. Establish corrective action(s) to be taken when monitoring indicates that there is a deviation from an established critical limit (out of limit). The action(s) should bring back the process under control, and eliminate the hazard potentially created by deviation from the plan. If the hazard cannot be remediated then the product should be removed. Overall, the action(s) must show that the hazard was brought under control.

6. Establish effective record keeping procedures that document the HACCP system. This is a crucial step in running the program. The entire HACCP plan must be kept on file and be made available, at any time, to an official government inspector. Examples of forms used for recording and documenting are provided later on in the chapter. While some inspection agencies require the use of standardized forms, others let the plant develop its own, which must first be approved before use.

7. Establish procedures for verification. This ensures that the HACCP system is functioning correctly and effectively, and that it is delivering products as promised. Verification consists of procedures and tests to show that the system is in compliance with the prescribed plant. An example of a verification step might be a scheduled or random insertion of metal into a marked package to show that the system is capable of identifying it when metal has been identified as a potential hazard. The verification process should also confirm that all hazards have been identified and dealt with when the HACCP plan was developed. Some of the verification measures may include compliance with a set of standard criteria (e.g., microbiological test referencing) provided by government or industry bodies. Verification procedures should include activities such as reviews of the HACCP plan, checking CCP records/deviations, random sample collections, and written record verifications. The reports should also include the name(s) of the individual(s) responsible for each step in the HACCP plan.

6.3 Generic HACCP Models

Several generic models have been developed by government agencies and industry bodies worldwide to provide working blueprints for various meat processing operations (e.g., primary processing of poultry/beef/pork, ready to eat meat products) and other foods (e.g., yogurt, frozen vegetables). A generic model provides processors with a useful template that can be adapted as needed. As indicated before, some countries have mandated the use of HACCP. For example, the United States Department of Agriculture (USDA) ruled in July 1996 that

HACCP be implemented as a system of process control in all USDA inspected meat and poultry plants (and these supplying US markets). To help the industry, government bodies such as the USA Food Safety and Inspection Service (FSIS), and the Canadian Food Inspection Agency, have published generic models. However, it should be noted that there are several procedures that should be in place prior to the implementation of a HACCP plan. They include procedures such as Good Manufacturing Practices (GMPs), the Standard Operating Procedures (SOPs), and the Sanitation Standard Operating Procedures (SSOPs). Good Manufacturing Practices are minimum sanitary and processing requirements applicable to all companies processing food; sections related to different sectors of the food industry are available on the Internet. Standard Operating Procedures are step-by-step directions for executing major plant procedures that specifically describe the method for conducting and controlling each procedure. SOPs are designed to ensure minimum standards are met and should be evaluated regularly (i.e., daily, weekly, or monthly, depending on the step) to confirm proper and consistent application. They should also be modified as necessary to ensure proper control. Once GMPs and SOPs are in place, the HACCP generic models can be used as a starting point for the development of a process specific plan that reflects the plant environment. The generic models are not intended to be used "as is", but rather should be developed to address the hazards relevant to a specific product manufacturing (e.g., account for different machinery, plant lay out, unique intervention methods, local regulations, etc.). See also discussion in Chapter 15 about current requirements for sanitary equipment design.

6.4 Poultry Slaughter - A HACCP Generic Model

The generic model provided here is the revised Canadian Food Inspection Agency (CFIA) model for chilled, ready to cook, whole chicken (CFIA, 2011). The previous CFIA model, from 1998, was revised with the intention to reduce the number of CCPs from 9 to 5 and to focus more on the prerequisite programs. The previous CFIA model is quite similar to the USDA (1999) HACCP model. Note: the USDA model is still being revised as some other related documents are being finalized (FSIS, 2014).

In the introduction of the revised CFIA model there are a few important notes:

> "This generic model has been developed based on incoming materials and a sequence of processing steps that are common to a chicken slaughter establishment operating on a HACCP

based inspection system (including on-line reprocessing and reconditioning with downstream cavity defect detection). Considering the many variations in the set-up of chicken slaughter establishments and numerous types of products produced, it would be difficult to include all possible scenarios. Operators, therefore, need to adapt this generic model to their plant specific environment when developing their HACCP plans; i.e., as they are also responsible for food safety in their plant.

Additional hazards may also have to be considered when this model is used for either other poultry species or other classes of poultry; for instance, in the cases of mature poultry such as spent laying hens or spent breeder hens (any species of poultry), contamination and cross-contamination by eggs or egg proteins during the evisceration and chilling process must be considered as a significant chemical hazard that should be controlled and/or mitigated otherwise it could reach unacceptable levels. The ultimate control available for that allergen is the avoidance through the labeling of all products and by-products made of mature poultry to inform further users and/or consumers in order to prevent allergic reactions" (CFIA, 2011).

The flow diagram included in the CFIA model (Fig. 6.4.1) starts with receiving the live bird (i.e., can be used for chickens, turkeys, ducks, etc.), the packaging materials, and the various chemicals (e.g., antimicrobial agents, salt) that will be used in the process. Figure 6.4.1 lists all of the steps and provides a general overview of the process (see also Fig. 5.1.3 in Chapter 5) with an emphasis on potential hazards and points at which they can be controlled (CCPs).

In addition to the flow diagram, plant management is also required to submit an Employee Traffic Pattern Diagram. This schematic provides a basis for evaluating potential areas of cross contamination and must include:

a. The flow of raw products, ingredients and finished products.
b. The flow of packaging materials.
c. The employee traffic pattern throughout the establishment including change rooms, washrooms and lunchrooms.
d. The flow of waste, inedible products, and other non-food products that could cause cross contamination.
e. The hand/boot washing and sanitizing installations/stations.

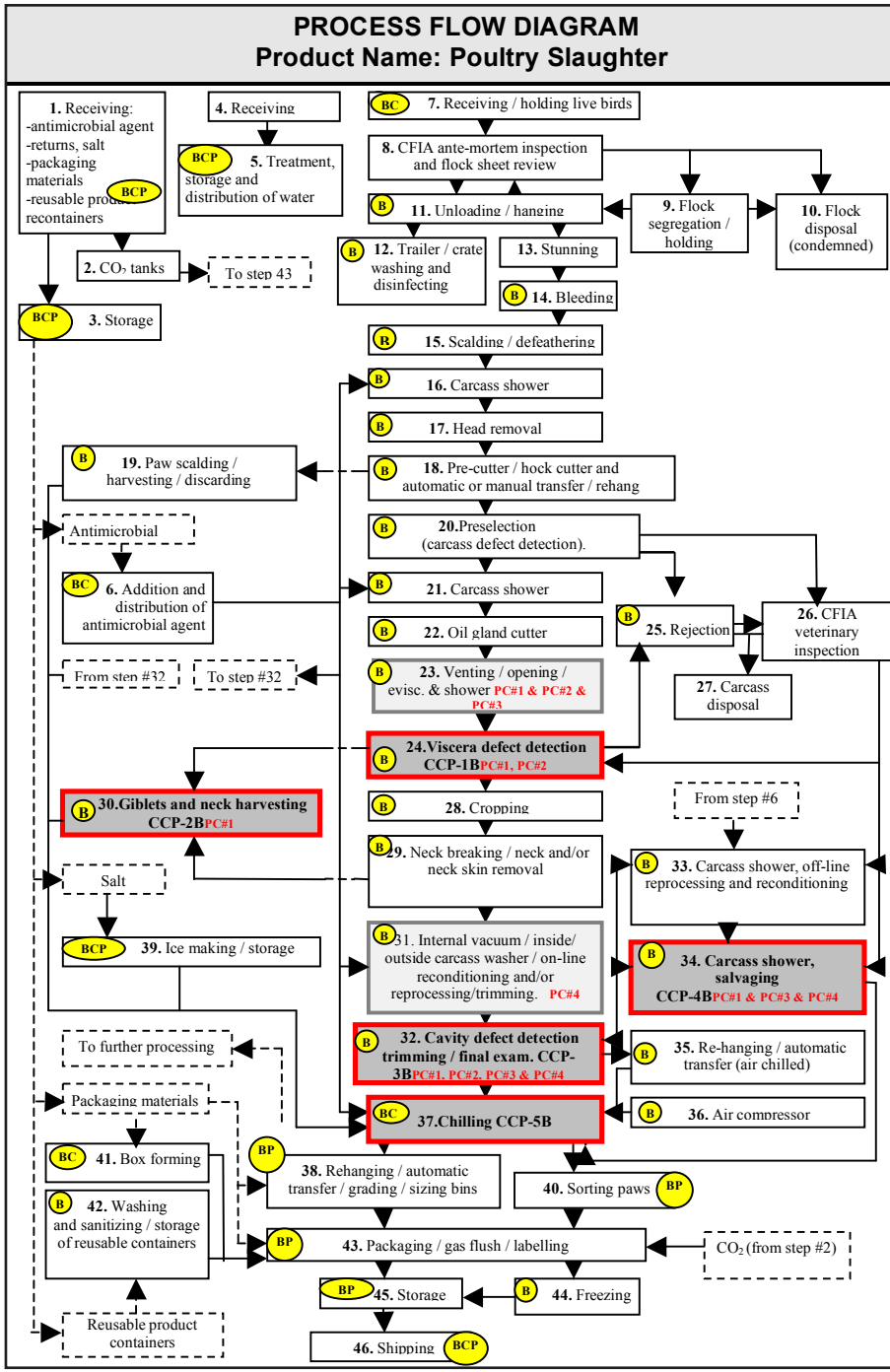


Figure 6.4.1 Process flow diagram for poultry primary processing, including suggested critical control points (CCPs) marked as shaded areas. From CFIA (2011).

The official HACCP document starts with a product description (Table 6.4.1) that includes detailed information regarding the products intended use, shelf life, holding temperature, etc. As indicated above, this is a generic model and each plant should revise it to fit its needs/intended uses (e.g., can have different hazards in a plant that uses water chilling vs. air chilling). Fitting / adjusting the model is a very important step in developing a HACCP plan, as later on it will become an official document that the plant uses when dealing with the government.

Table 6.4.2 and Figure 6.4.1 show that there are three main streams in receiving: live animals/meat, non-meat components (e.g., water/ice, gases for modified atmosphere packaging, salt), and packaging materials (e.g., Styrofoam trays, absorbent pads, plastic film wraps, and cardboard boxes). All non-meat components and packaging materials will be in contact with food and therefore should meet certain agreed specifications (outlined in the prerequisite program or Letter of Guarantee from the supplier).

Table 6.4.3 lists examples of potential hazards from the incoming raw materials. The goal is to systematically identify and prioritize all hazards in order to control the risks and devise procedures to eliminate/minimize the hazards. A HACCP plan should be supported by scientific evidence. Overall, there are various scientific studies that point to procedures that can help reduce bacterial load in ready to cook poultry meat:

a. Timely feed withdrawal that results in empty crops; i.e., to reduce gut spills.
b. High quality water in chilling tanks.
c. Spray washing carcasses with sufficient water volume and pressure can remove about 0.5-1.0 log CFU of bacterial load (i.e., up to 90%). See more discussion and actual references in Chapter 15.
d. Forced air cooling with ozone.
e. Reprocessing or decontamination of carcasses with visible fecal/other contamination (see step 33 in Fig. 6.4.1).
f. Cooling of meat to < 40C to minimize bacterial growth.
g. Using counter flow scalders and water chillers (see also Chapters 5 and 15).
h. Using antimicrobial agents (where permitted) such as chlorine, hot water, or lactic acid during washing and/or water chilling of carcasses (see Chapter 15 for in depth discussion).
i. Constant cleaning of transfer belts and automatic evisceration equipment (e.g., using sprays for rinsing in a so called cleaning in place operation) to reduce cross contamination.

Table 6.4.1 Example of product description form which is part of the official HACCP document. From CFIA (2011).

PRODUCT DESCRIPTION – FORM #1 **Process/Product Type Name: Poultry Slaughter**	
1. Product name(s)	- Raw whole chicken - Raw chicken portions (bone-in and deboned) - Chicken giblets (heart, liver, gizzard) - Chicken paws
2. Important product characteristics (a_w, pH, preservatives, etc)	Non applicable
3. Intended use	Carcasses, portions, giblets and paws: - Ready to cook - For further processing.
4. Packaging	Consumer-size (Modified Atmosphere Packaging) - Styrofoam tray (food contact) - Absorbent pads (food contact) - Plastic film wrap (food contact) - Cardboard boxes (non-food contact) Bulk packs - Plastic/metal breast tags (food contact) - Waxed cardboard boxes (food contact) - Plastic liners / bags (food contact) - Combos (metal cages / plastic / cardboard) (non-food contact) - Plastic containers (food contact) - Stainless steel vats (food contact) - Plastic/metal clips (non-food contact)
5. Shelf life	Consumer-size (Modified Atmosphere Packaging) - Carcasses & portions – "Y" days at ≤ 4°C Bulk packs - Fresh carcasses & portions – "Y" days at ≤ 4°C - Fresh giblets and paws – "Y" days at ≤ 4°C - Frozen carcasses – "Y" days at ≤ -18°C
6. Where it will be sold	Consumer-size - Retail – General population Bulk packs - Federally registered establishments for further processing - Institutions - Restaurants
7. Labelling instructions	Keep refrigerated Keep frozen Best before date Safe handling instructions (recommended)
8. Special distribution control	Fresh product: maintained at ≤ 4°C Frozen product: maintained in a frozen state

Table 6.4.2 Example of the product ingredients and incoming materials used to make and distribute fresh poultry meat. From CFIA (2011).

LIST OF PRODUCT INGREDIENTS AND INCOMING MATERIAL – FORM #2 Product Name: Poultry Slaughter					
Live Animals	**code**	**Non Meat Products**	**code**	**Packaging Materials**	**code**
Chickens	BC	water	BCP	**Food contact**	
		ice	BCP	styrofoam tray	BCP
		CO_2 (Modified Atmosphere Packaging – MAP)	C	absorbent pads	BCP
		salt	C	plastic liners / bags / film wrap	BCP
		air (compressed)	BC	plastic / metal breast tags	BCP
				waxed cardboard boxes	BCP
				stainless steel vats	BP
Meat Products				plastic containers	BCP
Returned products	BCP			**Non-food contact**	
				cardboard boxes	P
				combos (metal cages / plastic / cardboard)	P
				plastic / metal clips	
				pallets	P
Antimicrobial Agents	**code**	**Others**	**code**		
antimicrobial agents e.g.: • Chlorine (Cl_2) • Acidified Sodium Chlorite • Trisodium Phosphate (TSP) • Lactic Acid • Chlorine dioxide					
Explanation of codes: B : Biological; C : Chemical; P : Physical					

The generic model also includes provisions for optional processing schemes, such as using manual re-hanging versus automatic transfer (see step 35 in Fig. 6.4.1). Another example is for plants equipped with different technologies for evisceration (e.g., total separation of viscera from carcass or keeping the viscera attached to the carcass during inspection). Such procedures should be clearly identified in the HACCP document in order to get the appropriate government approval.

Table 6.4.3 Examples of hazard identification using a decision-tree for critical point (CCP) determination and other control measures [Prerequisite Program (PP), Process Control (PC)] for a poultry slaughter operation. Adapted from CFIA (2011).

List each ingredient / process where hazard has been identified	Identify hazard (B,C,P) + describe. Determine if fully controlled by PP. YES-indicate (last column). Move to next hazard. NO- Move to Q1.	Q1. Could control measure(s) be used? NO-indicate how hazard controlled (last column). Move to next hazard. YES-describe measure. Move to Q2.	Q2. Is it likely contamination occurs in excess of acceptable level? NO-identify reason(s). Move to next hazard. YES-identify acceptable level wherever possible. Move to Q3.	Q3. Is this process specifically designed to prevent/ eliminate occurrence? YES-CCP (last column). NO- Move to Q4.	Q4. Will a subsequent step eliminate/reduce hazard? NO-CCP (last column). Move to next hazard. YES-identify next control step. Move to Q5.	Q5. Does step provide partial control? YES-PC (last column). Move to next hazard. NO- Move to next hazard.	Controlled at: #CCP #PC PP - before/after process.
Live chicken	**Biological** – Presence of pathogenic bacteria on feathers, skin, intestinal tract. **NO**	**NO**					**Farm level:** Husbandry practices and On-Farm Safety Program. **Further Processing:** Use thermal process that leads to a 7 log reduction in pathogens. **Consumer level:** Ultimate control through proper handling and cooking of meat.
	Biological – Pathogenic contamination during evisceration due to inadequate feed withdrawal. **YES**						PP: 1, 3, 4, 5, 6 *
	Chemical –Unacceptable levels of drug (antibiotics, coccidiostats) in live chicken. **YES**	**NO**					PP: 1, 3, 4, 5, 6
	Chemical – Unacceptable heavy metal/pesticide levels in live chicken. **NO**						**Farm level:** Prevent exposure to chemical products and On-Farm Food Safety Program.

List each ingredient / process where hazard has been identified	Identify hazard (B,C,P) + describe. Determine if fully controlled by PP. YES-indicate (last column). Move to next hazard. NO- Move to Q1.	Q1. Could control measure(s) be used? NO-indicate how hazard controlled (last column). Move to next hazard. YES-describe measure. Move to Q2.	Q2. Is it likely contamination occurs in excess of acceptable level? NO-identify reason(s). Move to next hazard. YES-identify acceptable level wherever possible. Move to Q3.	Q3. Is this process specifically designed to prevent/ eliminate occurrence? YES-CCP (last column). NO- Move to Q4.	Q4. Will a subsequent step eliminate/reduce hazard? NO-CCP (last column). Move to next hazard. YES-identify next control step. Move to Q5.	Q5. Does step provide partial control? YES-PC (last column). Move to next hazard. NO- Move to next hazard.	Controlled at: #CCP #PC PP - before/after process.
Water	**Biological** – Not meeting the drinking water criteria established by Government **YES**						PP: 2*
	Biological – Presence of pathogenic bacteria (e.g., *Salmonella spp., Campylobacter jejuni, Staphylococcus aureus, Shigella spp., Streptococcus sp, Yersinia spp., Escherichia coli, Listeria monocytogenes*). **YES**						PP: 2
Salt	**Chemical** – Non-food grade or contaminated at source. **YES**						PP: 1, 3, 4, 5, 6
3. Storage	**Biological** – Contamination due to improper handling / practices **YES**						PP: 1, 3, 4, 5, 6, 8

List each ingredient / process where hazard has been identified	Identify hazard (B,C,P) + describe. Determine if fully controlled by PP. YES-indicate (last column). Move to next hazard. NO- Move to Q1.	Q1. Could control measure(s) be used? NO-indicate how hazard controlled (last column). Move to next hazard. YES-describe measure. Move to Q2.	Q2. Is it likely contamination occurs in excess of acceptable level? NO-identify reason(s). Move to next hazard. YES-identify acceptable level wherever possible. Move to Q3.	Q3. Is this process specifically designed to prevent/ eliminate occurrence? YES-CCP (last column). NO- Move to Q4.	Q4. Will a subsequent step eliminate/reduce hazard? NO-CCP (last column). Move to next hazard. YES-identify next control step. Move to Q5.	Q5. Does step provide partial control? YES-PC (last column). Move to next hazard. NO- Move to next hazard.	Controlled at: #CCP #PC PP - before/after process.
	Biological – Pathogen contamination due to pests **YES**						PP: 1, 3, 4, 5, 6, 9, 10
	Chemical – Contamination of incoming / packaging materials during storage (e.g. cleaners, sanitizers, lubricants). **YES**						PP: 1, 3, 4, 5, 6
5. Treatment, distribution, storage - water	**Biological** – Contamination due to "dead ends" or back siphoning. **YES**						PP: 2
	Chemical – Excess chlorine **YES**						PP: 2
7. Receiving / holding live birds	**Biological** – Contamination during evisceration due to inadequate feed withdrawal. **YES**						PP: 1, 3, 4, 5, 6
	Chemical – Accepting bird with residues (e.g. antibacterial, pesticides) **YES**						PP: 1, 3, 4, 5, 6

List each ingredient / process where hazard has been identified	Identify hazard (B,C,P) + describe. Determine if fully controlled by PP. YES-indicate (last column). Move to next hazard. NO- Move to Q1.	Q1. Could control measure(s) be used? NO-indicate how hazard controlled (last column). Move to next hazard. YES-describe measure. Move to Q2.	Q2. Is it likely contamination occurs in excess of acceptable level? NO-identify reason(s). Move to next hazard. YES-identify acceptable level wherever possible. Move to Q3.	Q3. Is this process specifically designed to prevent/ eliminate occurrence? YES-CCP (last column). NO- Move to Q4.	Q4. Will a subsequent step eliminate/reduce hazard? NO-CCP (last column). Move to next hazard. YES-identify next control step. Move to Q5.	Q5. Does step provide partial control? YES-PC (last column). Move to next hazard. NO- Move to next hazard.	Controlled at: #CCP #PC PP - before/after process.
11. Unloading / hanging	**Biological** – Pathogens in septicemic birds which were dead on arrival that are hung instead of being discarded. **YES**						PP: 1, 3, 4, 5, 6
12. Trailer / crate washing and disinfecting	**Biological** – Contamination of subsequent flocks / live birds due to poorly cleaned crates. **YES**						PP: 1, 3, 4, 5, 6, 9 ,10
14. Bleeding	**Biological** – Contamination of bleeding incision due to build-up of organic debris on equipment and / or faulty cleaning of the hands and knife of the back-up employee. **YES**						PP: 2, 7, 8, 9 ,10
15. Scalding / defeathering	**Biological** – Spread of pathogens through scald water due to inadequate temperature and/or inadequate water replacement/supply. **YES**						PP: 2, 7, 8

List each ingredient / process where hazard has been identified	Identify hazard (B,C,P) + describe. Determine if fully controlled by PP. YES-indicate (last column). Move to next hazard. NO- Move to Q1.	Q1. Could control measure(s) be used? NO-indicate how hazard controlled (last column). Move to next hazard. YES-describe measure. Move to Q2.	Q2. Is it likely contamination occurs in excess of acceptable level? NO-identify reason(s). Move to next hazard. YES-identify acceptable level wherever possible. Move to Q3.	Q3. Is this process specifically designed to prevent/ eliminate occurrence? YES-CCP (last column). NO- Move to Q4.	Q4. Will a subsequent step eliminate/reduce hazard? NO-CCP (last column). Move to next hazard. YES-identify next control step. Move to Q5.	Q5. Does step provide partial control? YES-PC (last column). Move to next hazard. NO- Move to next hazard.	Controlled at: #CCP #PC PP - before/after process.
	Biological – Contamination of muscle resulting from breakage of the skin barrier due to: 1. improper scald water temperature:**YES** 2. improper adjustment of feather pickers: **YES** 3. kill line stoppage and overscalding product: **YES**						1. PP: 2, 8 2. PP: 7, 8 3. PP: 2, 7, 8
16. Carcass shower	**Biological** – Failure to reduce pathogen levels due to inadequate application of a water film preventing bacterial attachment and removal of visible contamination on carcasses (e.g., insufficient water volume/pressure, spray nozzles at improper location). **YES**						PP: 2, 7, 8
	Biological – Pathogen survival due to insufficient antimicrobial agent. **YES**						PP: 7

List each ingredient / process where hazard has been identified	Identify hazard (B,C,P) + describe. Determine if fully controlled by PP. YES-indicate (last column). Move to next hazard. NO- Move to Q1.	Q1. Could control measure(s) be used? NO-indicate how hazard controlled (last column). Move to next hazard. YES-describe measure. Move to Q2.	Q2. Is it likely contamination occurs in excess of acceptable level? NO-identify reason(s). Move to next hazard. YES-identify acceptable level wherever possible. Move to Q3.	Q3. Is this process specifically designed to prevent/ eliminate occurrence? YES-CCP (last column). NO- Move to Q4.	Q4. Will a subsequent step eliminate/reduce hazard? NO-CCP (last column). Move to next hazard. YES-identify next control step. Move to Q5.	Q5. Does step provide partial control? YES-PC (last column). Move to next hazard. NO- Move to next hazard.	Controlled at: #CCP #PC PP - before/after process.
18. Pre-cutter / hock cutter and automatic/ manual transfer / rehang	**Biological** – Contamination due to build-up of organic debris. **YES**						PP: 1, 3, 4, 5, 6, 7, 8, 9, 10 *
	Biological – Cross-contamination due to cloacal leakage. Subsequent: 1. carcass-to-carcass contact: **YES** 2. chute-, table- or belt-to-carcass contact: **YES**						1. PP: 1, 2, 3, 4, 5, 6, 8, 9, 10 2. PP: 1, 4, 5, 6, 8, 9, 10
19. Paw scalding / harvesting / discarding	**Biological** – Inadequate removal of faecal contamination due to inadequate temperature of scald water. **YES**						PP: 2, 7, 8
	Biological – Pathogen growth due to delay in processing. **YES**						PP: 1, 3, 4, 5, 6

List each ingredient / process where hazard has been identified	Identify hazard (B,C,P) + describe. Determine if fully controlled by PP. YES-indicate (last column). Move to next hazard. NO- Move to Q1.	Q1. Could control measure(s) be used? NO-indicate how hazard controlled (last column). Move to next hazard. YES-describe measure. Move to Q2.	Q2. Is it likely contamination occurs in excess of acceptable level? NO-identify reason(s). Move to next hazard. YES-identify acceptable level wherever possible. Move to Q3.	Q3. Is this process specifically designed to prevent/ eliminate occurrence? YES-CCP (last column). NO- Move to Q4.	Q4. Will a subsequent step eliminate/reduce hazard? NO-CCP (last column). Move to next hazard. YES-identify next control step. Move to Q5.	Q5. Does step provide partial control? YES-PC (last column). Move to next hazard. NO- Move to next hazard.	Controlled at: #CCP #PC PP - before/after process.
	Biological – Failure to discard paws from condemned / rejected carcasses. **YES**						PP: 7, 8
21. Carcass shower	**Biological** – Inadequate application of a water film preventing bacterial attachment and the removal of visible contamination e.g., insufficient volume / pressure, spray nozzles improper location. **YES**						PP: 2, 7, 8
23. Venting / opening / evisceration and shower	**Biological** – Contamination from gut content due to evisceration accidents (inadequate feed withdrawal, equipment operation / adjustment, back-up failure). **NO**	**YES** - Monitoring application of : 1. Evisceration standards 2. Presentation standards 3. Defect detection standards	**YES**	**NO**	**YES** Step # 24 CCP#1B Step # 30 CCP#2B Step # 32 CCP#3B Step # 34 CCP#4B	**YES**	PC: #1 PC: #2 PC: #3

List each ingredient / process where hazard has been identified	Identify hazard (B,C,P) + describe. Determine if fully controlled by PP. YES-indicate (last column). Move to next hazard. NO- Move to Q1.	Q1. Could control measure(s) be used? NO-indicate how hazard controlled (last column). Move to next hazard. YES-describe measure. Move to Q2.	Q2. Is it likely contamination occurs in excess of acceptable level? NO-identify reason(s). Move to next hazard. YES-identify acceptable level wherever possible. Move to Q3.	Q3. Is this process specifically designed to prevent/ eliminate occurrence? YES-CCP (last column). NO- Move to Q4.	Q4. Will a subsequent step eliminate/reduce hazard? NO-CCP (last column). Move to next hazard. YES-identify next control step. Move to Q5.	Q5. Does step provide partial control? YES-PC (last column). Move to next hazard. NO- Move to next hazard.	Controlled at: #CCP #PC PP - before/after process.
24. Viscera Defect Detection	**Biological** – Pathogens on viscera due to failure to detect visible fecal contamination as a result of: 1. viscera inadequate presentation. **YES** 2. lack of synchronization between carcass and viscera. **YES** 3. inadequate lighting. **YES**						1. PP: 7, 8 2. PP: 7, 8 3. PP: 2
	Biological – Pathogens in / on viscera due to failure to remove visible fecal contamination. **NO**	**YES** Monitoring application of Defect Detection Standards for viscera	**YES**	**YES**			**CCP-1B**
32. Cavity Defect Detection and examination	**Biological** – Presence ofpathogens due to failure to detect and/or remove internal / external ingesta . **NO**	**YES** - Monitoring application of Carcass Dressing Standards (CDS)	**YES**	**YES**			**CCP-3B**

List each ingredient / process where hazard has been identified	Identify hazard (B,C,P) + describe. Determine if fully controlled by PP. YES-indicate (last column). Move to next hazard. NO- Move to Q1.	Q1. Could control measure(s) be used? NO-indicate how hazard controlled (last column). Move to next hazard. YES-describe measure. Move to Q2.	Q2. Is it likely contamination occurs in excess of acceptable level? NO-identify reason(s). Move to next hazard. YES-identify acceptable level wherever possible. Move to Q3.	Q3. Is this process specifically designed to prevent/ eliminate occurrence? YES-CCP (last column). NO- Move to Q4.	Q4. Will a subsequent step eliminate/reduce hazard? NO-CCP (last column). Move to next hazard. YES-identify next control step. Move to Q5.	Q5. Does step provide partial control? YES-PC (last column). Move to next hazard. NO- Move to next hazard.	Controlled at: #CCP #PC PP - before/after process.
33. Carcass shower, off-line reprocessing and reconditioning	**Biological** – Failure to reduce pathogen level due to inadequate application of water film to prevent bacterial attachment (e.g. water- wrong direction of spray nozzle, insufficient volume / pressure). **YES**						PP: 2, 7, 8 *
All Steps	**Chemical** – Contamination by non-food chemicals (e.g., mineral oil, hydraulic fluid, cleaners, sanitizers, dust, refrigerant). **YES**						PP: 1, 2, 3, 4, 5, 6, 7, 9, 10
All Steps (to be considered from # 16 and higher)	Physical – Contamination with metal / plastic fragments from equipment wear (e.g., conveyors). **YES**						PP: 2, 7
*The prerequisite programs (PP) related to this model include: 1. Transportation; 2. Premises; 3. Purchasing; 4. Receiving; 5. Shipping; 6. Storage; 7. Equipment; 8. Personnel; 9. Sanitation; 10. Pest Control							

Table 6.4.3 lists examples of potential biological (B), chemical (C) and physical (P) hazards that might be a problem in each of the steps during processing (note: the full CFIA 2011 document contains more examples, and there are also Hazard Databases found on the Internet). It is the responsibility of the HACCP team to identify all potential problems so that proper measures can be taken to minimize hazards specific to their plant. The first example describes hazards associated with raw materials entering the plant (e.g., live chicken, water, salt) and ways that these hazards can be addressed. This is done by using a decision tree (see Table 6.4.3, questions 1-5) to determine how to categorize and deal with each hazard.

This table is part of the package that is submitted to the government during certification. It provides the inspector a way to review the thought process of the team and helps to direct the plant's personnel through constructive comments. It is also a very important document for the plant's management, especially during times of employee and equipment turnover (i.e., the document serves as a guide and a reference for ongoing improvements). It should be pointed out again that today many of the hazards are (should be) controlled by GMP's.

Table 6.4.4 focuses on the critical control points (CCPs) determined by the aforementioned decision tree process. The first CCP listed is "Viscera Defect Detection" and is identified as CCP 1B. It provides a detailed description of the hazard and its critical limits as well as specific monitoring, deviation, and verification procedures. These procedures should be well thought out by the HACCP team, as they will later become official binding procedures (i.e., can also be reviewed in the course of an audit).

As can be seen in Table 6.4.3, some of the identified hazards may be controlled through a prerequisite program and/or various process controls while others are controlled via critical control points (CCPs). The prerequisite programs related to this model are listed at the bottom of Table 6.4.3. A detailed document for each can be obtained from the CFIA website. A process control (PC) is a control used at a point or step that will contribute to the effectiveness of the related CCP(s) or postmortem inspection activities. According to the Canadian model, poultry related PCs must be utilized by poultry slaughter establishments as described in Chapter 19 of the Canadian Food Inspection Agency Manual of Procedures (MOP). Any deviation of a CCP will require an evaluation of the supporting PC(s) as part of the deviation procedures associated with that CCP.

The following is a list of CCPs and their supporting PCs in the Poultry Generic Model (CFIA, 2011) described in Tables 6.4.3 and 6.4.4:

- CCP-1B. Step 24 Viscera Defect Detection:
  - PC #1 (Evisceration Standards)
  - PC #2 (Presentation Standards)

- CCP-2B. Step 30 Giblet and Neck Harvesting:
  - PC #1 (Evisceration Standards)

- CCP-3B. Step 32 Final Examination:
  - PC #1 (Evisceration Standards)
  - PC #2 (Presentation Standards)
  - PC #3 (Defect Detection Standards, carcass group)
  - PC #4 (Carcass Dressing Standards)

- CCP-4B. Step 34 Salvaging:
  - PC #1 (Evisceration Standards)
  - PC #3 (Defect Detection Standards, carcass group)
  - PC #4 (Carcass Dressing Standards)

- CCP-5B. Step 37 Chilling:
  - PC #1 (Evisceration Standards)
  - PC #3 (Defect Detection Standards, carcass group)
  - PC #4 (Carcass Dressing Standards)

In Canada, operators are required to have a written program for each PC. The material must meet the requirements found in Chapter 19 of the Manual of Procedures (CFIA, 2010).

Table 6.4.4 Detailed description of the individual critical control points (CCPs) listed in the HACCP generic model (Figure 6.4.1).

CRITICAL CONTROL POINTS Product Name: Poultry Slaughter							
Process Steps	**CCP/ Hazard number**	**Hazard Description**	**Critical Limits**	**Monitoring Procedures**	**Deviation Procedures**	**Verification Procedures**	**HACCP Records**
24. Viscera Defect Detection	CCP-1B	Presence of pathogens in or on viscera due to failure to detect visible fecal and/or ingesta contamination and/or failure to detect visceral pathological conditions and/ or improper removal (e.g. Septicaemia/ Toxaemia or Hepatitis).	As per MOP (Manual of Procedures 19.6.2.4) viscera defect group as per DDS program.	Randomly, once per hour, "CCP-1B monitor" will visually monitor "X" number of randomly selected viscera on the line after the viscera helper, for fecal, ingesta and\ or pathological defects as per DDS program. Records observations and date\time and signs on "CCP-1B Form". Note: see Company Random Selection Procedures.	If lot is rejected, "CCP-1B monitor" will contact maintenance to find and correct the cause of deviation. "CCP-1B monitor" will contact Supervisor to conduct a food safety assessment and either add additional employees or slow down the line. "CCP-1B monitor" will conduct a retest. If the re-test also fails, product since last successful test will be held and the DDS decision tree will be followed as per MOP 19.6.2.5.2.10. If the lot is rejected for Septicaemia/ Toxaemia, immediate carcass and viscera post chill verification is required as per DDS decision tree MOP 19.6.2.5.2.10. The following information is documented on deviation CCP-1B Form: 1. A description of the deviation and its cause 2. Action(s) taken to control affected product 3. Corrective action(s) taken to restore control of the CCP 4. Measures taken to prevent reoccurrence of the deviation The following information is documented on the "Defect Detection Standards Defects Log Post Chill Product Verification" record. Verification of effectiveness of corrective and preventative actions taken (re-tests) Both forms must include initials, date and exact time an entry is made Any deviation will require an evaluation at the supporting PC#1 and PC#2.	The "CCP-1B verifier" observes the "CCP- 1B monitor" once every "Y" (validated frequency) to ensure he/she is performing his/her task as per written program. The "CCP-1B verifier" also examines "X" day(s) worth of "CCP-1B Forms" and "Defect Log" once per "Y" days to ensure monitoring is performed as specified by written procedures and forms are completed and appropriate corrective and preventative measures were taken as required. Also to ensure Pre-shipment review is completed as per MOP 11, USA, Annex Q, Q.1.1b. If deficiencies are noted during verification procedures, a root cause analysis and food safety assessment will be performed. Corrective actions/ preventative measures may include retraining of "CCP -1B monitor" and/ or employees and/or re-evaluation of monitoring/deviation procedures. Verification observations, verifier's signature and date\time are recorded on "CCP-1B Verification Form".	"CCP-1B Form" "CCP 1B Verification Form" "Defect Detection Standards Defects Log Post Chill Product Verification" record.

CRITICAL CONTROL POINTS Product Name: Poultry Slaughter							
Process Steps	**CCP/ Hazard number**	**Hazard Description**	**Critical Limits**	**Monitoring Procedures**	**Deviation Procedures**	**Verification Procedures**	**HACCP Records**
30. Giblets and neck harvesting	CCP-2B	Pathogen contamination on giblets due to presence of fecal and ingesta as a result of failure to discard contaminated giblets.	Edible giblets free of visible fecal/ingesta contamination as defined in the CDS program (MOP 19.6.2.7).	Once per "Y" hour(s), "CCP-2B monitor" will select "X" number of hearts, livers and gizzards and evaluate for the presence of fecal and ingesta. Records observations and date\time and signs on "CCP-2B Form".	If fecal/ingesta is observed on edible giblets or if ingesta/ crop portion are observed on necks, "CCP-2B monitor" will hold all product (as per Company Hold Procedures) since last successful test and product will be re-worked or discarded. Supervisor will be contacted to conduct a food safety assessment and evaluate the giblet or neck harvesting procedure and identify any deficiencies and implement corrective actions. The following information is documented on deviation CCP-2B Form: 1. A description of the deviation and its cause 2. Action(s) taken to control affected product 3. Corrective action(s) taken to restore control of the CCP 4. Verification of effectiveness of corrective measures 5. Measures taken to prevent reoccurrence of the deviation 6. Verification of effectiveness of preventative measures CCP-2B Form must include initials, date and exact time an entry is made Any deviation will require an evaluation at the supporting PC#1.	The "CCP-2B verifier" observes the "CCP- 2B monitor" once every "Y" days to ensure he/she is performing his/her task as per written program. The "CCP-2B verifier" also examines "X" day(s) worth of "CCP-2B Forms" once per "Y" days to ensure monitoring is performed as specified by written procedures and forms are completed and appropriate corrective and preventative measures were taken as required. Also to ensure Pre-shipment review is completed as per MOP 11, USA, Annex Q, Q.1.1b. If deficiencies are noted during verification procedures, a root cause analysis and food safety assessment will be performed. Corrective actions/ preventative measures may include retraining of "CCP -2B monitor" and/ or employees and/or re-evaluation of monitoring/deviation procedures. Verification observations, verifier's signature and date\time are recorded on "CCP-2B Verification Form".	"CCP-2B Form". "CCP-2B Verification Form".
		Pathogen contamination of necks due to presence of ingesta or with the remaining portion of crops.	Free of visible ingesta contamination or crop portions as defined in the CDS program (MOP 19.6.2.7).	Once per "Y" hour(s), "CCP-2B monitor" will select "X" number of necks and evaluate for the presence of ingesta and crop portions. Records observations and date\time and signs on "CCP-2B Form".			

CRITICAL CONTROL POINTS Product Name: Poultry Slaughter							
Process Steps	**CCP/ Hazard number**	**Hazard Description**	**Critical Limits**	**Monitoring Procedures**	**Deviation Procedures**	**Verification Procedures**	**HACCP Records**
32. Cavity Defect Detection and trimming / final examination	CCP-3B	Presence of pathogens due to failure to detect and/or remove internal or external ingesta and/or fecal material contamination and/or portions of Gastro Intestinal Tract (GIT) from carcasses.	As per CDS defect groups FS1 (Food Safety), FS2, FS3 accept/ reject numbers (MOP 19.6.2.7)	Randomly, once per hour, "CCP-3B monitor" will visually monitor "X" number of randomly selected carcasses prior to chilling for fecal, ingesta and\or GIT defects as per CDS program. Records observations and date\time and signs on "CCP-3B Form". Note: see Company Random Selection Procedures.	If lot is rejected for ingesta or GIT, "CCP-3B monitor" will contact maintenance to find and correct the cause of deviation."CCP-3B monitor" will contact supervisor to conduct a food safety assessment and evaluate the upstream process and determine the root cause. If the lot is rejected for fecal, immediate product post chill verification is required as per CDS decision tree (MOP 19.6.2.7.6.7). When process evaluation leads to a rejection of an FS group, the "CCP-3B monitor" will conduct a retest. If the re-test also fails for ingesta and/or GIT, product since last successful test will be held as per CDS decision tree (MOP 19.6.2.7.6.7). The following information is documented on deviation CCP-3B Form: 1. A description of the deviation and its cause 2. Action(s) taken to control affected product 3. Corrective action(s) taken to restore control of the CCP 4. Measures taken to prevent reoccurrence of the deviation The following information is documented on the "Carcass Dressing Standard Defect Log Post Chill Verification" record. Verification of effectiveness of corrective and preventative actions taken (re-tests) Both forms must include initials, date and exact time an entry is made Any deviation will require an evaluation at the supporting PC#1, PC#2, PC#3 and PC#4.	The "CCP-3B verifier" observes the "CCP- 3B monitor" once every "Y" (validated frequency) to ensure he/she is performing his/her task as per written program. The "CCP-3B verifier" also examines "X" day(s) worth of "CCP-3B Forms" and "Defect Log" once per "Y" days to ensure monitoring is performed as specified by written procedures and forms are completed and appropriate corrective actions and preventative measures were taken as required. Also to ensure Pre-shipment review is completed as per MOP 11, USA, Annex Q, Q.1.1b. If deficiencies are noted during verification procedures, a root cause analysis and food safety assessment will be performed. Corrective actions/ preventative measures may include retraining of "CCP -3B monitor" and/ or employees and/or re-evaluation of monitoring/deviation procedures. Verification observations, verifier's signature and date\time are recorded on "CCP-3B Verification Form".	"CCP-3B Form" "CCP-3B Verification Form" "Carcass Dressing Standard Defect Log Post Chill Verification" record.

CRITICAL CONTROL POINTS Product Name: Poultry Slaughter							
Process Steps	**CCP/ Hazard number**	**Hazard Description**	**Critical Limits**	**Monitoring Procedures**	**Deviation Procedures**	**Verification Procedures**	**HACCP Records**
34. Carcass shower, salvaging	CCP-4B	Salvaging: Presence of pathogens on portions due to failure to effectively remove visible contamination (e.g. inadequate performance of employees and/or too many defective carcasses)	Free of visible fecal and ingesta contamination as defined in the CDS program (MOP 19.6.2.7).	Once per "Y" hour(s), "CCP-4B monitor" will select "X" number of portions and evaluate for the presence of fecal and ingesta. Records observations and date\time and signs on CCP-4B Form.	If fecal/ingesta are observed, "CCP-4B monitor" will hold all product (as per Company Hold Procedures) since last successful test and product will be re-worked or discarded. Supervisor will be contacted to conduct a food safety assessment and evaluate the portion harvesting procedure and identify any deficiencies and implement corrective actions. The following information is documented on deviation CCP-4B Form: 1. A description of the deviation and its cause 2. Action(s) taken to control affected product 3. Corrective action(s) taken to restore control of the CCP 4. Verification of effectiveness of corrective measures 5. Measures taken to prevent reoccurrence of the deviation 6. Verification of effectiveness of preventative measures CCP-4B Form must include initials, date and exact time an entry is made Any deviation will require an evaluation at the supporting PC#1, PC#3 and PC#4.	The "CCP-4B verifier" observes the "CCP- 4B monitor" once every "Y" days to ensure he/she is performing his/her task as per written program. The "CCP-4B verifier" also examines "X" day(s) worth of "CCP-4B Forms" once per "Y" days to ensure monitoring is performed as specified by written procedures and forms are completed and appropriate corrective and preventative measures were taken as required. Also to ensure Pre-shipment review is completed as per MOP 11, USA, Annex Q, Q.1.1b. If deficiencies are noted during verification procedures, a root cause analysis and food safety assessment will be performed. Corrective actions/ preventative measures may include retraining of "CCP-4B monitor" and/ or employees and/or re-evaluation of monitoring/deviation procedures. Verification observations, verifier's signature and date/time are recorded on "CCP-4B Verification Form".	"CCP-4B Form" "CCP-4B Verification Form"

CRITICAL CONTROL POINTS Product Name: Poultry Slaughter							
Process Steps	**CCP/ Hazard number**	**Hazard Description**	**Critical Limits**	**Monitoring Procedures**	**Deviation Procedures**	**Verification Procedures**	**HACCP Records**
37. Chilling	CCP-5B	Pathogen growth due to inadequate chilling resulting from time / temperature abuse.	As per "dressed poultry carcasses and parts" of the MOP (19.8.2.4.1 & 19.8.4.1). Portions/ necks/ giblets - chilled to 4°C or lower within 2 hours after evisceration (salvaged turkey breasts, breast fillets, legs, drumsticks and thighs shall be chilled to 4°C or lower within 4 hours after evisceration) as per MOP 19.8.2.4.2. Dressed poultry carcasses can be shipped to another registered establishment provided the product surface temperature has reached 7°C or lower before being shipped.	Every "Y" hour(s) for "X" number of carcasses, CCP-5B Monitor inserts a calibrated digital thermometer in the deepest part of the breast and records product temperature at the time/location specified within the validated chilling procedure. Every "Y" hour(s) for "X" number of portions/necks/ giblets, CCP-5B Monitor inserts a calibrated digital thermometer into each and records product temperature (s) at the time/location specified within the validated chilling procedure. It is highly recommended that the monitoring frequencies established by the operator must allow for the opportunity to effectively further cool the product prior to exceeding the regulatory time frame. CCP-5B Monitor records observations and date\time and signs on "CCP-5B Form".	If product temperature in carcasses and portions is not being brought down according to the prescribed temperature according to the operator's chilling protocol, the Supervisor is contacted and appropriate measures must be readily initiated to bring down the product temperature within the timeframe specified in the MH-MOP.Whenever a deviation is noticed in the chilling of carcasses or parts, the product could be either cooked or if kept fresh, the shelf life / best before date must be re-evaluated. If the violations result in the spoilage of the product, then the product must be disposed of to prevent its entry in the human food chain. In the case of portions/ necks/ giblets, a deviation is noticed, then the product must be disposed of to prevent its entry in the human food chain. Dressed poultry carcasses to be shipped to another registered establishment must reached product surface temperature of 7°C or lower before being shipped, otherwise the product must stay in the approved continuous chilling process until appropriate temperature is reached. The following information is documented on deviation CCP-5B Form: 1. A description of the deviation and its cause 2. Action(s) taken to control affected product 3. Corrective action(s) taken to restore control of the CCP 4. Verification of effectiveness of corrective measures 5. Measures taken to prevent reoccurrence of the deviation 6. Verification of effectiveness of preventative measures CCP-5B Form must include initials, date and exact time an entry is made	The "CCP-5B verifier" observes the "CCP- 5B monitor" once every "Y" days to ensure he/she is performing his/her task as per written program. The "CCP-5B verifier" also examines "X" day(s) worth of "CCP-5B Forms" once per "Y" days to ensure monitoring is performed as specified by written procedures and forms are completed and appropriate corrective and preventative measures were taken as required. Also to ensure Pre-shipment review is completed as per MOP 11, USA, Annex Q, Q.1.1b. If deficiencies are noted during verification procedures, a root cause analysis and food safety assessment will be performed. Corrective actions/ preventative measures may include retraining of "CCP -5B monitor" and/ or employees and/or re-evaluation of monitoring/deviation procedures. Verification observations, verifier's signature and date\time are recorded on "CCP-5B Verification Form".	"CCP-5B Form" "CCP-5B Verification Form"

6.5 Continuous Improvements by Implementing HACCP

Continuous improvements are an integral part of the HACCP program as new findings and growing experiences can help address new challenges and ultimately result in a safer product. In the USA, the Food Safety and Inspection Service (FSIS) got a mandate to verify that industry prerequisite (PR)/HACCP systems are effectively controlling the risks associated with human disease-causing bacteria in raw meat and poultry. The USA government set product specific performance standards for *Salmonella* that must be met by slaughter establishments and establishments producing raw ground meat and poultry products (Eblen et al., 2006). The performance standards are based on the prevalence of *Salmonella*, as determined by the FSIS's nationwide microbial baseline studies, and are expressed in terms of the maximum number of *Salmonella* positive samples that are allowed in a given sample set. From January 1998 through December 2000, federal inspectors collected 98,204 individual samples and 1,502 complete/batch sample sets for *Salmonella* analysis from large, small, and very small establishments that produced at least one of seven raw meat and poultry products: broilers, market hogs, cows and bulls, steers and heifers, ground beef, ground chicken, and ground turkey. *Salmonella* prevalence in most of the product categories was lower post-implementation of PR/HACCP programs than in pre-PR/HACCP baseline study surveys conducted by the FSIS. Results of testing from 1998 to 2000, at establishments of all sizes combined showed that >80% of the sample sets met the *Salmonella* prevalence performance standards (e.g., ≤20.0% prevalence for broilers, 8.7% for market hogs, 2.7% for cows and bulls). The decrease in *Salmonella* prevalence partly reflected industry improvements such as improved process control, incorporation of antimicrobial interventions, and increased microbial monitoring, all in conjunction with PR/HACCP implementation. A follow up study in 2003 revealed that 81% of establishments never had a failed test. In establishments that did experience a sample set failure, the failed sets were generally collected early in the establishment testing history. Small establishments were more likely to have experienced a set failure than were large or very small establishments (Eblen et al., 2006). The FSIS response to failed *Salmonella* sample sets, in-depth verification reviews and related establishment-initiated corrective actions, has likely contributed to declines in the number of establishments that failed the set procedure. The authors mentioned that focusing on food safety measures in small establishments should further reduce the number of sample sets that fail to meet the *Salmonella* performance standards. In Europe, the summary report by the European Food Safety Authority (EFSA, 2010) also discussed positive trends in microbial reduction and further ways to improve the situation.

Overall, interventions should be validated to determine their efficacy before they are introduced. A few examples are provided, below. However, this is by no

means a comprehensive list of all possible intervention procedures. Stopforth et al. (2007) looked at changes in aerobic plate counts (APC), total coliform counts (TCC), *E. coli* counts (ECC), and *Salmonella* incidences on poultry carcasses and parts as well as in poultry processing wastewater. They examined samples before and after individual interventions and after exposure to multiple sequential interventions at various stages of the slaughter process in three different plants. Interventions included post-evisceration wash, inside/outside bird washes, chlorine dioxide wash (note: chlorine is currently allowed in North America but not in Europe), chlorine dioxide wash plus chlorine chiller, chiller exit spray, post-chiller wash, and a tri-sodium phosphate wash at two of the plants. The majority of individual interventions effectively and significantly ($p < 0.05$) reduced microbial populations on or in carcasses, carcass parts, and processing water. Reductions in microbial counts in all three plants ranged from 0 to 1.2 log CFU/ml of sample rinse. Multiple sequential interventions resulted in significant reductions ($P < 0.05$) in APC, TCC, ECC, and *Salmonella* incidence of 2.4, 2.8, and 2.9 log CFU/ml and 79%, respectively, at the first plant; 1.8, 1.7, and 1.6 log CFU/ml and 91%, respectively, at second plant; and 0.8, 1.1, and 0.9 log CFU/ml and 40%, respectively, at the third plant. These results validated the in-plant poultry processing interventions and provided a source of information to help the industry in its selection of antimicrobial strategies with focus on some specific pathogens such as *Salmonella*. Gill et al. (2006) looked at different groups of bacteria after various interventions applied during broiler processing at a HACCP approved plant. The mean log numbers of aerobes, coliforms, *E. coli* and presumptive *Staphylococci* and *Listeria* on carcasses after scalding at 58°C and plucking were about 4.4, 2.5, 2.2 and 1.4 log cfu/cm^2, respectively. The number of bacteria on eviscerated carcasses was similar. After a series of operations to remove the crop, lungs, kidneys, and neck, the number of aerobes was decreased by about 1 log unit from the eviscerated carcass count, but the other numbers were unchanged. After water chilling, the coliform and *E. coli* counts were decreased by about 1 log unit and the counts for presumptive *Staphylococci* plus *Listeria* were decreased by about 0.5 log units from the dressed carcasses, but the number of aerobes was unchanged. Further discussion regarding these and other intervention methods can be found in Chapter 15.

Another emerging issue is the avian influenza virus (AIV) and, more specifically, the highly pathogenic strain known as H5N1. The possible human health threat that it poses has raised concerns over the food safety implications of this virus infecting poultry (note: this is currently not directly dealt with the processing plant's HACCP program, but can be found in various on-farm HACCP procedures. Overall, the meat processor should be aware of these procedures as part of the farm to fork concept). The European Food Safety Agency and the US

Department of Agriculture's Animal and Plant Health Inspection Service, have identified legal and illegal importations of infected poultry commodities (Beato et al., 2009). The authors indicate that AIV may be recovered from a variety of poultry products. However, its presence is influenced by the characteristics of the viral strain, particularly its ability to cause systemic infection (pathogenicity). As a consequence, the host also influences the likelihood of the virus being present. Overall, data are still incomplete and further studies should be carried out in a more extensive and coordinated manner in order to establish proper risk assessments on the spread of infection to a given area and/or host by poultry products. Although only a limited number of studies have been published, it is reassuring that heat and pressure treatments have been shown to inactivate, to acceptable levels, any viable viruses in selected commodities (Beato et al., 2009).

Equipment and machinery also play an important role in maintaining the cleanliness of the operation and, if correctly designed, can reduce cross contamination problems (i.e., equipment is covered under the prerequisite programs). An example is the evisceration line, where the first machine is used to make an opening to the abdominal cavity. In a highly functional machine, this is done at high speeds (e.g., 13,500 broilers per hr) with little to no damage to the carcass, which prevents gut spills from damaged intestines later on (i.e., bacterial count of gut content is about 10^8 to 10^9 per gram). The length of the cut should be adjusted to correspond to the size of the birds processed. It is very important that adjustments can be done quickly and easily during production as there is little time between flocks. Although equipment design is related to the prerequisite program (i.e., not HACCP), it is mentioned here because hygiene focused design helps keep the machine clean during operation. Even simple features such as sloped surfaces can help prevent water or debris accumulation on equipment. Avoiding blind spots also enables the machine to stay clean during operation and a water spray can be used to remove any material that falls on equipment at certain locations (see also Chapter 15 about Principles of Sanitary Equipment Design).

Consumer education and provision of adequate instructions are also important points in the overall picture. For example, the need for very clear cooking instructions was demonstrated in 2007 when frozen chicken and turkey pot pies were recalled after being undercooked by some customers in the USA (Anonymous, 2007). This led to 152 cases of *Salmonella* poisoning and 20 hospitalizations in 31 states. The company responded by: a) asking customers to return suspected products, b) reminding customers that these products were not ready-to-eat and must be thoroughly cooked, and c) most importantly, revising the cooking instructions on the label (including for microwave ovens and mentioning heating to an internal temperature of 71°C).

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7

INSPECTION AND GRADING

7.1 Introduction

Most countries have a mandatory inspection system for meat producing animals to ensure that meat sold to the public is safe and will not transfer disease. However, this has not always been the case. Some of the earliest documented rules and regulations for meat inspection are found in the Bible (e.g., no consumption of dead animals) but the regulations were not always enforced. In Europe, the sale of sick animals to the meat trade was prohibited in the 12th century. In 1906, Upton Sinclair revealed serious sanitation problems in Chicago meat plants in his book, "The Jungle", which later resulted in passing the Meat Inspection Act in the USA. The act enforced mandatory inspection of red meat animals. At the time, poultry was not included in the Act as it was considered a small back yard industry. Poultry was not included until 1924, when there was a major avian influenza outbreak in New York State.

Inspection is commonly carried out by a designated government agency, so there is little, if any, room for deviation that might compromise the public interest. The process commonly includes both ante and postmortem inspections (described later). In areas where live animals are sold directly to the consumer, individual animal inspection is not common. However, if disease outbreak information surfaces, the government will increase monitoring and inspection. In several countries where wet markets are popular, governments are trying to create more regulated environments. Over the past decade avian influenza outbreaks have resulted in canceling and/or more inspection of wet markets.

This chapter discusses poultry (e.g., broiler, turkey, duck) inspection and provides examples of national regulations, though US regulations are discussed as the primary example. The chapter also includes material on grading which may not be mandatory in some countries but is most often done to facilitate trade. The classification system of the major poultry species is also provided at the end of the chapter.

7.2 Setting up an Inspection Station

The postmortem inspection station is very important in ensuring that only healthy and uncontaminated (e.g., from gut spill) animals enter the food chain. Thus, the station should provide optimum working conditions for the inspector and his/her helpers (Fig. 7.2.1). Below are the requirements for a federally inspected US plant, but the exact station requirements for other countries can be found in their national regulations.

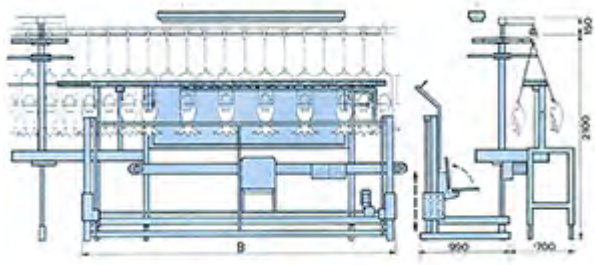


Figure 7.2.1 An illustration of an inspection station showing area for inspector to stand, clear view of poultry passing by (including a mirror at the back) and a holding rack.

Space: the exact amount of space required for the inspector and helper can vary depending upon the inspection method (to be discussed in the next section on line speed).

Lighting: lighting requirements vary depending on the inspection method. The minimum lighting requirements are as follows:

a. Traditional inspection – 50 foot-candles
b. Streamlined Inspection System (SIS) – 200 foot-candles
c. New Enhanced Line Speed (NELS) – 200 foot-candles
d. New Turkey Inspection System (NTIS) – 200 foot-candles

Other important factors are the quality and direction of the light. In addition, light should not change the colour of the inspected carcasses and should be shadow-free.

Hand-washing facilities: water for hand washing with a minimum temperature of 65°F must be available to the inspectors working at the postmortem inspection station.

Condemned containers: generally, there are two types of condemned containers at the postmortem inspection station. One is for parts and the other is for whole carcasses. These containers must be leak-proof and properly marked, indicating "U.S. Condemned Product" in legible letters that are at least two inches high. The parts/whole carcasses should be disposed of by an approved method (e.g., incineration, denaturation by chemicals and dyes, steam; parts condemned due to the presence of chemical/biological residues must be buried or burned).

Holder for inspection form: the plant uses this device to hold the lot tally sheet or FSIS Form 6000-16 (USDA, 1999) so that it is conveniently located for the plant helper to record dispositions as instructed by the USDA postmortem inspector.

Hangback racks: the primary purpose of the hangback rack is to retain questionable carcasses for veterinary review and disposition. The racks can also be used for carcasses designated as salvage, improper presentation, etc.

Other facility requirements: an adjustable platform is required at each inspection station, and re inspection stations must be provided at both the pre-chill and post-chill locations.

Overall, plant management should make every effort to minimize contamination of the carcass opening when preparing for evisceration. Most processors use the modified J-cut, although the bar-cut is also used.

Sanitation and consistency are important for a properly drawn carcass. Traditionally in a manual operation and in some automated lines, the viscera is completely withdrawn, left suspended by natural attachments and arranged consistently to the left or right side of the carcass. However, today a number of poultry slaughtering plants use automatic equipment that completely detaches the viscera and put it on another line. The equipment is often complex and requires careful adjustment for consistency (including synchronization) and properly handling the carcasses. It is the responsibility of plant management to ensure that the machinery is working properly at all times (e.g., when changing flock size, weight).

Depending on the facilities and local preferences, the plant may use one of several methods for suspending carcasses on the shackle line such as two-point suspension for broilers or three-point suspension for turkeys. Carcasses must be presented at the postmortem inspection station shackled in a consistent manner. On lines that have more than one inspector the shackles must be identified. They may be colour coded or mechanically separated (as in the case of "selectmatic" devices that "kick out" carcasses automatically). The latter helps reduce fatigue by taking "the search factor" out of postmortem inspection.

7.3 Inspection

Inspection is commonly done by specially trained government personnel who are responsible for ensuring that only wholesome fresh poultry and poultry products that are fit for human consumption reach the marketplace. Governmental control over inspection helps guarantee that inspectors are not influenced by marketing pressure. This is essential in many public health matters where an independent body should decide, approve, and later enforce the regulations. Personnel usually include licensed inspectors who may be veterinarians or other specially trained individuals.

Poultry inspection is usually divided into different sections. In the US system, the activities are divided into eight areas (USDA, 1987, 2014) that include:

a. Inspection of live birds prior to slaughter (ante mortem) – done by observing the birds in the crates/containers, or while being removed from the crates and suspended on the shackle line. The inspector looks for signs of disease and other abnormal situations such as edema, skin lesions, diarrhea, and respiratory problems. Birds that are dead on arrival (DOA) are automatically condemned. The inspector decides whether the birds pass the inspection, are suspected of illness, or are condemned. Suspected flocks are separated from healthy flocks and slaughtered (usually separately at the end of the day, so more attention can be given to each bird).
b. Inspection after slaughter (post-mortem) – identifies and removes all potential disease conditions that might affect human health. There are many details for this area of inspection, some of which are discussed later in the chapter.
c. Condemnation and disposition – deals with conditions requiring condemnation; discussed in more detail later in the chapter.
d. Sanitary slaughter and dressing inspection – minimizes/prevents fecal contamination resulting from gut spillage on the carcass and/or smearing on edible meat parts/surfaces. This is one of the most important points in sanitary slaughter and dressing operations. Contaminated carcasses are removed from the line (at the inspection station; Fig. 7.2.1) and are either condemned or sent for reprocessing. The latter operation can include trimming of certain parts, washing with water containing 20 ppm chlorine (in Canada tripolyphosphate), vacuuming, or a combination of these intervention methods.

e. Chilling of poultry – the government requires that carcasses are cooled within a certain period of time to minimize the chance of pathogen proliferation. The time to reach an internal deep muscle temperature of 4.4°C depends on carcass size: 4 hr for a 4 lb broiler, 6 hr for 4-8 lb broiler, and 8 hr for 8 lb broiler or turkey (unless cooked or frozen right away). Giblets should be chilled to 4.4°C or below within 2 hrs. The inspector also checks water absorption during water chilling. The percent allowed is also based on carcass weight (see more information in Chapter 5).
f. General plant sanitation – inspector monitors the plant to make sure it is clean prior to starting work (i.e., there are effective cleaning and sanitation procedures) and during working hours. Today most plants operate under HAACP (Barbut and Pronk, 2013; also see Chapter 6) and use prerequisite programs such as the Sanitation Standard Operating Procedures (SSOP). Such a program is divided into different sections that usually include building structure, premises, processing equipment, personnel facilities, water supply, waste handling, coolers and freezers, training of personnel, and pest control programs.
g. Carcass re-inspection of ready to cook (RTC) poultry –plant personnel and inspector(s) re-inspect the birds after chilling to make sure they have been properly processed (e.g., all viscera and feathers removed). These inspections include pre-chill and post-chill monitoring and it is common that plant quality control personnel check 10 samples every hr, while the inspector will run two tests per shift (or more if warranted).
h. Monitoring residues – products for human consumption are also monitored for prohibited drugs and chemicals. These residues could result from accidental exposure or an improper use of antibiotics, pesticides, herbicides, etc.

Overall, the inspection process is designed to prevent diseased animals from entering the food supply and to minimize the chance of transferring zoonotic diseases to humans. In addition, the inspector ensures that the processed product is handled, packaged, and labeled in accordance with the regulations. If necessary, the local inspector usually has the authority to stop the line and condemn a part or the entire lot.

Birds that have passed inspection receive a stamp/legend (Fig. 7.3.1) that signifies they have been examined by a qualified inspector and are wholesome and fit for human consumption.



a)



b)

Figure 7.3.1 Inspection shields: (a) U.S. Inspected, see plant number at bottom; (b) Canadian inspection shield.

7.3.1 Antemortem Inspection

The inspector examines birds that arrive at the processing plant either while they are still on the truck or while they are being unloaded. At this point the health and condition of the birds is monitored. If the whole flock shows a problem (e.g., diarrhea), the inspector can inform the plant to slow down the line speed and/or can condemn the flock so it will not be processed. In some countries where, for example, *Salmonella* monitoring is done on the farm prior to shipment, the inspector will evaluate the results and decide whether to postpone processing the flock until the end of the day (i.e., to prevent cross contamination with other flocks). Many companies will inform the inspector beforehand if they expect problems and will ship the flock towards the end of the day. The inspector will also monitor the rate of DOA and if an animal welfare problem is suspected an investigation and/or a fine can be imposed.

7.3.2 Postmortem Inspection

Postmortem inspections are performed by specially trained personnel who can recognize, evaluate, and make decisions about various disease conditions and abnormalities. The decision must be based on scientific principles and the evaluation criteria applied in a uniform manner. In the US, for example, every single bird is inspected in a federally inspected plant. It is the responsibility of the plant to prepare the carcasses for easy presentation on the line. If this does not occur, the inspector will instruct the plant to reduce line speed. Plant employees are usually positioned before the inspection station and are responsible for good and consistent presentation. This is important after the mechanical de feathering

and evisceration processes, where problems in presentation can be encountered (e.g., presence feathers, viscera not correctly removed). The inspector examines the carcass (inside and outside) along with its internal organs. The organs may be attached or, in newer lines, detached and presented on a separate moving line. In the latter case both lines must be synchronized. Such a system reduces the chance of carcass contamination by gut content. It also improves presentation, as the long section of gut does not interfere with the view of the internal organs. There is usually a mirror positioned at the station so the inspector can easily see the back of the moving carcass. The government inspector usually is aided by plant employee who is designated as a helper. This person helps the inspector by trimming and/or marking parts to be trimmed at the plant's final trimming station, by removing condemned birds from the line, by removing questionable birds from the line and putting them on a special rack for further inspection, by separating/marking carcasses contaminated with fecal material, and by helping record causes of contamination.

7.3.3 Condemnation and Disposition

Dispositions are made on carcasses based on the stage of disease development and the resolution of the disease or processes at the time of slaughter. If a disease process exists in the live animal, the pathogenesis of the disease stops at the time of slaughter but the lesions will remain. The inspector's responsibility is to evaluate and interpret the pathological lesions present after the animal is slaughtered and prepared for postmortem inspection. The inspector classifies carcasses as inspection passed, trimmed/salvaged/washed passed, retained for disposition by a veterinarian, or condemned. Examples of condemnation criteria found in the USDA/FSIS Tally Sheet (USDA, 1987, 1998) are provided below.

(1) Tuberculosis. Avian tuberculosis (TB) is caused by the bacterium *Mycobacterium avium* and usually is a chronic, slowly developing disease. It has largely been eradicated in domestic poultry in the United States, but is still found occasionally in mature birds.

Birds with TB develop a wasting condition characterized by loss of weight and diarrhea. At postmortem examination, their carcasses are typically emaciated. Gray to yellow, firm nodules (tubercles) are often scattered along the intestines and may be found in various organs, especially in the liver and spleen. Lungs generally have no gross lesions, although, in advanced cases, any organ or tissue can be involved. Avian tuberculosis can infect humans but is not considered to be a serious threat to people with healthy immune systems. One definitive lesion is all that is required to condemn a poultry carcass for tuberculosis (see also Lohren, 2012).

(2) Leukosis. This condemn category includes several neoplastic diseases caused by various viruses. All of them produce tumors in domestic poultry and present similar gross lesions. The age and species of bird affected by leukotic tumors suggests that a viral agent is involved. However, only a presumptive diagnosis can be made based on this information, because there is considerable overlap. The most common manifestations of the leukosis complex are as follows: a. Marek's disease, which is an important disease found only in chickens less than six months of age; b. lymphoid leukosis, which is most common in semi-mature and mature chickens; c. reticuloendotheliosis, which occasionally produces liver and spleen tumors in turkeys and, rarely, runting disease in chickens; and d. lymphoproliferative disease, which affects turkeys, producing a greatly enlarged spleen as well as tumors in other organs. There is no evidence that viruses of the leukosis complex are pathogenic for humans. One definitive lesion is all that is needed to justify condemnation of the carcass. Definitive means a lesion that can be defended grossly as a lesion of leukosis.

(3) Septicemia/toxemia. Septicemia is a disease state caused by pathogenic (disease-producing) microorganisms in the blood that have produced systemic change within the bird. Systemic change affects the body as a whole rather than localized portions of it. In septicemia, the normal functions of the bird's organ systems are disrupted. The cells of the body deteriorate. This deterioration may be very rapid when highly virulent microorganisms are the cause, or it may be more gradual if less virulent ones are involved. In some cases, the changes produced by the septicemia will overwhelm the bird and result in its death. In other cases, the bird's immune system will overcome the causative organism before irreversible damage occurs, and it will recover. Septicemia is manifested by a group of clinical signs, not all of which will be present in a single carcass. Therefore, judgment plays an important part in correct dispositions for this condemn category. Septicemic carcasses frequently have petechial (pinpoint) hemorrhages on the heart, liver, kidneys, muscles, and serous membranes. Blood-tinged exudates are often present in the body cavity. The liver and spleen are often swollen and hyperemic (contain an excess of blood), because they remove most of the bacteria from the circulating blood. Kidneys may appear swollen and congested. The skin of septicemic birds may be hyperemic. Depending upon the cause and duration of septicemia, carcasses at the time of slaughter may be hyperemic, cyanotic, anemic, dehydrated, and edematous or exhibit some combination of these signs. No single carcass will show all of these signs. Septicemia/toxemia is commonly referred to as sep/tox. If a carcass shows systemic change, it is condemned. This category is a catchall for those carcasses that have septicemia, toxemia, or a combination of septicemia-toxemia (see also Lohren, 2012).

(4) Synovitis. Synovitis may be caused by a number of organisms, most often members of the genus *Mycoplasma*. Injury and nutritional deficiencies can also lead to synovitis. The result is acute or chronic inflammation of the membranes lining one or more joints and tendon sheaths. Joints are often noticeably swollen and may contain exudate of variable amounts and consistency. The liver, kidneys, and spleen may be swollen, and the liver is sometimes stained green from bile stasis. Lesions vary depending upon whether or not the condition has been confined to the joints without affecting the overall health of the bird or has overwhelmed the bird's defense mechanisms and caused systemic changes. A carcass that has synovitis and also shows signs of sep/tox or systemic change is condemned. In other words, a carcass with synovitis is not condemned unless it also shows systemic change.

(5) Tumors. Several types of tumors besides those of the leukosis complex (described above) affect domestic poultry. Some of the more common ones include squamous cell carcinomas, adenocarcinomas, leiomyomas, and fibromas.

Squamous cell carcinomas are skin tumors found in young chickens. Adenocarcinomas generally are located on abdominal organs and are common in older birds. Leiomyomas are most often identified in the oviduct of fowl and fibromas may develop in any connective tissue and are also more common in older birds. Numerous other types of tumors occur in domestic poultry but at a low frequency. There is no evidence that any of these types of tumors are a health threat to humans. Condemn a carcass for tumors if there is "gross evidence" of metastasis present. The general rule is as follows: one tumor - trim and pass; two or more tumors - condemn if there is evidence of metastasis. Exclude leukosis from the tumor category. Leukosis is in a separate category.

(6) Bruises. If bruises are the reason for systemic change in a carcass, then the carcass is condemned and recorded under the bruises category.

(7) Cadaver. Poultry that die from causes other than slaughter are condemned under the cadaver category. Generally, the bird is not dead at the time of entering the scald tank, but upon submersion into the scald water, it drowns.

(8) Contamination. Carcasses that are contaminated to the extent that valid inspection cannot be made are condemned. An example would be a carcass contaminated with bile or feces to the extent that the inspector cannot determine whether the carcass is wholesome. Carcasses that fall into open sewers or evisceration troughs are condemned under the contamination category.

(9) Overscald. Carcasses that are cooked are condemned. Many times, these carcasses will also be machine-mutilated by picking machines.

(10) Airsacculitis. Numerous microorganisms can produce airsacculitis, inflammation of air sacs. Often, more than one infectious agent is identified in an outbreak. Members of the genus *Mycoplasma* are frequently involved. Birds are more susceptible to infections of the air sacs when they are under stress. Vaccination, other disease, poor nutrition, insanitary conditions, and poor ventilation may all be contributing factors. The lesions of airsacculitis can be acute or chronic. Their appearance can range from slight clouding of air sac membranes and small amounts of watery exudate to thickened, opaque membranes and large amounts of thick, white-to-cream coloured and/or cheesy exudates. The exudates can be confined to the air sacs and their diverticula, or they may be found in other areas if the air sac membranes are ruptured. Pneumonia, pericarditis, and perihepatitis might be present. In some cases, all portions of the respiratory tract (nasal passages, sinuses, trachea, bronchi, lungs, and air sacs and their diverticula) are affected. In other cases, little involvement beyond the air sacs is evident. One organism that can cause airsacculitis in birds, *Chlamydia psittaci*, can cause disease in humans. Outbreaks of this disease are sporadic and generally occur in turkeys rather than chickens. The turkey industry watches for any evidence of chlamydiosis so infected flocks generally are identified and treated before slaughter. However, inspectors must stay alert for any poultry that show signs suspicious for this disease. Carcasses are condemned if airsacculitis occurs in conjunction with systemic change. An airsacculitis condemnation is also justified by the presence of extensive airsacculitis. In the latter instance, the amount of exudate present prevents a valid evaluation of the wholesomeness of the carcass. If the exudate cannot be effectively removed, the carcass is also condemned.

(11) Other. There are several other subgroups:

a. Inflammatory process: if the condition is generalized, the carcass is condemned.
b. Plant rejects: if the plant elects to reject a carcass for inspection, it is condemned.
c. Carcasses condemned because there are no viscera available to inspect: disposition of no-viscera carcasses is determined by the veterinarian in charge and is based upon flock incidence of disease.
d. Xanthomatosis: if the condition is generalized, the carcass is condemned.
e. Parasites: if the infestation is generalized, the carcass is condemned.

Only condemnation of carcass parts is required for some localized conditions. If there is an unwholesome portion or part that can be effectively removed, the remainder of the carcass would be considered wholesome. Some organs or parts that may be condemned because of localized conditions without condemning the whole carcass are as follows:

a. Livers: livers that have fatty degeneration are condemned. Livers that have extensive petechiae or hemorrhaging must be condemned. A liver that is inflamed, has an abscess, has a necrotic area, or is affected with necrosis, is condemned. Cirrhotic livers, livers that have a single non-leukotic tumor or livers with cysts are also condemned. Discolourations in the liver due to a biliary system disorder or postmortem changes result in the liver being condemned. Livers are condemned if there has been contamination from intestinal content or noxious materials.

b. Kidneys: when there is renal or splenic pathology or hepatic lesions that cause liver condemnation, the kidneys must be removed. Pathological conditions requiring condemnation of all viscera also require the kidneys to be removed. Anytime there is airsacculitis, the kidneys must be removed when the carcass or its posterior portion is salvaged.

c. Fractures: a fracture with no associated hemorrhage need not be trimmed and can be passed. But a fracture with a hemorrhage of the affected part must be trimmed. A compound fracture, one in which the skin is broken, requires trimming, whether there is hemorrhage present or not.

d. Luxations: a luxation is a simple disjointment with no skin broken and no hemorrhage. The condition need not be trimmed. Hemorrhage extending into the musculature requires trimming or slitting/washing out. Simple redness of skin does not require any action.

To maintain a good production rate, one properly trained plant employee should be designated for each inspector as the inspector's helper in doing the following:

a. Remove condemned birds or parts from the line and place them in the designated U.S. condemn containers.
b. Remove retained carcasses from the line and place them in the appropriate area of the retain rack, designated for veterinary review.
c. Remove from the line carcasses designated for approved off-line salvage and place them in the appropriate area of the retain rack.
d. Record condemned carcasses in the appropriate blocks of the inspector's worksheet (FSIS Form 6000-16) as directed by the inspector.

e. Mark carcasses, at the inspector's direction, for trim or salvage.
f. Trim abnormalities.
g. Assist as much as possible to allow the inspector to devote full attention to postmortem inspection. The inspector and the helper must work as a team. The inspector may use various methods to give directions to the helper. In some cases, hand signals are given, but in other situations, directions are given by voice.

As mentioned in the opening section, inspection also includes looking into sanitary slaughter conditions in the plant, plant sanitation in general, and the chilling system (to assure plant is meeting temperature reduction in time). The inspector is also responsible for checking/monitoring residue levels (drugs, and chemicals such as pesticides).

7.4 Line Speeds

The number of inspectors assigned to a line depends on line speed. Countries have different requirements that also depend on the relative emphasis on ante mortem and postmortem inspection (e.g., some countries require single bird postmortem inspection while others are inspecting by lot unless there is a disease condition within the flock). In the US, single bird inspection is required (Bilgili, 2010). There are five main categories:

a. Traditional system – 35 birds per min (bpm) with one inspector per line
b. Streamline Inspection System (SIS) – 70 bpm with two inspectors per line (each checks alternate birds; shackles are marked with different colours)
c. New Enhanced Line Speed (NELS) – 91 bpm with three inspectors (each checks every third bird)
d. New Turkey Inspection System (NTIS) – 82 bpm of heavy birds (> 7kg) and 102 bpm of lighter turkeys
e. New system approved for two specific automated lines (i.e., Nu-tech by Stork, and Maestro by Meyn) – 140 bpm with four inspectors. The system can also examine 105 bpm when three inspectors are present.

FSIS does not require line speed adjustments due to the number of feathers on carcasses presented for postmortem inspection. Plant management is responsible for line speed adjustments related to ready-to-cook poultry.

FSIS uses the following considerations to decide if line speed adjustment is needed:

a. Bird's class and the size of the poultry in the class
b. Disease incidence
c. Presentation errors (viscera on the wrong side)
d. Plant personnel's ability to complete eviscerating procedures with minimal contamination
e. Physical limitations of inspectors
f. Plant facilities

Maximum line speeds are only permitted on the eviscerating line when optimal conditions exist. When less than optimal conditions are present (e.g., disease condition, high incidences of gut spillage, poor presentation), a line speed adjustment is required. The inspector in charge is responsible for directing plant management to reduce the line speed to permit adequate inspection and insure a smooth flow of product. The new Modernization of Poultry Slaughter Inspection Rule (USDA, 2014) maintains the same line speed as before (see above) but now requires that all poultry companies take measures to prevent *Salmonella* and *Campylobacter* contamination, rather than addressing contamination after it occurs.

7.5 Grading

Grading of meat is important in establishing a common language between sellers and buyers (e.g., local or international). Grades are also often used by producers to promote a brand name and their own product. Grading today is usually done on a voluntary basis, after birds have passed the mandatory inspection. The grade standards, developed by each country or trading community, are applied to a specific kind and class of poultry. However, some general criteria are considered in assessing most poultry. Factors such as overall conformation, presence of feathers/pinfeathers, discolouration, and missing parts are fairly universal criteria applied to all kinds of poultry.

Grading can be done by government-licensed graders or a private agency working under government regulations (i.e., various countries have privatized the grading system in order to reduce cost). The development of national standards that are accepted by all participants (e.g., producers, processors, consumers) is accomplished more easily and better monitored by a central body that is agreeable to all potential local and/or international buyers. In most places, grading is fee

for service. Examples of grading stamps are shown in Figure 7.5.1. The general standards used for grading ready to cook poultry in the United States are provided below. The description in the text below refers to Grade A chicken. Additional information is provided in Table 7.5.1a for Grade A poultry, in Table 7.5.2 for Grade B, and Table 7.5.3 for Grade C (USDA, 1998).



a)



b)

Figure 7.5.1 Grade stamps: (a) U.S. Grade A; (b) Canada stamp – grade letter is included (after grading) below "CANADA".

Table 7.5.1. Summary of specifications for standards of A-quality for individual carcasses and parts used in the United States (USDA, 1998).

A Quality							
Conformation: Breastbone Back Legs and Wings		Normal Slight curve or dent Slight curve Normal					
Fleshing:		Well fleshed, considering kind and class					
Fat Covering:		Well-developed layer—especially between heavy feather tracts					
Defeathering: Free of protruding feathers and hairs		**Turkeys**		**Ducks and Geese**[a]		**All Other Poultry**	
		(feathers less than 3/4 in.)		(feathers less than 1/2 in.)		(feathers less than 1/2 in.)	
		Carcass	**Parts**	**Carcass**	**Parts**	**Carcass**	**Parts**
		4	2	8	4	4	2
Exposed Flesh:[b] Weight Range		**Carcass**		**Large Carcass Parts**[c] (halves, front and rear halves)		**Other Parts**[c]	
Minimum	Maximum	Breast & Legs	Elsewhere	Breast & Legs	Elsewhere		
None	2 lbs.	1/4 in.	1 in.	1/4 in.	1/2 in.	1/4 in.	
Over 2 lbs.	6 lbs.	1/4 in.	1 1/2 in.	1/4 in.	3/4 in.	1/4 in.	
Over 6 lbs.	16 lbs.	1/2 in.	2 in.	1/2 in.	1 in.	1/2 in.	
Over 16 lbs.	None	1/2 in.	3 in.	1/2 in.	1 1/2in.	1/2 in.	
Discolourations: **Carcass**		**Lightly Shaded**			**Moderately Shaded**[d]		
		Breast & Legs	Elsewhere		Hock of Leg	Elsewhere	
None	2 lbs.	3/4 in.	1 1/4 in.		1/4 in.	5/8 in.	
Over 2 lbs.	6 lbs.	1 in.	2 in.		1/2 in.	1 in.	
Over 6 lbs.	16 lbs.	1 1/2 in.	2 1/2 in.		3/4 in.	1 1/4 in.	
Over 16 lbs.	None	2 in.	3 in.		1 in.	1 1/2 in.	
Discolourations: **Large Carcass Parts** (halves, front and rear halves)		**Lightly Shaded**			**Moderately Shaded**[d]		
		Breast & Legs	Elsewhere		Hock of Leg	Elsewhere	
None	2 lbs.	1/2 in.	1 in.		1/4 in.	1/2in.	
Over 2 lbs.	6 lbs.	3/4 in.	1 1/2 in.		3/8 in.	3/4 in.	
Over 6 lbs.	16 lbs.	1 in.	2 in.		1/2 in.	1 in.	
Over 16 lbs.	None	1 1/4 in.	2 1/2 in.		5/8 in.	1 1/4 in.	
Discolourations: **Other Parts**		**Lightly Shaded**			**Moderately Shaded**[d]		
None	2 lbs.	1/2 in.			1/4 in.		
Over 2 lbs.	6 lbs.	3/4			3/8 in.		
Over 6 lbs.	16 lbs.	1			1/2 in.		
Over 16 lbs.	None	1 1/4			5/8 in.		

A Quality	
Disjointed and Broken Bones:	Carcass—one disjointed and no broken bones. Parts—thighs with back portion, legs or leg quarters may have femurs disjointed from the hip joint. Other parts—none.
Missing Parts:	Wing tips and tail. In ducks and geese, the parts of the wing beyond the second joint may be removed if removed at the joint, and both wings are so treated. The tail may be removed at the base.
Freezing Defects:	Slight darkening on back and drumstick. Overall bright appearance. Occasional pockmarks due to drying. Occasional small areas of clear, pinkish- or reddish-coloured ice.

[a]Hair or down is permitted on the carcass or part, provided the hair or down is less than 3/16 inch in length and is scattered so that the carcass or part has a clean appearance, especially on the breast and legs.
[b]Maximum aggregate area of all exposed flesh. In addition, the carcass or part may have cuts or tears that do not expand or significantly expose flesh, provided the aggregate length of all such cuts and tears does not exceed a length tolerance equal to the permitted dimensions listed above.
[c]For all parts, trimming of skin along the edge is allowed, provided at least 75% of the normal skin cover associated with the part remains attached, and the remaining skin uniformly covers the outer surface and does not detract from the appearance of the part.
[d]Moderately shaded discolourations and discolourations due to flesh bruising are free of clots and limited to areas other than the breast and legs except for the area adjacent to the hock.

Table 7.5.2 Summary of specifications for standards of B-quality for individual carcasses and parts used in the United States (USDA, 1998).

B Quality						
Conformation: *Breastbone* *Back* *Legs and Wings*	Moderate deformities Moderately dented, curved or crooked Moderately crooked Moderately misshaped					
Fleshing:	Moderately fleshed, considering kind and class					
Fat Covering:	Sufficient fat layer—especially on breast and legs					
Defeathering: A few scattered protruding feathers and hairs	**Turkeys** (feathers less than 3/4 in.)		**Ducks and Geese**[a] (feathers less than 1/2 in.)		**All Other Poultry** (feathers less than 1/2 in.)	
	Carcass	**Parts**	**Carcass**	**Parts**	**Carcass**	**Parts**
	6	3	10	5	6	3
Exposed Flesh: Weight Range	**Carcass**			**Parts**		
Minimum	Maximum					
None	2 lbs.	No part on the carcass (wings, legs, entire back or entire breast) has more than one-third of the flesh exposed		No more than one-third of the flesh normally covered by skin exposed		
Over 2 lbs.	6 lbs.					
Over 6 lbs.	16 lbs.					
Over 16 lbs.	None					

<table>
<tr><th colspan="4">B Quality</th></tr>
<tr><td colspan="2" rowspan="2">Discolourations:[b]
Carcass</td><td colspan="2">Carcass
Lightly or Moderately Shaded Discolourations</td></tr>
<tr><td>Breast and Legs</td><td>Elsewhere</td></tr>
<tr><td>None</td><td>2 lbs.</td><td>1 1/4 in.</td><td>2 1/4 in.</td></tr>
<tr><td>Over 2 lbs.</td><td>6 lbs.</td><td>2 in.</td><td>3 in.</td></tr>
<tr><td>Over 6 lbs.</td><td>16 lbs.</td><td>2 1/2 in.</td><td>4 in.</td></tr>
<tr><td>Over 16 lbs.</td><td>None</td><td>3 in.</td><td>5 in.</td></tr>
<tr><td colspan="2" rowspan="2">Discolourations:[b]
Large Carcass Parts
(halves, front and rear halves)</td><td colspan="2">Large Carcass Parts
Lightly or Moderately Shaded Discolourations</td></tr>
<tr><td></td><td>Breast and Legs</td><td>Elsewhere</td></tr>
<tr><td>None</td><td>2 lbs.</td><td>1 in.</td><td>1 1/4 in.</td></tr>
<tr><td>Over 2 lbs.</td><td>6 lbs.</td><td>1 1/2 in.</td><td>1 3/4 in.</td></tr>
<tr><td>Over 6 lbs.</td><td>16 lbs.</td><td>2 in.</td><td>2 1/2 in.</td></tr>
<tr><td>Over 16 lbs.</td><td>None</td><td>2 1/2 in.</td><td>3 in.</td></tr>
<tr><td colspan="2" rowspan="2">Discolourations:[b]
Other Parts</td><td colspan="2">Other Parts
Lightly or Moderately Shaded Discolourations</td></tr>
<tr><td colspan="2">Breasts, Legs and Parts</td></tr>
<tr><td>None</td><td>2 lbs.</td><td colspan="2">3/4 in.</td></tr>
<tr><td>Over 2 lbs.</td><td>6 lbs.</td><td colspan="2">1 in.</td></tr>
<tr><td>Over 6 lbs.</td><td>16 lbs.</td><td colspan="2">1 1/2 in.</td></tr>
<tr><td>Over 16 lbs.</td><td>None</td><td colspan="2">1 3/4 in.</td></tr>
<tr><td colspan="2">Disjointed and Broken Bones:</td><td colspan="2">Carcass—two disjointed and no broken bones, or one disjointed and one nonprotruding broken bone. Parts— may be disjointed, no broken bones; wing beyond second joint may be removed at a joint.</td></tr>
<tr><td colspan="2">Missing Parts:</td><td colspan="2">Wing tips, second wing joint and tail.</td></tr>
<tr><td colspan="2" rowspan="2">Trimming:</td><td>Carcass</td><td>Parts</td></tr>
<tr><td>Slight trimming of the carcass is permitted provided the meat yield of any part on the carcass is not appreciably affected. The back may be trimmed in an area not wider than the base of the tail to the area halfway between the base of the tail and the hip joints.</td><td>A moderate amount of meat may be trimmed around the edge of a part to remove defects.</td></tr>
<tr><td colspan="2">Freezing Defects:</td><td colspan="2">May lack brightness. Few pockmarks due to drying. Moderate areas showing a layer of clear, pinkish or reddish coloured ice.</td></tr>
<tr><td colspan="4">[a]Hair or down is permitted on the carcass or part, provided the hair or down is less than 3/16 inch in length and is scattered so that the carcass or part has a clean appearance, especially on the breast and legs.
[b]Discolourations due to flesh bruising shall be free of clots and may not exceed one-half the total aggregate area of permitted discolouration</td></tr>
</table>

Table 7.5.3 Summary of specifications for standards of C-quality for individual carcasses and parts used in the United States (USDA, 1998)

<table>
<tr><th colspan="8">C Quality</th></tr>
<tr><td colspan="2">Conformation:
Breastbone
Back
Legs and Wings</td><td colspan="6">Abnormal
Seriously curved or crooked
Seriously crooked Misshapen</td></tr>
<tr><td colspan="2">Fleshing:</td><td colspan="6">Poorly fleshed</td></tr>
<tr><td colspan="2">Fat Covering:</td><td colspan="6">Lacking in fat covering over all parts of carcass</td></tr>
<tr><td colspan="2" rowspan="3">Defeathering:
Scattering of protruding feathers and hairs</td><td colspan="2">Turkeys
(feathers less than 3/4 in.)</td><td colspan="2">Ducks and Geese[a]
(feathers less than 1/2 in.)</td><td colspan="2">All Other Poultry
(feathers less than 1/2 in)</td></tr>
<tr><td>Carcass</td><td>Parts</td><td>Carcass</td><td>Parts</td><td>Carcass</td><td>Parts</td></tr>
<tr><td>8</td><td>4</td><td>12</td><td>6</td><td>8</td><td>4</td></tr>
<tr><td colspan="2" rowspan="2">Exposed Flesh:
Weight Range</td><td colspan="3" rowspan="2">Carcass</td><td colspan="3" rowspan="2">Parts</td></tr>
<tr></tr>
<tr><td>Minimum</td><td>Maximum</td><td colspan="6" rowspan="4">No limit</td></tr>
<tr><td>None</td><td>2 lbs.</td></tr>
<tr><td>Over 2 lbs.</td><td>6 lbs.</td></tr>
<tr><td>Over 6 lbs.</td><td>16 lbs.</td></tr>
<tr><td>Over 16 lbs.</td><td>None</td><td colspan="6"></td></tr>
<tr><td colspan="2">Discolourations:</td><td colspan="6">Carcass</td></tr>
<tr><td colspan="2">Carcass</td><td colspan="3">Breast and Legs</td><td colspan="3">Elsewhere</td></tr>
<tr><td>None</td><td>2 lbs.</td><td colspan="6" rowspan="3">No limit on size, number of areas or intensity of discolourations and flesh bruises if such areas do not render any part of the carcass unfit for food.</td></tr>
<tr><td>Over 2 lbs.</td><td>6 lbs.</td></tr>
<tr><td>Over 6 lbs.</td><td>16 lbs.</td></tr>
<tr><td>Over 16 lbs.</td><td>None</td><td colspan="6"></td></tr>
<tr><td colspan="2">Discolourations:
Parts
(includes large carcass parts)</td><td colspan="6">Parts
Breasts, Legs and Parts</td></tr>
<tr><td>None</td><td>2 lbs.</td><td colspan="6">No limit on size, number of areas or intensity of discolourations and flesh bruises if such areas do not render any part unfit for food.</td></tr>
<tr><td>Over 2 lbs.</td><td>6 lbs.</td><td colspan="6" rowspan="3"></td></tr>
<tr><td>Over 6 lbs.</td><td>16 lbs.</td></tr>
<tr><td>Over 16 lbs.</td><td>None</td></tr>
<tr><td colspan="2">Disjointed and Broken Bones:</td><td colspan="6">No limit</td></tr>
<tr><td colspan="2"></td><td colspan="3">Carcass</td><td colspan="3">Parts</td></tr>
<tr><td colspan="2">Missing Parts:</td><td colspan="6">Wing tips, wings and tails.
Backs shall include all meat and skin from pelvic bones, except that the meat contained in the ilium (oyster) may be removed.

The vertebral ribs and scapula with meat and skin and the backbone located anterior (forward) if ilia bones may also be removed (front half of back).</td></tr>
</table>

C Quality	
Trimming:	Trimming of the breast and legs is permitted but not to the extent that the normal meat yield is materially affected. The back may be trimmed in an area not wider than the base of the tail and extending from the tail to the area between the hip joints.
Freezing Defects:	Numerous pockmarks and large dried areas.
[a]Hair or down is permitted on the carcass or part, provided the hair or down is less than 3/16 inch in length and is scattered so that the carcass or part has a clean appearance, especially on the breast and legs.	

The major criteria for Grade A are as follows:

a. Conformation: the carcass or part is free of deformities that detract from its appearance or that affect the normal distribution of flesh. Slight deformities, such as slightly curved or dented breastbones and slightly curved backs, may be present.

b. Fleshing: the carcass has a well-developed covering of flesh, considering the kind, class, and part. The breast is moderately long and deep, and has sufficient flesh to give it a rounded appearance, with the flesh carrying well up to the crest of the breastbone along its entire length (see Fig. 7.5.2). The leg is well fleshed and moderately thick and wide at the knee and hip joint area, and has a well-rounded, plump appearance with the flesh carrying well down toward the hock and upward to the hip joint area. The drumstick is well fleshed and moderately thick and wide at the knee joint and has a well-rounded, plump appearance with the flesh carrying well down toward the hock. The thigh is well to moderately fleshed. The wing is well to moderately fleshed.

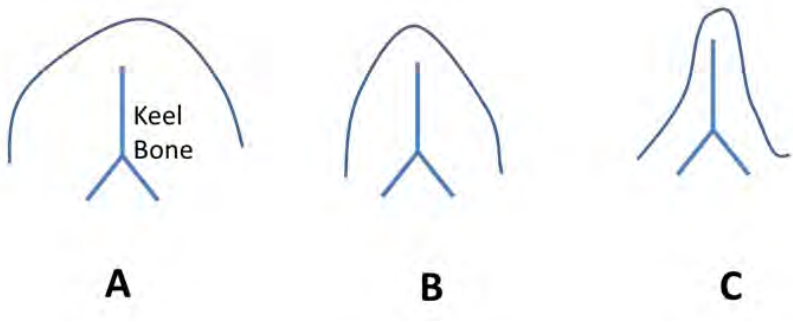


Figure 7.5.2 Illustration of poultry breast area (cross section) showing variation in the amount of flesh covering the breastbone. Drawing on the left shows an example of Grade A.
A= well fleshed; B=fairly well fleshed; C poorly fleshed.

c. Fat covering: the carcass or part, considering the kind, class and part, has a well-developed layer of fat in the skin. The fat is well distributed so that there is a noticeable amount of fat in the skin in the areas between the heavy feather tracts.

d. Defeathering: the carcass or part shall have a clean appearance, especially on the breast and legs, and shall be free of protruding feathers. A carcass or part shall be considered free from protruding feathers when it complies with the tolerances specified in Table 7.5.1. (Note: for Grades B and C specifications, see Tables 7.5.2 and 7.5.3, respectively).

e. Discolouration: the requirements contained in this section are applicable to discolourations of the skin and flesh of poultry and the flesh of skinless poultry. The carcass, parts derived from the carcass, or large carcass parts may have slight discolourations, provided the discolourations do not detract from the appearance of the product.

The carcass may have lightly shaded areas of discolouration, provided the aggregate area of all discolourations does not exceed an area equivalent to the area of a circle of the diameter specified in Table 7.5.1. Evidence of incomplete bleeding, such as more than an occasional slightly reddened feather follicle, is not permitted.

The carcass may have moderately shaded areas of discolouration and discolourations due to flesh bruising, provided the following:

a. They are not on the breast or legs, except for the area adjacent to the hock joint.
b. They are free of clots.
c. They may not exceed an aggregate area equivalent to the area of a circle of the diameter specified in Table 7.5.1.

Parts, other than large carcass parts, may have lightly shaded areas of discolouration, provided the aggregate area of all discolourations does not exceed an area equivalent to the area of a circle of the diameter specified in Table 7.5.1. Evidence of incomplete bleeding, such as more than an occasional slightly reddened feather follicle, is not permitted. Parts, other than large carcass parts, may have moderately shaded areas of discolouration and discolourations due to flesh bruising, provided the following:

a. They are not on the breast or legs, except for the area adjacent to the hock joint.

b. They are free of clots.
c. They may not exceed an aggregate area equivalent to the area of a circle of the diameter specified in Table 7.5.1.

Large carcass parts, specifically halves, front halves, or rear halves, may have lightly shaded areas of discolouration, provided the aggregate area of all discolourations does not exceed an area equivalent to the area of a circle of the diameter specified in Table 7.5.1. Large carcass parts, specifically halves, front halves, or rear halves, may have moderately shaded areas of discolouration and discolourations due to flesh bruising, provided the following:

a. They are not on the breast or legs, except for the area adjacent to the hock joint.
b. They are free of clots.
c. They may not exceed an aggregate area equivalent to the area of a circle of the diameter specified in Table 7.5.1.
d. Disjointed/broken bones and missing parts: parts are free of broken bones. Parts are free of disjointed bones except that thighs with back portions, legs, or leg quarters may have the femur disjointed from the hip joint. The carcass is free of broken bones and has not more than one disjointed bone.

The wing tips may be removed at the joint, and in the case of ducks and geese, the parts of the wing beyond the second joint may be removed, if removed at the joint and both wings are so treated. The tail may be removed at the base.
Cartilage separated from the breastbone is not considered a disjointed or broken bone.

g. Exposed flesh: the requirements contained in this section are applicable to exposed flesh resulting from cuts, tears, and missing skin.

Large carcass parts, specifically halves, front halves or rear halves, may have exposed flesh due to cuts, tears, and missing skin, provided the aggregate area of all exposed flesh does not exceed an area equivalent to the area of a circle of the diameter specified in Table 7.5.1.

The carcass may have exposed flesh due to cuts, tears, and missing skin, provided the aggregate area of all exposed flesh does not exceed an area equivalent to that of a circle of the diameter specified in Table 7.5.1.

For all parts, trimming of the skin along the edge is allowed, provided that at least

75% of the normal skin cover associated with the part remains attached and further provided that the remaining skin uniformly covers the outer surface in a manner that does not detract from the appearance of the part.

Other parts may have exposed flesh due to cuts, tears, and missing skin, provided the aggregate area of all exposed flesh does not exceed an area equivalent to that of a circle of the diameter specified in Table 7.5.1. In addition, the carcass or part may have cuts or tears that do not expand or significantly expose flesh, provided the aggregate length of all such cuts and tears does not exceed a length tolerance using the dimensions listed in Table 7.5.1.

h. Freezing defects: with respect to consumer packaged poultry, parts, or specified poultry food products, the carcass, part, or specified poultry food product is practically free from defects that result from handling or occur during freezing or storage. The following defects are permitted if they, alone or in combination, detract only very slightly from the appearance of the carcass, part or specified poultry food product:

a. Slight darkening over the back and drumsticks, provided the frozen bird or part has a generally bright appearance occasional pockmarks due to drying of the inner layer of skin (derma); however, none may exceed the area of a circle 1/8 inch in diameter for poultry weighing 6 pounds or less and 1/4 inch in diameter for poultry weighing over 6 pounds.
b. Occasional small areas of clear, pinkish or reddish coloured skin.
c. Occasional small areas of dehydration, white to light gray in colour, on the flesh of skinless carcasses, parts or specified poultry food products not to exceed the permitted aggregate area for discolourations as provided in Table 7.5.1. Note: A-quality poultry backs shall meet all applicable provisions of this section pertaining to parts and shall include the meat contained on the ilium (oyster), pelvic meat and skin and vertebral ribs and scapula with meat and skin.

An internal, in-plant system for deboned meat and/or parts can sometimes be used and may include the following:

a. Presence of bruises and/or blood clots
b. Presence of bones and cartilage
c. Other factors

Another example is from the British Grading Guide (DEFRA, 2011). According to the Guide, poultry cuts and carcasses can be graded as either A or B, according

to conformation and appearance. The definition starts with Class B and indicates that the minimum standards for a whole bird to be graded as B are that the carcass is:

a. Intact, taking into account presentation as described in the Regulations.
b. Clean, free from any visible foreign matter, dirt or blood.
c. Free from any foreign smell.
d. Free of visible blood stains unless small and unobtrusive.
e. Free of protruding broken bones.
f. Free of severe bruising.
g. For fresh poultry, there should be no trace of the carcass having been frozen.

In addition to the points mentioned above, the following conditions apply to the Class A carcasses:

a. Must have good conformation.
b. The flesh must be plump.
c. The breast must be well developed (described as broad, long and fleshy).
d. The legs should be fleshy.
e. On chickens, young ducks or ducklings, and turkeys there should be a thin regular layer of fat on the breast, back, and thighs.
f. On cocks, hens, ducks, and young geese, a thicker layer of fat is permissible.
g. On geese, a moderate to thick fat layer shall be present all over the carcass.
h. A few small feathers, stubs (quill ends) and hairs (filo-plumes) may be present on the breast, legs, back, foot joints, and wing tips.
i. In the case of boiling fowl, ducks, turkeys, and geese, a few feathers may also be present on other parts.
j. Some damage, bruising and discolouration is allowed, provided that it is small and unobtrusive, and not present on the breast or legs.
k. Wing tips may be missing.
l. A slight redness in wing tips and follicles is allowed.
m. For frozen or quick-frozen poultry there should be no traces of freezer burn (freezer burn is the local or area-type irreversible drying up of skin and/or flesh which may produce changes: in the original colour (usually paler); or in smell (rancid); or in flavour (flavourless); or in texture (dry, spongy) on the breast or legs. Small unobtrusive traces of freezer burn are allowed on other parts of the carcass.

In recent years a grading system based on meat quality attributes, such as water-holding capacity and texture, has been discussed for use by the industry. Such a system is of interest to further processors who are looking for meat that will hold added moisture (high quality protein) and not fall apart during cooking (good texture) regardless of skin tears or missing parts (Barbut, 1998).

7.6 Poultry Classification

Different species of poultry (e.g., chicken, turkey, duck) can be divided into classes. The following are the various classes of poultry used in the United States (USDA, 1998).

7.6.1 Chicken Classifications

a. Rock Cornish game hen or Cornish game hen – is a young immature chicken (usually less than five weeks of age), of either sex with a ready to cook weight of not more than two pounds, that was bred from a Cornish chicken or the progeny of a Cornish chicken crossed with another breed of chicken.

b. Rock Cornish fryer, roaster, or hen – is the progeny of a cross between a purebred Cornish and a purebred Rock chicken, without regard to the weight of the carcass involved; however, the term "fryer," "roaster" or "hen" shall apply only if the carcasses are from birds with ages and characteristics that qualify them for such designation under paragraphs (c) and (d) of this section.

c. Broiler or fryer – is a young chicken (usually under 10 weeks of age), of either sex, that is tender-meated with soft, pliable, smooth-textured skin and flexible breastbone cartilage.

d. Roaster or roasting chicken – is a young chicken (usually less than 12 weeks of age), of either sex, that is tender-meated with soft, pliable, smooth-textured skin and breastbone cartilage that may be somewhat less flexible than that of a broiler or fryer.

e. Capon – is a surgically unsexed male chicken (usually under four months of age) that is tender-meated with soft, pliable, smooth- textured skin.

f. Hen, fowl, or baking or stewing chicken – is a mature female chicken (usually more than 10 months of age) with meat less tender than that of a roaster or roasting chicken and a nonflexible breastbone tip.

g. Cock or rooster – is a mature male chicken with coarse skin, toughened and darkened meat, and hardened breastbone tip.

7.6.2 Turkey Classifications

a. Fryer-roaster turkey – is a young immature turkey (usually under 12 weeks of age), of either sex, that is tender-meated with soft, pliable, smooth-textured skin and flexible breastbone cartilage.

b. Young turkey – is a turkey (usually under six months of age) that is tender-meated with soft, pliable smooth-textured skin and breastbone cartilage that is somewhat less flexible than that of a fryer- roaster turkey. Sex designation is optional.

c. Yearling turkey – is a fully matured turkey (usually under 15 months of age) that is reasonably tender-meated with reasonably smooth-textured skin. Sex designation is optional.

d. Mature turkey or old turkey (hen or tom) – is an old turkey of either sex (usually in excess of 15 months of age) with coarse skin and toughened flesh.

Note: for labeling purposes, the designation of sex within the class name is optional, and the two classes of young turkeys may be grouped and designated as "young turkeys."

7.6.3 Duck Classifications

a. Broiler duckling or fryer duckling – is a young duck (usually under eight weeks of age), of either sex, that is tender-meated and has a soft bill and a soft windpipe.

b. Roaster duckling – is a young duck (usually under 16 weeks of age), of either sex, that is tender-meated and has a bill that is not completely hardened and a windpipe that is easily dented.

c. Mature duck or old duck – is a duck (usually over six months of age), of either sex, with toughened flesh, hardened bill and hardened windpipe.

7.6.4 Goose Classifications

a. Young goose – A young goose may be of either sex, is tender-meated and has a windpipe that is easily dented.

b. Mature goose or old goose – A mature goose or old goose may be of either sex and has toughened flesh and a hardened windpipe.

7.6.5 Guinea Fowl Classifications

a. Young guinea – is tender-meated and has flexible breastbone cartilage.

b. Mature guinea or old guinea – may be of either sex and has toughened flesh and a hardened breastbone.

7.6.6 Pigeon Classifications

a. Squab – is a young, immature pigeon of either sex that is extra tender-meated.

b. Pigeon – is a mature pigeon of either sex, with coarse skin and toughened flesh.

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8

STUNNING

8.1 Introduction

Stunning meat producing animals prior to slaughter achieves fast immobilization, onset of insensibility or unconsciousness (i.e., for animal welfare reasons) and allows easier and safer handling (i.e., immobilizing large animals by mechanical, electrical or gas stunning). Overall, welfare considerations are becoming more important and today various agencies evaluate/monitor compliance with animal welfare standards. In Europe, for example, the new suggested stunning regulations that specify detailed conditions and settings (EU, 2009) came into effect in 2013. A notable change from the previous regulations is the requirement that a certain level of current should be applied to each individual bird when electrical stunning is applied. In the past, EU regulations indicated conditions for a group of birds going through a water bath stunner (to be further discussed below). In other regions conditions for poultry stunning are not always specifically legislated (e.g., in the USA, poultry is not covered under the Humane Methods of Slaughter Act, 1978). Nevertheless, all plants use stunning (electrical, gas, or mechanical) with help from national guidelines/regulations.

Stunning and immobilizing poultry also assists in operating an efficient automated line. Initially, electrical stunning for poultry was introduced to immobilize the animals to allow application of bleeding through a high speed automated process. Later, gas stunning was introduced (Fletcher, 1999) and today both methods are widely used around the world. Stunning is usually not employed during traditional religious-based ritual slaughters such as Halal and Kosher (Regenstein et al., 2003; Velarde et al., 2014). For these methods, an exemption is given by the appropriate government agency and it is explained that the fast slaughter method and sharp equipment used prevents animal suffering (see discussion on no stunning later in the chapter). It is interesting to note that a number of regulations found in places where stunning is performed are actually based on Old Testament laws that discuss treating animals in a humane way, preventing suffering, and indicating that animals acceptable for food must be killed and not allowed to die due to natural causes, disease, or accident.

There is no single, universal, animal welfare code and this presents a challenge for processors in meeting different animal welfare codes and developing equipment. This is true not only among regulatory agencies that have different requirements for stunning levels, but also between national and some religious groups. It should be mentioned that the World Organization for Animal Health does have a guideline for animal slaughter (OIE, 2014), but it is not recognized in all places. Overall, the two most common methods used for stunning poultry are electrical and gas stunning. As indicated above, electrical stunning was introduced first and is still used in over half of the birds processed around the world. Controlled gas stunning (CAS) has become more popular in Europe and it is now estimated to account for over half of the birds processed there. The higher use of CAS in Europe is actually the result of the different stunning requirements. As will be described in the chapter, the EU requires a higher degree of stun compared to other regions. This requires a higher voltage and lower frequency, and can result in damaged meat quality (i.e., more muscle contractions and possibly more haemorrhages; see Table 8.1.1). Certain gas stunning treatments can overcome this problem while still yielding a high degree of stunning and have thus become more popular in Europe.

Table 8.1.1 Examples of average haemorrhage scores in breast and thigh meat related to different stunning methods (n = 144). Adapted from Schreurs et al. (1999). Note: averages also depend on exact conditions used, e.g., lower electrical current or higher frequency can lower the values.

Stunning method[1]	Average haemorrhage score[2]		pH-time postmortem			R value-time postmortem		
	Thigh meat	Breast meat	1h	2h	4h	1h	2h	4h
Whole body (electrical)	3.15 ± 1.17^{a}	3.56 ± 1.17^{a}	6.47^{a}	6.21^{a}	6.05^{a}	0.87^{c}	0.94^{c}	1.20^{b}
Head only (electrical	2.42 ± 0.94^{b}	3.07 ± 1.23^{b}	6.01^{c}	6.00^{b}	5.98^{b}	1.14^{a}	1.27^{a}	1.35^{a}
Argon (gas)	2.08 ± 0.96^{c}	1.75 ± 0.89^{d}	6.11^{bc}	6.04^{b}	6.00^{ab}	0.94^{b}	1.09^{b}	1.29^{a}
CO_2 (gas)	2.07 ± 0.92^{c}	1.66 ± 0.93^{d}	6.30^{ab}	6.21^{a}	6.02^{ab}	0.88^{bc}	0.93^{c}	1.17^{b}
Captive bolt (mechanical)	2.04 ± 0.90^{c}	1.96 ± 0.93^{c}	6.29^{ab}	6.23^{a}	5.97^{b}	0.94^{b}	0.99^{c}	1.29^{a}

[1] Whole body - 100 V, 120 mA and 50 Hz for 10 sec. Head only - 120 mA, 300 Hz for 1 sec. Argon - 70% Argon + 30% CO_2. CO_2 - anesthetic mixture of 40% CO_2 + 30% O_2 + 30% N_2 followed by an anoxia mixture of 80% CO_2 + 20% N_2. Captive bolt - mechanical.
[2] Means and standard deviations, within each column, followed by a different superscript are significantly different ($P < 0.05$).

It is also important to note that within each of the stunning methods, variations can be seen within the same country and even between two adjacent processing plants.

This chapter mainly focuses on stunning poultry but the principles that apply to other meat producing animals are basically the same. In other species a certain method might be more prevalent (e.g., beef – captive bolt; pigs – electrical and gas stunning; fish – electrical stunning) where conditions (voltage, frequency, gas type, and concentration) and time can vary (see reviews by Gregory, 2008; Grandin, 2014).

8.2 Electrical Stunning

8.2.1 General

Electrical stunning is currently the most commonly used method to immobilize poultry prior to slaughter. The systems developed for poultry were primarily designed to immobilize the animals or render them unconscious long enough to allow manual or automated neck cutting. The equipment is relatively inexpensive, has a small footprint in the plant, is compatible with current line speeds, and is easy to maintain (Bilgili, 1999). However, proper adjustment of currents has sometimes been reported to be a problem at the plant level (Raj, 2003). Different electrical stunner models exist on the market and include high and low voltage, high and low frequency, and stunners that use alternating current (AC), direct current (DC), or DC followed by AC (examples provided below). Usually, a fiberglass water bath (or any other non-conductive, salt resistant material) is fitted under the overhead shackle line. The birds, suspended from the line, are moved into the shallow bath filled with water or a brine solution (1% salt is recommended). The height of the bath can be adjusted in order to ensure that the heads of the birds are fully immersed. Stunning is accomplished by passing a sufficient amount of electrical current through the body of the animal for a specified amount of time. The current may paralyze the birds or render them unconscious, depending on the characteristics of the current applied. The state of unconsciousness results from the inhibition of impulses from both the reticular activating and the somatosensory systems (electroencephalogram data is presented below). The stunning current that reaches the brain must be sufficient to induce an epileptic seizure. The state of unconsciousness that results from electrical stunning is believed to be due to neural disruption of nuclei, and structures within the brain (e.g., intra laminar nuclei in the thalamus) that are needed to maintain a waking state (Butler and Cotterill, 2006). As indicated in the introduction, there are differences in the currents used around the world. The current used in the USA is usually lower than that required for

ventricular fibrillation and an irreversible stun. Therefore, an adequate level of current should be used (adjusted for bird size and number of birds in the water bath) and be followed by rapid bleeding so birds will not regain consciousness (Bilgili, 1999; Joseph et al., 2013). Insufficient current may physically immobilize the bird, but may not prevent perception of pain and stress. In order to apply the current, an electrical metal grate is submerged at the bottom of the brine bath and spans its entire length. In a dry plate application (usually after the birds have been initially stunned) there is no water in the lower part and the birds touch a bottom metal plate. The shackle line is connected to earth, where a ground bar connects the line to complete the electrical circuit. The birds pass through the stunner in a continuous procession (e.g., 180 birds per min in a fast processing line) and the current flows through the bird's body. In this way, the birds on the shackle line represent a series of resistors connected in parallel. The amount of current that flows through each bird depends upon the voltage applied, the electrical impedance of the bird, and the number of birds. It has been shown that the resistance of broiler chickens ranges between 1,000 to 2,600 Ω (Woolley et al., 1986). As birds enter and leave the stunner, they constantly change the total resistance of the system. At a given constant voltage (as is the case for many commercial stunners), the birds receive a current proportional to their own resistance.

The effectiveness of the stunner depends not only on the electrical variables, but also on factors that determine the bird's impedance such as contact of the leg with the shackle, weight, body composition, sex, and feather cover. Therefore, one of the main goals of research and development in this area is focused on defining and standardizing the variables used in the process.

8.2.2 Settings

As indicated above, different regions can have different requirements for stunning. The EU regulations require a deeper stun than the North American requirements. To meet these regulations EU stunners have to operate at a higher voltage (e.g., 50-60 V) to assure minimum currents of 100 to 400 mA per bird, depending on the type of bird (chickens, turkey , ducks, geese or quails) and frequency applied (see Table 8.2.2.1), than stunners in North America that operate at lower voltage (10 – 25 V) and higher frequency (> 400 Hz) resulting in a lower current that passes through the bird (e.g., 25 – 50 mA).

Table 8.2.2.1 Influence of stunning current (50 Hz sine wave AC) on percentage of broiler carcasses showing meat quality defects (n = 1,300; laboratory study). Adapted from Gregory and Wilkins (1989a).

Appearance	Stunning current (mA; average)						
	45	85	121	141	161	181	220
Red wingtips	7	8	15	16	8	9	9
Haemorrhagic wing veins	4	7	11	16	12	8	9
Haemorrhagic shoulder	12	-	22	23	14	18	13
Haemorrhage in deep breast muscle	15	10	17	25	23	28	19
Haemorrhage in superficial breast	8	3	5	8	5	8	5
Haemorrhage in deep leg muscle	5	5	4	3	5	4	6
Haemorrhage superficial leg	12	5	13	14	14	19	13
Birds with ventricular fibrillation	21	80	87	99	99	100	100

The various electrical stunners that are used can also employ different types of waveform (Fig. 8.2.2.1). There are not many scientific papers reporting the conditions used in the field. However, examples from data collected in three different regions in 1987, 1994, and 2014 will be discussed below.

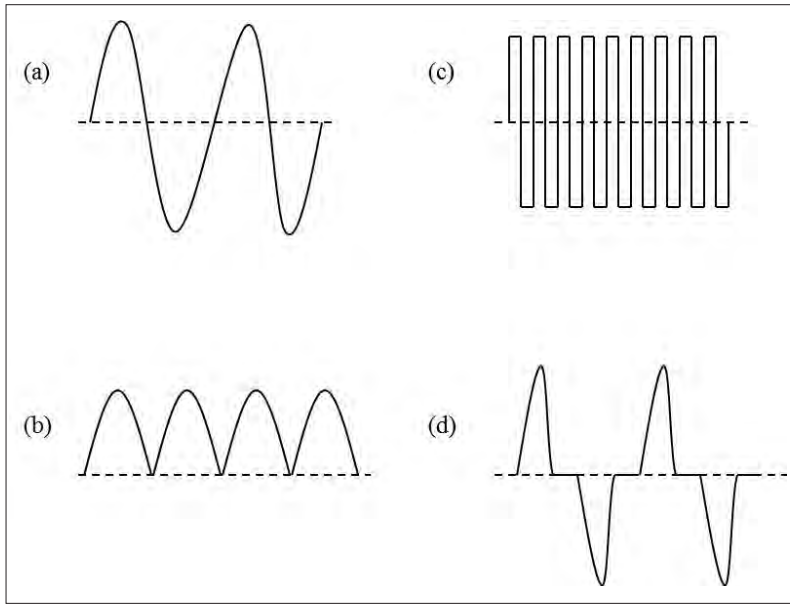


Figure 8.2.2.1 The main types of electrical waveform used in water bath stunners. Based on a survey by Gregory and Wotton (1987) in the UK. See text for details.

The first was a survey done in the UK (Gregory and Wotton, 1987), where 7 of 13 water bath stunners applied a 50 Hz sinusoidal AC (Fig. 8.2.2.1.a). One stunner used a full-wave rectification of the main supply at 100 Hz (see "b"). Square waves, which vary depending on frequency and whether they have a spiked leading edge (usually 280 or 550 Hz), were also used (see "c"). Another stunner used fractional sine waves (see "d") produced by varying the voltage of the AC current through the introduction of a thyristor into the circuit of the sinusoidal AC at 50 Hz. It was also reported that one stunner was wired up incorrectly, such that the water in the stunning bath was at error potential and the rubbing bar was live (stunner not included in study). This points out the importance of proper installation, maintenance, monitoring, and adjustment of the stunner. In most plants studied, electrical adjustments to the stunner were possible and were done to accommodate different bird sizes, but sometimes the equipment was too old or the operator was not qualified/trained to adjust the current. This can result in under-stunning in which stunning duration is not long enough to allow birds to become unconscious as a result of the blood loss. On the other hand, it could result in over-stunning in which a high percentage of haemorrhages and broken bones could occur (Joseph et al., 2013). Gregory and Wotton (1987) concluded that the diversity of frequencies and waveforms employed made it difficult to recommend a standard current for either stunning or inducing a cardiac arrest (i.e., death by electrocution). This conclusion is especially pertinent when a group of countries, such as the EU, tries to establish a standard recommendation. Later, the revised EU regulation (EU, 2009) presented a change in the requirements where a specified current (mA) has to be delivered to each individual bird (Table 8.2.2.2). Prior to that, the regulations referred to a group of birds, and because of potential variations in body size, fat level, etc., the current received per bird varied. Gregory and Wotton (1987) indicated that when they used a 50 Hz sinusoidal AC current, a level of 148 mA per bird was required to induce cardiac arrest in 99% of the broilers. The minimum recommended current of 100 mA is based on the fact that this amount, when delivered using 50 to 350 Hz, will result in sustained loss of evoked somatosensory responses in the chicken's brain. Incidentally, when delivered using a low frequency current, it also induces cardiac arrest in about 90% of chickens.

Table 8.2.2.2 Electrical requirements for water bath stunning equipment (average values per animal). EU (2009).

Frequency (Hz)	Chickens	Turkeys	Ducks and geese	Quails
< 200 Hz	100 mA	250 mA	130 mA	45 mA
From 200 to 400 Hz	150 mA	400 mA	Not permitted	Not permitted
From 400 to 1 500 Hz	200 mA	400 mA	Not permitted	Not permitted

The second survey (Heath et al., 1994) revealed that low voltage stunners were most popular in 329 US poultry plants that used electrical stunners. Overall, 92% used electrical stunners as a method of pre-slaughter immobilization. The remaining 8% were subject to religious slaughter procedures. Low voltage (10 to 25 V) and high frequency (500 Hz) stunners were used in 77% of the plants that used an electrical stunner. The remaining plants reported variation in stunning conditions ranging from 7.5 to 600 V, with no specified wave form (AC or DC) reported, and currents ranging from 0.3 to 10 mA. The authors concluded that although there were variations in methods of stunning and slaughter, the majority of plants were in voluntary compliance with the humane slaughter provisions, and the birds were stunned sufficiently to remain unconscious through exsanguinations.

The third survey consisted of small scale industry questionnaire, done by this author, which inquired about stunning settings used in the USA. It was found that the three most common conditions are:

a. 33 to 38 V at 500 to 600 Hz, delivering 25 to 35 mA per bird
b. 25 to 30 V at 350 Hz, delivering 40 mA per bird
c. First stage, 12 V DC, followed by 14.5 V delivering about 13 mA per bird (this included 9 sec in a water bath, followed by 3 sec dry plate configuration).

Overall, the North American low voltage systems are different from the high voltage and current systems utilized in Europe. It should also be mentioned that the EU also specifies that electrical stunning must be immediate (< 1 sec current application to result in unconsciousness) and induce heart failure such that broilers could not regain consciousness. This is designed to be an irreversible stun that ensures animal welfare, but does not necessarily avoid carcass defects. Application of high voltages has been associated with possible red wing tips, damaged viscera, bruised wing joints, breast meat haemorrhages, split wishbones, and separation of shoulder muscle tendons (Bilgili, 1999). Under commercial conditions, it is sometimes difficult to isolate the effect of electrical stunning from other causes of injury such as catching, hanging, wing flipping, bleeding deficiency and feather picking (Kranen et al., 2000). Although there is no precise relationship between stunning current and carcass quality, haemorrhages in the deep breast muscle have been shown by some researchers to increase with high stunning currents (Table 8.2.2.1). The data presented show that the percentage of downgrading tended to increase when currents of 121-161 mA per broiler are applied. High stunning voltages have also been linked to increased incidences of red wing tips and broken bones, whereas high stunning frequencies have been shown to reduce the severity of thigh and breast haemorrhages and result in fewer bruised/ broken bones. Overall, the causes of muscle haemorrhages in broilers are multi-

factorial and involve factors related to production, loading and unloading, hanging the birds upside down, as well as stunning. Stunning baths present a challenge because a number of birds are connected to the circuitry at the same time, forming a parallel electrical system in which the current experienced by each bird cannot be controlled as a result of variation in electrical resistance among the birds. Also, it is usually unknown how much current is actually flowing through the brain of an individual bird.

Over the years attempts have been made to design a head only electrical stunner for high speed poultry processing lines (Lambooij et al., 2010). However, implementation of such a system in a commercial slaughter line has been limited. In a high speed commercial line it is difficult, if not impossible, to isolate each bird (suspended on shackles approximately 15 cm apart) long enough to determine its resistance and deliver the precise current required. Further development of the system was recommended.

It is important to note that the stunning, neck cutting, and bleeding operations are interrelated. The evolution of electrical stunners has been, for the most part, influenced by different operations/procedures within the slaughter line (e.g., bleed time, scald time, automation of the evisceration process). Usually, the line speed is dictated by the speed of the evisceration line(s). In the US, each kill line typically supplies carcasses for two evisceration lines whereas in Europe it is common that each evisceration line is served by a separate kill line (Bilgili, 1999).

8.2.3 Study Effects on Consciousness and Fibrillation

Several methods are used by scientists/industry people to determine unconsciousness including observation of corneal reflex response, eye blinking, limb movement, and spontaneous breathing. However, EEG analysis is considered the most scientific method (Coenen et al., 2009) and scientific investigation of the effects of stunning on brain function in various animals (broilers, turkeys, pig, sheep) has resulted in its increased use to precisely determine (loss of) consciousness. Therefore, EEG data is also currently used to propose stunning conditions. (e.g., electricity, gas mixtures) as will be discussed below. In general, brain electroplectic activities have three main phases (Fig. 8.2.3.1). The first is the normal alert baseline and the second is seen during stunning and is the epileptiform phase that consists of hyper-synchronous activity that resembles a Grand mal seizure. The third phase is an electrically quiet or "isoelectric" period. It has been suggested that the two latter phases represent the period of unconsciousness following electrical stunning. Gregory and Wotton (1987) studied the effects of different electrical stun settings on the EEG of broilers using a conventional 50 Hz sigmoidal alternating current.

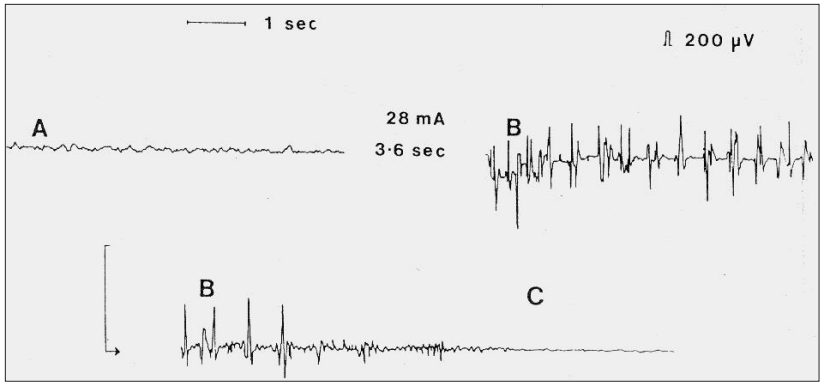


Figure 8.2.3.1 Electroencephalogram of a chicken that developed low frequency polyspike activity after electrical stunning. A is a sample of the period before stunning; B is the epileptiform phase; C is the quiescent phase. From Gregory and Wotton (1987). With permission.

They reported three types of EEG waveforms following stunning when using 20 to 143 mA per bird. The first waveform was low frequency and poly-spiked epileptiform activity (< 5 Hz) followed by a quiescent phase (Fig. 8.2.3.1) The poly-spiked activity was taken to be the typical response to a water bath stunning, which was observed in 16 of the 18 stunned broilers. The remaining two broilers showed high frequency epileptiform activity at approximately 6 Hz (Fig. 8.2.3.2).

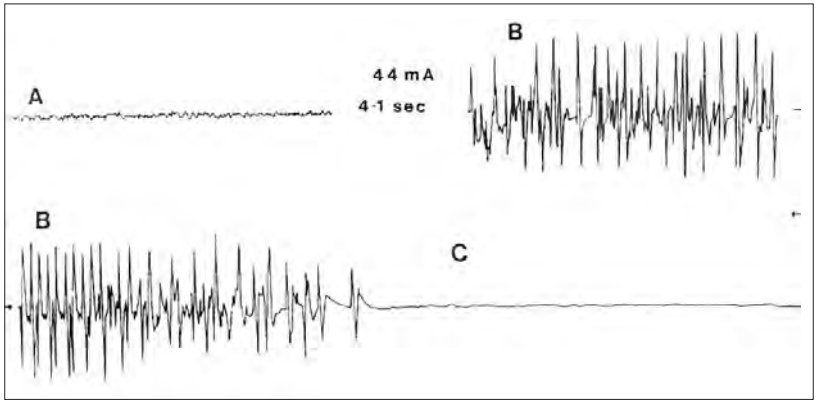


Figure 8.2.3.2 Electroencephalogram of a chicken that developed high frequency polyspike activity after electrical stunning. A is a sample of the period before stunning; B is the epileptiform phase; C is the quiescent phase. From Gregory and Wotton (1987). With permission.

The poly-spike ended abruptly and occurred, on average, 17 sec (between 8-36 sec) after the start of stunning. The poly-spiked activity was followed by a quiescent phase. The authors indicated that it was not possible to quantify the duration of this phase because the broilers were bled before normal EEG activity returned. The low frequency poly-spike activity, seen in the graph, was interpreted by the authors as a Petit mal epilepsy seizure. The authors mentioned that in red meat animals (sheep, pig), the hypersynchronization of EEG activity leads to high activity, in the range of 8 to 13 Hz, or a Grand mal epilepsy seizure followed by a flat isoelectric phase that indicates unconsciousness.

Figure 8.2.3.3 shows the waveform pattern in broilers that were stunned at higher currents (> 100 mA). Broilers that fibrillated showed poly-spiked brain activity that was suppressed to the extent that the EEG did not always show an epileptiform phase. Gregory and Wotton (1987) also determined the current necessary to cause a cardiac arrest when broilers were subjected to electrical stunning with sinusoidal AC at 50 Hz. This was done because it was suggested that electrical stunning (in a water bath), under certain conditions, can induce unconsciousness and fibrillate the heart simultaneously. This, in turn, has a potential animal welfare advantage over conventional stunning, which does not cause fibrillation, as fibrillation can result in a quicker kill, and it does not depend on the bleeding step. The authors studied voltages between 50 and 270 V to achieve a range of currents applied through the birds (at least 25 birds in each of the 30 mA increments). They also recorded heart activity (via electrocardiogram, ECG) immediately after stunning to determine whether there was a ventricular fibrillation. On average, the current received by broilers that fibrillated was twice that of non-fibrillated birds. As indicated above, the current required to produce fibrillation in 99% of the birds was 148 mA (95% confidence interval = 132 to 164 mA). The bird's live weight did not significantly affect the incidence of cardiac arrest. At currents of 30 to 60 mA, less than 5% of the broilers underwent fibrillation. As mentioned above, in the broilers that fibrillated, poly-spiked brain activity was suppressed to the extent that the EEG did not always show an epileptiform phase (Fig. 8.2.3.3). Such attenuated brain activity occurred in broilers that received a level of current > 100 mA. Similarly, poly-spiked activities were markedly reduced in broilers subjected to head only stunning when the current was > 100 mA. Overall, using high currents in water bath stunning was found to have two effects. First, there was attenuation of epileptiform expression. Second, there was an increased likelihood of inducing cardiac arrest. The inhibition of epileptiform activity was probably not due to the induction of cardiac arrest, since a similar effect occurred when broilers were stunned with comparable currents across the head and, thereby, did not experience cardiac arrest at all.

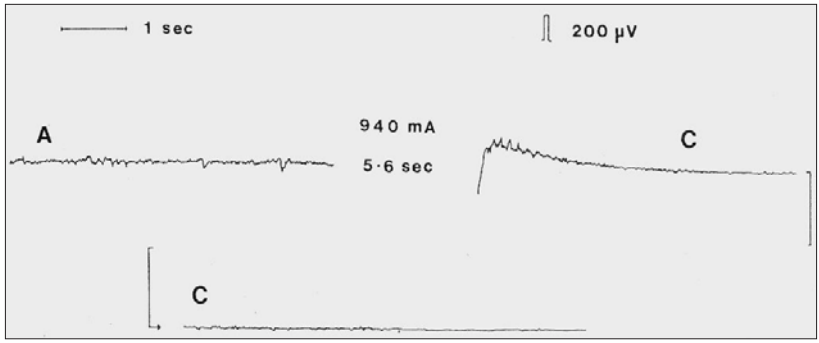


Figure 8.2.3.3 Electroencephalogram of a chicken that did not develop polyspike activity after electrical stunning. A is a sample of the period before stunning; B is the epileptiform phase; C is the quiescent phase. From Gregory and Wotton (1987). With permission.

Lambooij et al. (2010) used EEG to evaluate the electrical stunner for the head only, using pin electrodes, and reported that a general epileptiform insult was observed when a set current of at least 190 mA (approximately 100 V, 50 Hz) was applied for 0.5, 3, or 5 sec. This insult showed a tonic phase, followed by a clonic phase and an exhaustion phase, after which the birds recovered. On the basis of visual observation, these birds may have been unconscious for approximately 30, 44, or 65 sec, respectively. According to correlation dimension analysis scores (note: for more information on this scoring system see Coenen et al., 2007), these durations were 18, 12, and 16 sec, respectively. Within a confidence limit of 95%, taking into account the number of birds with a reliable EEG, the chance of an effective stun lies between 0.95 and 1.00 with an average current of 190 ± 30 mA. After stunning, the ECG revealed fibrillation and the heart rate decreased significantly ($P < 0.05$) but recovered thereafter. It was concluded that broilers were insensible and unconscious after head-only electrical stunning using pin-electrodes. Because broilers can rapidly regain consciousness, cutting the neck immediately after stunning is recommended (Lambooij et al., 2010; Raj, 2003). Prinz et al. (2010) also used EEG and showed that more than 80% of broilers stunned with 120 to 150 mA at 200 Hz or stunned with 100 mA at 70 to 100 Hz did not recover, showing that amperage and frequency interact with respect to stunning efficiency. Generally higher currents are needed with increasing frequency.

8.3. Gas Stunning

8.3.1 General

In the past, gas stunning was mainly used for large red meat animals (e.g., pigs). Although gas stunning of poultry was initially investigated in the 1950s (Kotula et al., 1957), it only started to appear in commercial plants in Europe in the 1990s. Interest in gas stunning for poultry was triggered by concerns that high voltage electrical stunning could result in defects (i.e., also related to the increased demand for cut up poultry meat where defects can be more visible) and challenges related to the use of automation. Schreurs et al. (1999) presented data that compared the incidence of haemorrhages in breast and thigh meat resulting from different stunning methods (Table 8.1.1). According to their data, CAS (two stages, CO_2 or Ar gas) resulted in lower incidences compared to high current electrical stunning (whole body at 100 V, 120 mA, and 50 Hz for 10 sec, or head only at 120 mA, 300 Hz, for 1 sec). Later, more studies and industry data were published that investigated the effects of different gas mixtures (Raj et al., 1998; McKeegan et al., 2007). The goal of those studies was to establish conditions that addressed welfare criteria while reducing meat defects.

As mentioned above, automation was another driver to develop CAS. Gas stunning does not require manual unloading and placing conscious birds on the shackle line. Therefore, it can improve working conditions and reduce injuries associated with removing live birds from their crates. Figure 8.3.1.1 shows a CAS system that employs an automated unloading system (i.e., tilting onto a moving conveyor belt). In this system, bruising is minimal because birds are not manually removed. Currently, there are a number of large scale stunning systems like this installed in Europe and other parts of the world. Other approaches include leaving the birds in their crates and sealing the truck in such a way that CO_2 or other gases can be introduced, or moving the crates off the truck and introducing gas by moving them through a tunnel or lowering them into a pit (CO_2 is heavier than air). This approach reduces stress associated with uncarting and shackling live birds prior to stunning and can be an important consideration as these steps can induce a significant stress response. This also points out the need for more comprehensive studies that evaluate stress levels associated with the whole process (i.e., unloading, shackling and stunning). Most studies today only focus on the stunning phase.

Low atmospheric pressure stunning (LAPS) is done by using a vacuum pump to remove oxygen and induce anoxia. Joseph et al. (2013) stated that although minimal research has been performed on LAPS, Purswell et al. (2007) reported

that it appeared to be an effective method for broilers. Currently, the system is not widely used but it has been tried in some plants in the USA. Purswell et al. (2007) reported arterial blood partial oxygen pressure decreased from 80 to 23 mm Hg when measured right after birds were removed from the system. As mentioned above, the question of when convulsions occur (before or after unconsciousness has been induced) and to what extent is also an important question for the LAPS process.

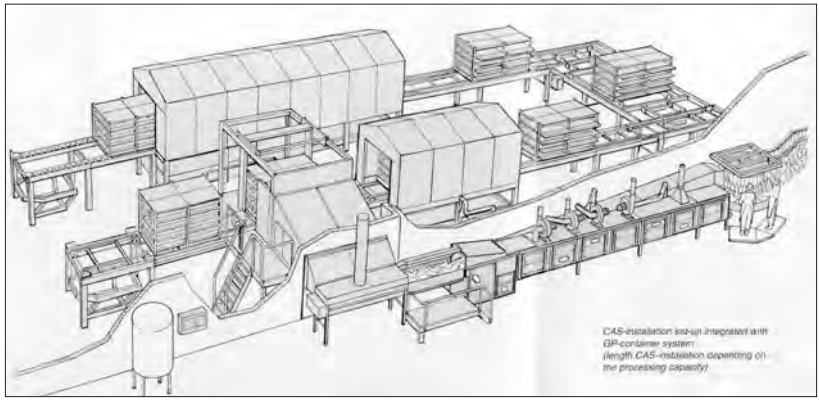


Figure 8.3.1.1 A gas stunning system. Middle – modules with birds arrive on a conveyer belt and then are gently tilted so birds are moved to the row close to the reader where the CAS tunnel is located. The far row is used for washing the modules. Courtesy of Stork Inc.

8.3.2 Settings

Over the past two decades studies dealing with different gas mixtures and low pressures (vacuum) have been published. The gases/gas mixtures mainly included carbon dioxide (CO_2), argon (Ar), nitrogen (N_2), and oxygen (O_2). In these cases, loss of consciousness (reversible or irreversible) can be due to hypoxia (lack of O_2), hypercapnic hypoxia (excess CO_2), hypercapnic anoxia (combination of the first two), hypercapnic hyperoxygenation (elevated O_2 level to ~ 30% together with enriched CO_2) or by low atmospheric pressure/depressurization (Hoen and Lankhaar, 1999; McKeegan et al., 2007; Coenen et al., 2009; Joseph et al., 2013). McKeegan et al. (2007) mentioned that although gas stunning can reduce some of the welfare problems associated with electrical stunning, it is important that the birds do not find the anaesthesia aversive and that the stunning will introduce minimal stress and pain to the bird. Raj (2003) also indicated a potential problem with reversible stun settings in that birds can regain consciousness shortly after

exiting the controlled gaseous atmosphere. Differences in the initial effects of various gases are known and, therefore, the gas/gas mixture should be introduced in the right concentrations and for the required times. Ar, for example, is an inert gas that can induce anoxia at a high concentration (e.g., > 90%, less than 2% O_2). CO_2, on the other hand, is an acidic gas that can be pungent to inhale at concentrations above 40% for both broilers and turkeys. The gas is also a potent respiratory stimulant that can cause breathlessness before loss of consciousness. From a welfare standpoint, this means that birds could experience an unpleasant sensation during the inhalation of a high concentration of this gas. For example, it was reported that three out of eight hens and six out of 12 turkeys showed an aversion to entering a chamber to obtain food plus water when it contained 72% and 47% atmospheric CO_2, respectively (Raj, 2003). Conversely, when Ar with less than 2% O_2 was used, six out of six hens and 11 out of 12 turkeys spontaneously entered the chamber. Finally, when the chamber contained 30% CO_2, 60% Ar, and 10% air, no aversion was seen in 80% of the turkeys entering the feeding chamber. Analysing the behaviour of broiler chickens exposed to an air stream with a certain gas mix while feeding, suggested mild or at most moderate immediate aversion to carbon dioxide in the form of reduced feeding and occurrence of headshakes (McKeegan et al., 2006). Enrichment with oxygen to 30% was associated with increased feeding time and reduced headshaking. In order to eliminate concern about high initial CO_2 concentrations, a mini system consisting of two-stages was used (Hoen and Lankhaar, 1999). In the first stage, an anaesthetic mixture of 40% CO_2, 30% O_2, 30% N_2 was used, while the second stage had a gas mixture consisting of 80% CO_2, 20% N_2 (i.e., to induce anoxia). Results from a similarly built system (Table 8.1.1) showed lower haemorrhage scores compared to high current electrical stunning. The results for the Ar treatment represent a system developed in Great Britain in which a mixture of 70% Ar and 30% CO_2 is used. Overall, the two gas stunning methods significantly lowered haemorrhage scores in thigh and breast meat as compared to the two electrical stunning methods tested in that study. Captive bolt stunning, also included in the comparison, caused lower haemorrhage scores compared to electrical stunning; however, it is not commonly used in large operations because of technical limitations that will be discussed later.

In a CAS system where broilers and turkeys are kept in cages, the cages can stay on the truck or be placed on a conveyor belt that either carries them to the stunning tunnel or lowers them into a pit where Ar or CO_2 are used. The conveyor speed is adjusted to achieve the required dwell time. The tunnel/pit is equipped with various safety devices to protect employees working in the area and CO_2 and Ar detectors are installed in the room to verify that employees are not exposed to dangerous levels.

After stunning, the unconscious birds are transferred to a moving shackle line, which is easier to operate and causes less downgrading than removing and transferring live birds. If birds are stunned in cages it is crucial that birds dead on arrival (DOA) are removed prior to stunning and do not enter the food chain as this is prohibited by regulatory agencies around the world. In such a system, plants must demonstrate that they can deal with DOAs. Figure 8.3.1.1 shows a system where the birds are placed on a moving conveyer belt that passes by an employee who watches the birds and their postures. This is more complicated with cages but must be done to ensure food safety. Another point that requires attention is the time from stunning to bleeding. If the time between the two is too long (e.g. when a full truck load is stunned at once), poor bleeding can result. Moreover, feather removal could become more difficult, as well as bearing the risk of dislocated wing joints (e.g., muscles get into rigor state).

Several reports have indicated differences in the rate of post mortem pH decline between electrical and gas stunning. Some researchers have shown that electrical stunning can temporarily delay rigor development (see also data in Table 8.1.1). Papinaho and Fletcher (1995) reported that a stunning current between 0 and 200 mA affected the rate of early rigor development, but had no effect on final meat quality. They reported higher breast meat pH for electrically versus gas stunned broilers and mentioned that electrical stunning is known for its inhibition of glycolysis (up to 6 hr) in broilers. Gas stunning methods that are associated with massive convulsive wing flapping, have been found to produce a more rapid post mortem pH drop in broiler and turkey breast meat (Raj, 2003), but after 8 hrs the pH of all samples reached about the same level (6.0). The results for breast meat glycogen content showed the same trend of slower glycolysis early in the post mortem period in electrically stunned birds. Water holding capacity (WHC) averages over time (note: averages were taken since no significant interactions between stunning method and time were found) showed that head only electrical stunning resulted in the highest water loss, while CO_2 stunning resulted in the lowest water loss from the post rigor meat. Similar trends can be seen in Table 8.1.1, where pH values after 4 hrs were similar for all treatments. Data at 8 hrs were very similar to the 4 hrs results (data for 8 hrs not presented here).

8.3.3 Study Effects on Consciousness

Stunning poultry with gas does not result in an instantaneous loss of consciousness and, therefore, it is important to ensure that the induction of unconsciousness is not stressful. Coenen et al. (2009) measured the effects of three gas mixtures with commercial applications:

a. anoxia with N_2 and < 2% residual O_2,
b. hypercapnic anoxia with N_2, 30% CO_2 and < 2% residual O_2,
c. a two phase stunning employing a hypercapnic hyperoxygenated anesthetic phase with 40% CO_2, 30% O_2, and 30% N_2 for 80 sec, followed by a euthanasia phase with 80% CO_2 in air.

The birds in the experiment were placed in a mini commercial unit (small version of a large scale commercial unit) consisting of two compartments (to allow two phase stunning). They entered the first compartment on a moving conveyor belt and spent an average 80 sec in that section. All broilers showed loss of posture in the first compartment. They were then introduced to the second compartment for 120 sec (note: a different gas mixture was only used for the third treatment, but all birds went through the two phases). Figure 8.3.3.1 shows the raw EEG and ECG recordings of all birds at baseline (45 sec) as well as during the first part of the euthanasia process (up to 105 sec). Artifacts, shown in the figure, started immediately after placing the birds in the system and were caused by physical movements of the birds (e.g., wing flaps, clonic convulsions, struggling), which were verified by comparing the EEG traces with behavioral recordings (detailed table provided in their original publication). Movement artifacts occurred over the entire duration of the first compartment, but their number and length strongly diminished with time. Movement artifacts were rare or absent in the second compartment. The data show that both the duration and total number of artifacts were lowest in the two phase group, where the gas mixture in the first compartment was hyperoxygenated.

Overall, the duration of artifacts was much longer than in the EEG traces, except in the two phase treatment. Statistics showed that the latter treatment differed significantly from the first two treatments in the extent of EEG artifacts. It was also apparent that ECG artifacts almost completely coincided with those seen in the EEG recordings (produced by obvious movements of the birds). However, ECG artifacts seen in birds receiving the anoxic treatments only partly coincided with the EEG artifacts. In general, the artifacts lasted much longer and were characterized by prolonged artifacts as opposed to several short disturbances. Behavioral observations indicated that these prolonged ECG artifacts coincided with convulsive activity (such as wing flapping) that was often followed by a distinctive posture in which the wings were held rigidly forward. This is thought to indicate tonic convulsion and, in particular, sustained contraction of the pectoralis muscle. Thus, the artifacts in the ECG recordings were composed of movement artifacts and artifacts caused by tonic convulsions. The results show that the two anoxia treatments (N_2 and N_2 + CO_2) induced considerable tonic convulsions, whereas this response was seen only once with the two phase approach. Moreover,

duration of wing flapping was observed to be much longer under anoxic conditions than at the two phase stunning. This also explains the rapid pH decline reported after anoxic gas stunning observed by other authors.

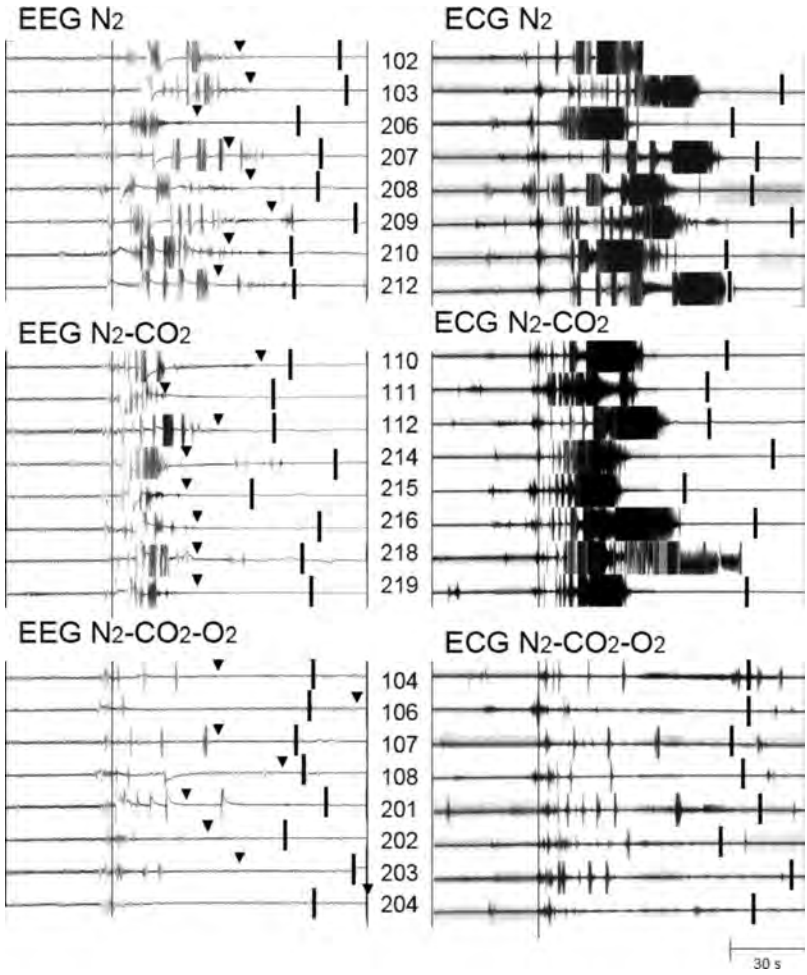


Figure 8.3.3.1 Electroencephalogram (EEG) recordings (left) and electrocardiogram (ECG) recordings (right) of chickens placed in the 3 treatment conditions (N_2; N_2 + CO_2; 2-phase with N_2- CO_2- O_2). The recordings were synchronized when birds entered the first compartment, as indicated by a continuous vertical line, representing approximately 45 s after the beginning of the recording (the baseline EEG and ECG). In the EEG recordings, the onset of isoelectricity is indicated by an arrow. The drop artifact (the transition between the first and second compartment) can be seen in variable positions in the right-central part of the recordings and is highlighted with a black vertical bar. From Coenen et al. (2009). With permission.

Unconsciousness is defined as the point where the EEG shows an isoelectric pattern. The authors indicated that death is the point when birds show an isoelectric EEG pattern with non-reversible properties. They mentioned that this is always so when the heart rate is extremely low (in chickens less than 180 beats per min). Onset of isoelectricity for each bird is shown by arrows marked in Figure 8.3.31. Statistics indicated no significant differences between groups, although the N_2 + CO_2 group tended to have the shortest time to isoelectricity. Overall, all three treatments effectively achieved non-recovery states; time to loss of consciousness for each bird was determined by a visual determination of the isoelectric EEG and by calculating the correlation dimension of the EEG. Hypercapnic anoxia resulted in rapid unconsciousness and an irreversible stunning; both anoxic treatments were associated with early onset prolonged wing flapping and sustained tonic convulsions as displayed in the electrophysiological recordings. These responses were seen in the period when consciousness remained a possibility. The two phase approach was associated with respiratory disruption, but this treatment eliminated initial clonic convulsions in the stunning process, and tonic convulsions were not seen. These results suggest that the presence of O_2 in the first stage of CAS is associated with an absence of potentially distressing behavioral responses. In this and their previous study (McKeegan et al., 2007; see additional discussion below), the authors argued that respiratory discomfort, although unpleasant, may be preferred to the risks of vigorous wing flapping and its associated injuries while birds are conscious and struggling.

Raj et al. (1998) also studied the effect of three gas mixtures on time to onset of changes in spontaneous EEG and the loss of stomatal sensory evoked potential (SEP). They evaluated:

a. argon (Ar) gas by itself
b. a mixture of 60% Ar, 30% CO_2 in air
c. a mixture of 40% CO_2, 30% O2, and 30% N_2

In 10 of the 16 birds it was shown that exposure to 100% Ar resulted in high amplitude low frequency (HALF) electrical activity, in the EEG, that started about 10 sec after exposure (Fig. 8.3.3.2). The other six broilers did not show HALF activity, and instead showed a gradual suppression in the amplitude of EEG signals. The average time to onset of EEG suppression was 17 sec (n = 16). All broilers showed intermittent convulsion after the onset of HALF activity or suppressed EEG. During the convulsive episodes, the EEG showed either epilepthiform activity (bipolar, high amplitude spikes; n = 4), high amplitude, low frequency activity (n = 7), polyspike activity (unipolar, high amplitude spikes; n = 2), or suppressed EEG (n = 3). An isoelectric EEG occurred, on average, 58 sec after exposure to the Ar gas.

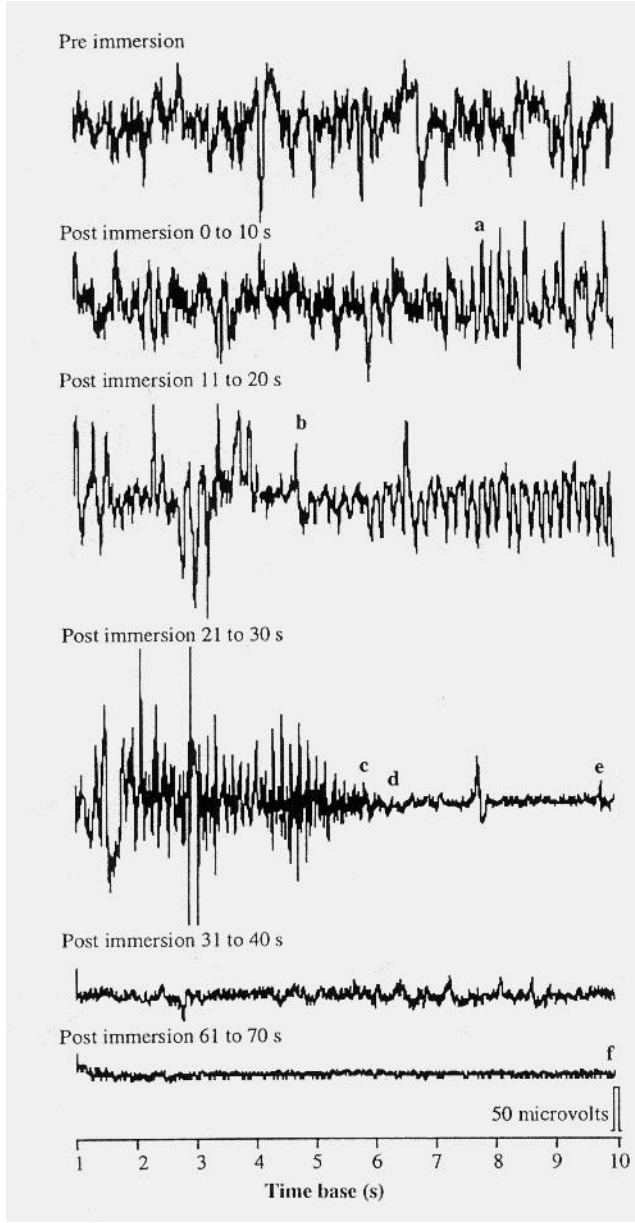


Figure 8.3.3.2 Changes in the spontaneous electroencephalogram (EEG) of a broiler during exposure to Argon with less than 2% oxygen (a = onset of HALF activity; b = onset of convulsions; c = end of convulsions; d = onset of EEG suppression; e = loss of SEP's; f = onset of isoelectric EEG).
From Raj et al. (1998). With permission.

For treatment (b), exposure to 30% CO_2 and 60% Ar in air, only one out of the 12 broilers showed HALF activity in the EEG (at 10 sec). However, all 12 broilers had suppressed EEGs (graph not shown here) and the average time to the onset of EEG suppression was 19 sec. All broilers showed intermittent convulsions after the onset of EEG suppression. During the convulsive episodes, the EEG showed either epileptiform activity (n = 6), polyspike activity (n = 4), or remained suppressed (n = 2). An isoelectric EEG occurred, on average, 41 sec after exposure to this gas mixture.

For treatment (c), exposure to 40% CO_2, 30% O_2 and 30% N_2 for 2 min, none of the 17 broilers showed HALF activity; instead, suppressed EEG with low frequency activity occurred on average 40 sec after exposure (Fig. 8.3.3.3). Only 3 out of the 17 broilers exposed to this mixture died (isoelectric EEG seen after 77, 83 and 93 sec), whereas in the other two gas mixtures, all birds died after 2 min. The 14 broilers that survived the 2 min exposure to the third gas mixture showed two types of electrical activity. The EEG remained suppressed in 8 out of the 14 broilers and in the other 6 broilers there were frequent bursts of unipolar, low frequency, high amplitude spikes that started occurring at random in the suppressed EEG as can be seen in Figure 8.3.3.3. In general, the amplitude of the spikes gradually increased during the initial stages of their development. Analysis of variance showed that the time to onset of EEG suppression was similar in the Ar by itself, and the CO_2 + Ar mixture (17 ± 1.9 sec and 19 ± 1.9 sec, respectively), and both were significantly shorter than the time to onset reported for the $O_2 + CO_2 + N_2$ mixture, which occurred 40 ± 2.3 sec after exposure. Based on the time to onset of EEG suppression, exposure of broilers to the first two gas mixtures resulted in a quicker loss of consciousness than during exposure to the last gas mixture, which has been suggested as an alternative for stunning broilers, followed by killing with a high concentration of CO_2.

The time to induce anaesthesia for each of the three gas mixtures was determined from the time required to lose stomatal sensory evoked potentials (SEP) in the brain. The mean time to lose SEP in broilers and turkeys exposed to Ar were 29 and 44 sec, respectively. For the Ar + CO_2 mixture times were reduced to 19 and 22 sec, respectively. The results indicate that the Ar + CO_2 mixture is more rapid than Ar alone in achieving a loss in brain function in both chickens and turkeys. However, the turkey brain appeared to be relatively more tolerant of anoxia than the chicken brain. Raj et al. (1998) indicated that the use of CO_2 for killing chickens does not seem to have a welfare advantage over using 90% Ar in air or 60% Ar + 30% CO_2 in air. For turkeys, times to lose SEP during exposure to 50, 65 or 85% CO_2 in air were reported to be 20, 15 and 21 sec, respectively. These times were not significantly different from the times measured when a mixture of Ar and CO_2 was used. The authors indicated that in commercial trials, turkeys

stunned and killed with Ar or an Ar + CO_2 mixture showed less breast muscle haemorrhaging and downgrading over turkeys stunned with 50 Hz sinusoidal AC electrical current.

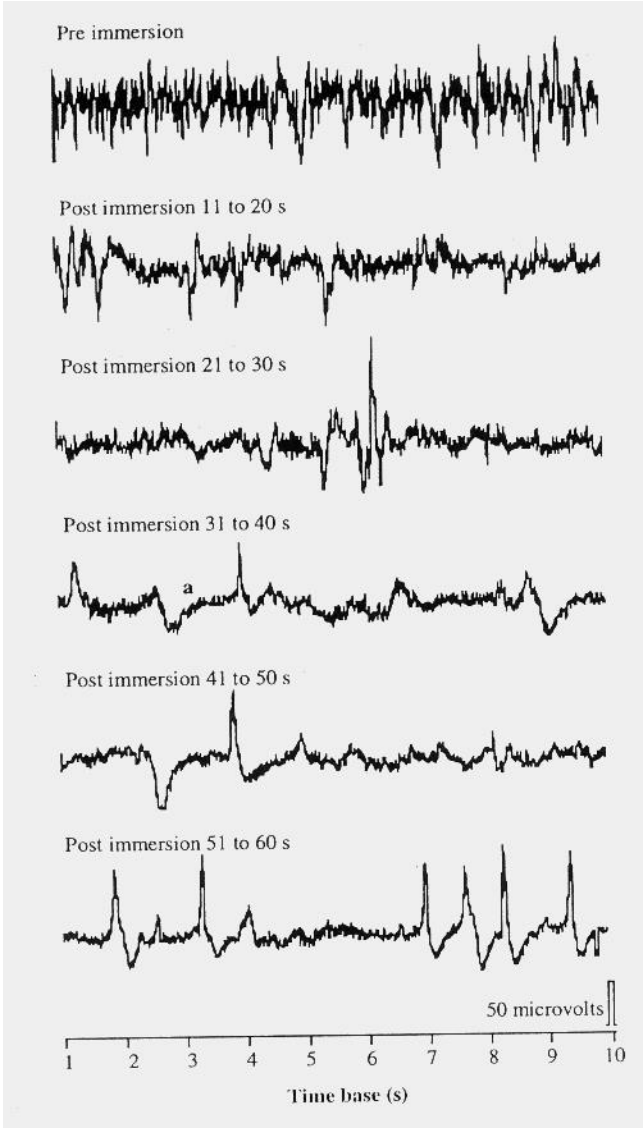


Figure 8.3.3.3 Changes in the spontaneous electroencephalogram (EEG) of a broiler during exposure to mixture of 30% oxygen, 40% carbon dioxide and 30% nitrogen (a = onset of suppressed EEG with random spike activity). From Raj et al. (1998). With permission.

McKeegan et al. (2007) evaluated the welfare implications (likelihood of an induced negative state or experiences during the conscious phase) of three treatments:

a. induction of anoxia with either N_2 or Ar; both with < 2% residual O_2,
b. hypercapnic anoxia with either 30% CO_2 in Ar or 40% CO_2 in N_2,
c. a biphasic method employing 40% CO_2, 30% O_2, 30% N_2 for 60 sec, followed by 80% CO_2 in air.

Anoxic mixtures induced vigorous wing flapping (graphic presentation is provided in the paper), and EEG analysis using the correlation dimension (i.e., a non-linear measure of complexity) suggested that anoxic wing flapping occurred during periods in which a form of consciousness could not be excluded. Hypercapnic mixtures were associated with strong respiratory responses. The biphasic approach exacerbated respiratory responses but eliminated the possibility of vigorous behavioural responses occurring during a conscious phase. As indicated above, the authors have stated that respiratory discomfort may be preferable to the risks of vigorous wing flapping and its associated injuries in poultry conscious during CAS.

8.4 No Stunning

Certain traditional slaughter practices forbid stunning as part of religious laws. The most well-known practices are the Jewish and Muslim regulations (known as Kosher and Halal, respectively), which indicate that animals cannot be stunned and should die by bleeding only. However, it should be mentioned that some Muslim authorities have accepted high frequency stunning of poultry that causes a reversible stun rather than cardiac arrest prior to religious slaughter. Slaughtering without stunning is performed by a trained person using a very sharp knife to cut the jugular veins. During the process, a blessing is cited and the whole process should be done very quickly to prevent animal suffering (Regenstein et al., 2003). As mentioned earlier, under these religious or ritual slaughter procedures, animals must be killed under strict guidelines, many of which are based on solid health and sanitary principles. For example, animals acceptable for food must be killed and may not be allowed to die by a disease or accident. The same principles are used for today's inspection regulations performed by non-religious government bodies. Velarde et al. (2014) evaluated current practices for the Halal and Kosher slaughter of poultry, cattle, and sheep. Information was collected by visiting religious slaughter abattoirs in Australia, Belgium, Germany, Italy, the Netherlands, Spain,

Turkey, and the United Kingdom. To standardize the information, a questionnaire was designed for each species. The results showed differences in the time from restraining to cutting, bleeding times, and cutting procedures.

8.5 Mechanical Stunning

Mechanical means of stunning, including concussion, are common in large, red meat animals (e.g., cows, steers) but not poultry. Currently, there are no large scale mechanical stunning systems in use for poultry because of the welfare and logistical difficulties of precisely positioning the bird's head on a high speed line. In general, the lack of a fast, suitable head fixing device, required for animal welfare, has prevented commercial application/development of such a system for broilers, turkeys, or ducks. In addition, this stunning method requires adequate restraint of the birds to prevent carcass damage that may occur during post-stun convulsions (e.g., wing flapping) while the birds are on the shackle line. Over the past few years a European company has been trying to develop a system that includes head and body restraints, mainly for high speed electrical head only stunning; however, the system has yet to be proven economical/viable.

Table 8.1.1 shows that captive bolt stunning with adequate head and body restraints results in comparable haemorrhage scores to gas stunning. Lambooij et al. (1999) evaluated captive bolt stunning of broilers using a pneumatically propelled solid captive bolt (5 mm in diameter and 25 mm penetration depth) or a similarly propelled hollow bolt (needle) that injected compressed air (2 atm) into the skull. Although the main objective was to determine the effects of captive bolt stunning on carcass and meat quality, the researchers also evaluated the effectiveness of this type of stunning. They concluded that these devices are acceptable in terms of bird welfare. However, more studies are needed to evaluate whether captive bolt stunning induces an immediate loss of consciousness and sensibility in poultry species, and to determine the effects associated with the dimensions and velocity of the bolt.

8.6 Neck Cutting and Bleeding

Following stunning (electrical, gas, mechanical), blood vessels in the animal's neck are cut. In North America, the carotid arteries and jugular veins are usually cut on both sides by a deep ventral cut within 8 to 12 sec of electrical stunning. This is usually done using automatic equipment and backup personnel. Ensuring

rapid blood drainage causes anoxia and usually prevents birds from regaining consciousness during the subsequent 80-90 sec bleed time. In Europe, neck cutting is usually performed dorsolaterally or on one side only. Because the rate of blood loss is slower, bleed times are usually extended to 120-180 sec (Bilgili, 1999). This type of cut often leaves some blood supply to the brain, which gives birds the opportunity to regain consciousness if the cut or bleeding is incomplete. From an animal welfare standpoint, this potential to regain consciousness has been a major reason that 100 mA per bird (i.e. an instantaneous and irreversible stun) has been mandated in Europe (EU, 2009). In contrast with Europe, electrical currents in North America have traditionally been in the range of 25-45 mA per bird, as explained earlier in the chapter. In Europe, concerns over a deep bilateral neck cut, which can often sever the trachea and might cause the head to be pulled off in the picker, have also prevented processors from using this technique in the past.

The time between stunning and neck cutting should be closely monitored to ensure adequate bleeding (see Chapter 5 for more details). It is usually recommended that neck cutting occur within 10 sec of electrical stunning, especially if a low current is applied. The time between gas stunning and neck cutting would be longer than that for electrical stunning because the birds are in crates or on a conveyor belt and have to be transferred to the shackle line. Although research has shown that the efficiency of bleeding in broiler chickens is not impaired when neck cutting is done immediately after gas stunning/killing (e.g., can be a few min), a long delay could increase the prevalence of downgrading associated with poor bleeding. By contrast, delayed neck cutting (after gas killing) of turkeys does not impede blood loss as much. The difference between chickens and turkeys may be attributable to a difference in carcass cooling rate, but other factors may also be involved (Raj and Johnson, 1997). Usual blood loss represents about 4-5% of the total body weight (i.e., some blood stays in the carcass). However, the initial rate of bleeding has been shown to be slower in birds that were killed rather than stunned, due to the lack of sharp reduction in heart activity. Considering the minimum legislated bleed out time in the US, 90 sec for broilers and 120 sec for turkeys, the industry should be able to achieve a satisfactory bleed out via a bilateral cut (Gregory and Wilkins, 1989b).

Another concern is that birds killed by inducing cardiac arrest, during electrical or gas stunning, might not bleed out adequately since their wings might hang too low, resulting in a stagnation of blood in their wing veins. Such situations could exacerbate the presence of engorged wing veins and noticeable haemorrhages associated with the massaging of the plucking machine. In fact, stunning currents that induce ventricular fibrillation can be associated with a higher incidence of red wing tips and haemorrhaging in the shoulders and wings.

In case of waterfowl, Fernandez et al. (2010) compared four methods to stun ducks and three methods for geese while also examining bleeding efficiencies, pH drop, meat texture, and sensory characteristics. They evaluated water bath stunning (50 Hz AC, 130 mA for 4 sec), head only electrical stunning (50 Hz AC, 600 mA for 4 sec), mechanical stunning (captive bolt) and CAS (two phases as described earlier in the chapter). For geese, the head only method was not used. Compared to CAS and water bath methods, mechanical stunning allowed the highest recovery of blood in geese. In ducks, water bath stunning resulted in the lowest bleeding efficiency. During the first 5 min after slaughter more convulsions and wing flapping were seen in the mechanically stunned birds and there were higher incidences of head movement in the electrical head only stunning as well as the captive bolt method in both ducks and geese. Meat texture, assessed instrumentally, and drip loss were not affected by the stunning method.

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9

PORTIONING, DEBONING AND FRESH MEAT COMPOSITION

9.1 Introduction and Classifications

Increased marketing of portioned and deboned meat (Chapter 2) has resulted in an increased demand for mechanical cutting up and deboning operations. Currently, various setups are available to the meat processor, ranging from a simple cone line (i.e., a carrier that helps manual deboning) to fully automated equipment to cut up and debone the whole carcass. Marketing of cut-up poultry (Table 9.1.1) has also resulted in more frames and trims left behind at the processing plant, which has opened the market for equipment that mechanically debones meat (discussed below).

Table 9.1.1 Examples of prepared cut up poultry portions available at retail.

	Description	Comments
1	Front quarter	See drawing below
2	Hind quarter	Leg and back attached
3	Thigh	Skin on/off
4	Breast quarter / halves	Bone in/boneless; skin on/off
5	Whole wing	Popular for BBQ
6	Wing drumette	Common for fast food
7	Nine piece cut	Common for fast food
8	Back	Mainly for soup
9	Giblets	Liver, heart, gizzard
10	Paws	Chicken/duck bottom leg

Different classification systems for poultry are used around the world and are very important for communication between sellers and buyers. An example of a

classification system used in the USA is provided below (USDA, 2014). It shows various classes of poultry:

a. Chickens

(i) Rock Cornish game hen or Cornish game hen is a young immature chicken (less than 5 weeks of age), of either sex, with a ready-to-cook carcass weight of not more than 2 pounds.
(ii) Broiler or fryer is a young chicken (less than 10 weeks of age), of either sex, that is tender-meated with soft, pliable, smooth-textured skin and flexible breastbone cartilage.
(iii) Roaster or roasting chicken is a young chicken (less than 12 weeks of age), of either sex, that is tender-meated with soft, pliable, smooth-textured skin and breastbone cartilage that is somewhat less flexible than that of a broiler or fryer.
(iv) Capon is a surgically neutered male chicken (less than 4 months of age), that is tender-meated with soft, pliable, smooth-textured skin.
(v) Hen, fowl, baking chicken, or stewing chicken is an adult female chicken (more than 10 months of age), with meat less tender than that of a roaster or roasting chicken and a nonflexible breastbone tip.
(vi) Cock or rooster is an adult male rooster with coarse skin, toughened and darkened meat, and a nonflexible breastbone tip.

b. Turkeys

(i) Fryer-roaster turkey is an immature turkey (less than 12 weeks of age), of either sex, that is tender-meated with soft, pliable, smooth-textured skin, and flexible breastbone cartilage.
(ii) Young turkey is a turkey (less than 6 months of age), of either sex, that is tender-meated with soft, pliable, smooth-textured skin and breastbone cartilage that is less flexible than that of a fryer-roaster turkey.
(iii) Yearling turkey is a turkey (less than 15 months of age), of either sex, that is reasonably tender-meated with reasonably smooth-textured skin.
(iv) Mature or old turkey is an adult turkey (more than 15 months of age), of either sex, with coarse skin and toughened flesh. Sex designation is optional.

c. Ducks

(i) Duckling is a young duck (less than 8 weeks of age), of either sex, that is tender-meated and has a soft bill and soft windpipe.
(ii) Roaster duck is a young duck (less than 16 weeks of age), of either sex, that is tender-meated and has a bill that is not completely hardened and a windpipe that is easily dented.
(iii) Mature duck or old duck is an adult duck (more than 6 months of age), of either sex, with toughened flesh, a hardened bill, and a hardened windpipe.

d. Geese

(i) Young goose is an immature goose, of either sex, that is tender-meated and has a windpipe that is easily dented.
(ii) Mature goose or old goose is an adult goose, of either sex, that has toughened flesh and a hardened windpipe.

e. Guineas

(i) Young guinea is an immature guinea, of either sex, that is tender-meated and has a flexible breastbone cartilage.
(ii) Mature guinea or old guinea is an adult guinea, of either sex, that has toughened flesh and a non-flexible breastbone.

This chapter describes the portioning, deboning, and sorting of cut-up poultry prior to tray packing. Although there are different types of poultry (chicken, turkey, duck), the cutting is mostly similar. In addition, a discussion on the composition of fresh meat is provided.

9.2 Whole Bird Cutting

9.2.1 Basic Poultry Cuts

Consumers today have the option of buying the whole bird or cut up parts (e.g., wings, legs, breast fillets). The names of the major parts, including major bones, are shown in Figure 9.2.1.1. Depending on the market, poultry can be sold live, as an eviscerated whole carcass (with or without giblets; see Table 9.1.1), split into halves or quarters, or as separate pieces (e.g., wings or legs), with or without bones and skin.

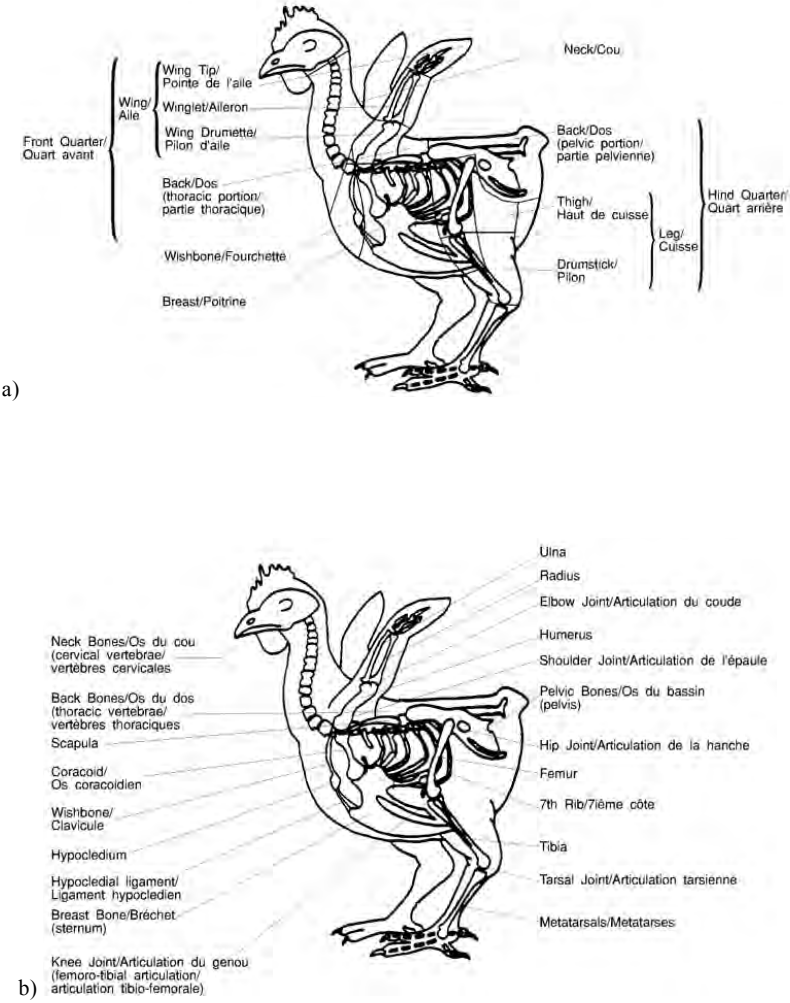


Figure 9.2.1.1 Illustration of major poultry parts a), and major poultry bones b). From CFIA (2012).

In this section, examples of the North American system and then the Japanese system are presented to illustrate broiler cutting. While there are many similarities between the systems, each is designed to serve a specific market. A detailed description of the actual meat cut nomenclature and description of poultry cutting parts listed by the North American/Canadian Food Inspection Agency (CFIA, 2012) are provided below:

a. Poultry: is meat derived from dressed carcasses of birds as defined by the Meat Inspection Act and Regulations. Note: the name of the bird species from which the meat is derived is required to appear in the product description in lieu of the word poultry.

b. Dressed poultry carcass (whole poultry): means a poultry carcass from which the feathers, hair, head, the feet at the tarsal joints and uropygial gland have been removed and the carcass has been eviscerated.

c. Poultry half (half poultry): means one of the two approximately equal portions of a dressed poultry carcass obtained by cutting through the backbones (thoracic vertebrae), pelvic bones (pelvis) and keel bone (sternum) along the median line. Note: the poultry half shall exclude the neck. See Figure 9.2.1.2.

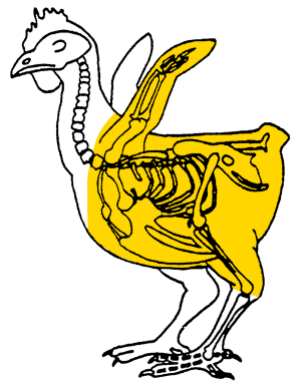
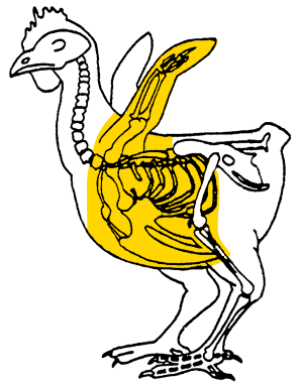
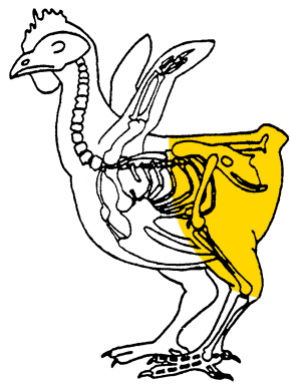


Figure 9.2.1.2 Illustrations of poultry portions as described in the CFIA 2012. Note: below are drawings showing various portions within the appropriate sections (sections c to q).

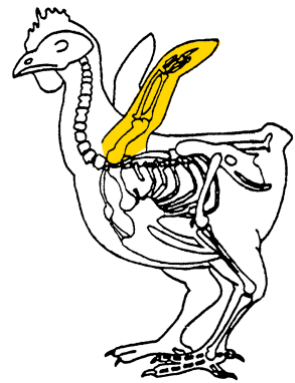
d. Front quarter (breast quarter): means the front (anterior) portion of a poultry half obtained by cutting immediately behind (posterior to) and parallel to the rib cage (posterior to the seventh thoracic vertebra, seventh rib and sternum).



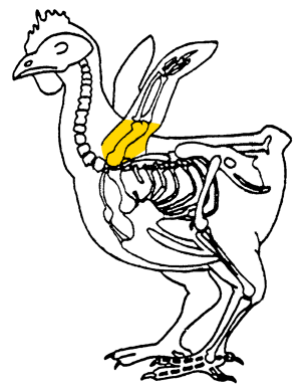
e. Hind quarter (leg quarter) (chicken leg, back attached): means the hind (posterior) portion of a poultry half which is separated from the front quarter as described above. Note: the term leg, back attached may also be used to identify this cut.



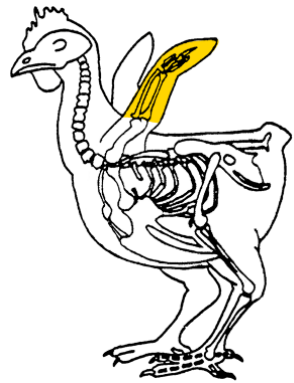
f. Wing: means that portion of the whole poultry obtained by cutting through the shoulder joint (articulation between the clavicle, coracoid and humerus). It includes the wing drumette, the winglet and may include the wing tip.



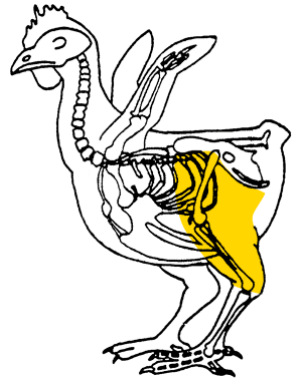
g. Wing drumette: means that proximal portion of the wing which is separated from the whole poultry by cutting through the shoulder joint as described, and from the winglet by cutting through the elbow joint (articulation between the humerus and radius/ulna). Note: the wing drumette shall not be referred to as drumstick.



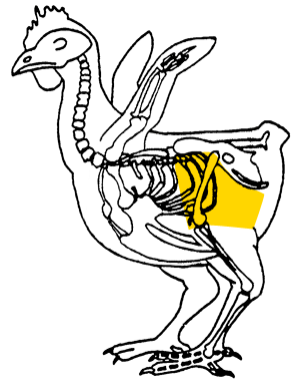
h. Winglet (v-wings): means that distal portion of the wing obtained by cutting through the elbow joint (articulation between the humerus and radius/ulna). Part of the wing tip may be removed.



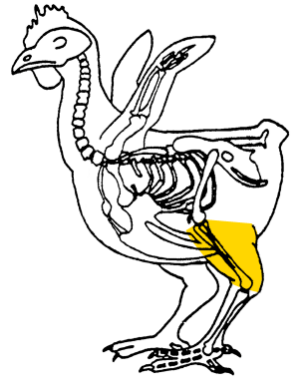
i. Leg: means that portion of the whole poultry obtained by cutting at the natural seam through the hip joint (articulation between the femur and the pelvis). It includes the thigh and drumstick jointed or disjointed and may include pelvic meat. It excludes pelvic bones, back skin, abdominal skin and excessive fat.



j. Thigh: means that proximal portion of the leg which is separated from the whole poultry by cutting at the natural seam through the hip joint as described, and from the drumstick by a straight cut through the knee joint (femoro-tibial articulation). It may include pelvic meat but shall exclude pelvic bones, back skin, abdominal skin and excessive fat.

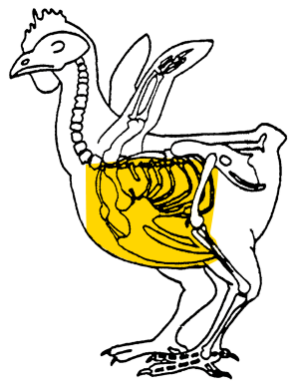


k. Drumstick: means that distal portion of the leg which is separated from the thigh by a straight cut through the knee joint as described above.

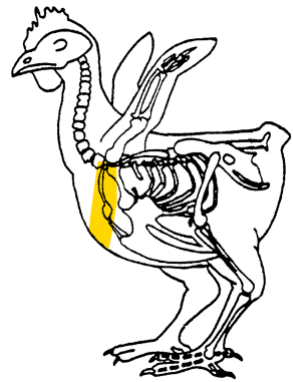


l. Breast (full breast): means that portion of the whole poultry which is separated from the wing by cutting through the shoulder joint, from the neck by cutting approximately through the twelfth neck bone (cervical vertebra), from the back by cutting through the ribs at the junction of the vertebral ribs and back and from the hind quarter by cutting immediately behind (posterior to) the rib cage (seventh rib and sternum). The breast includes the "Y" shaped ends of the ribs and excludes the neck skin.

m. Half breast: means one of the two approximately equal portions of a breast obtained by cutting through the breast bone (sternum) along the median line. Note: the breast may be portioned in two approximately equal parts (half breast) as described or in three parts by first removing the wishbone (see below) portion then by cutting the breast bone (sternum) along the median line. For exact weight-making purposes, these parts may be substituted for lighter or heavier pieces and the package may contain two or more of such parts without affecting the appropriateness of the product description as breast.

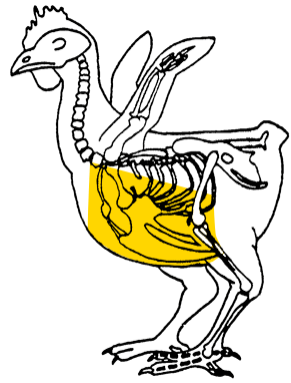


n. Wishbone: means that front (anterior) portion of the breast obtained by a cut passing through the hypocledial ligament located between the tip of the wishbone (hypocledium) and the front point of the breast bone (carinal apex of the sternum), then between the wishbone (clavicle) and coracoid up to a point where the wishbone (clavicle) joins the shoulder. The neck skin shall be excluded.

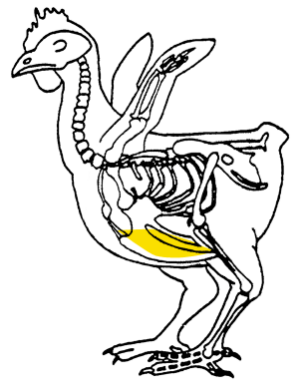


o. Trimmed breast: means that portion of the breast obtained by a cut passing along the junction of the vertebral and sternal ribs. The sternal ribs may be removed and the neck skin shall be excluded. Note: the trimmed breast may be portioned in two approximately equal parts (half trimmed breast) as described below, or in three parts by first removing the wishbone portion as described, then by cutting the breast bone (sternum) along the median line. For exact weight making purposes these parts may be substituted for lighter or heavier pieces and the package may contain two or more of such parts without affecting the appropriateness of the product description as trimmed breast.

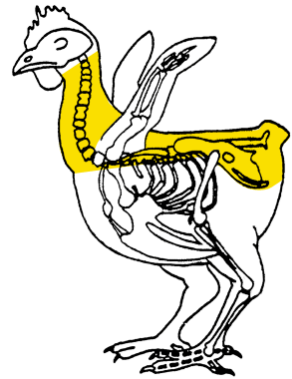
p. Half trimmed breast: means one of the two approximately equal portions of a trimmed breast obtained by cutting through the breast bone (sternum) along the median line.



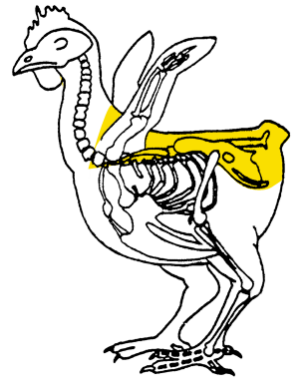
q. Breast fillet: means that round, elongated fusiform muscle, (supra coracoid muscle or deep pectoral) found on each side of the keel bone (sternum).



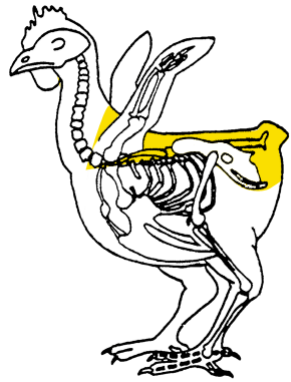
r. Whole back: means that portion of the whole poultry which is separated from the breast as described above. It includes the neck, thoracic vertebrae, pelvic bones and tail. It may include parts of the vertebral ribs.



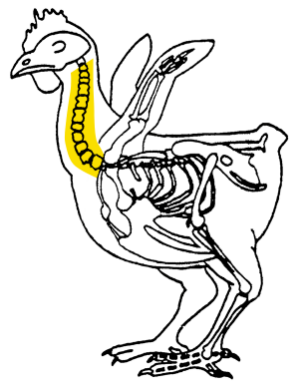
s. Back: means that portion of the whole back which is separated from the neck by cutting in the vicinity of the shoulder joint (approximately through the twelfth cervical vertebra). It includes the thoracic vertebrae, pelvic bones and tail, the skin and adhering meat. The vertebral ribs and/or scapula may be removed.



t. Stripped back: means the back from which the meat adhering to the pelvic bones has been removed.



u. Neck: means that front (anterior) portion of the whole back or carcass obtained by cutting near the shoulder joint (approximately through the twelfth cervical vertebra). It may include the skin.



v. Poultry giblets: means the liver, the heart or the gizzard or any combination thereof of the same species, obtained from a dressed poultry carcass.

w. Ground poultry: means fresh, boneless, skin on/skinless comminuted poultry meat that has a fat content identified by one of the following terms:

Regular – 30%
Medium – 23%
Lean – 17%
Extra Lean – 10%

Figure 9.2.1.3 is an example of cut up parts from a pamphlet used to identify poultry cuts going into trade. The guide is used to show customers the exact parts used in trade.

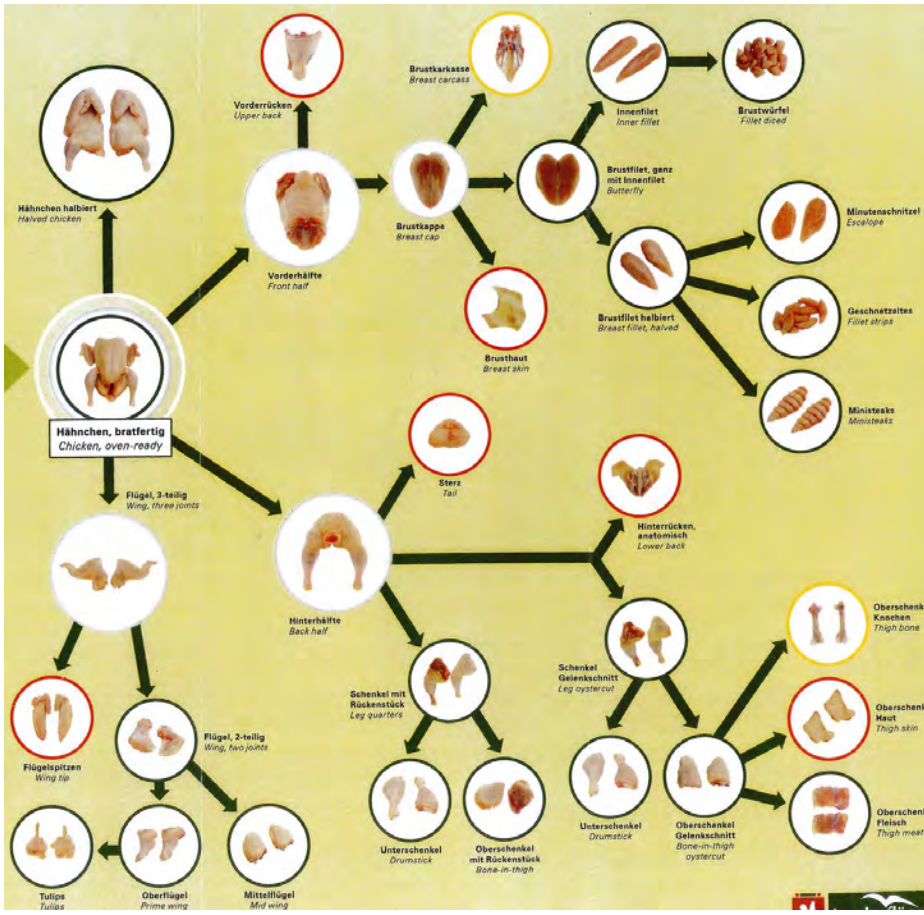
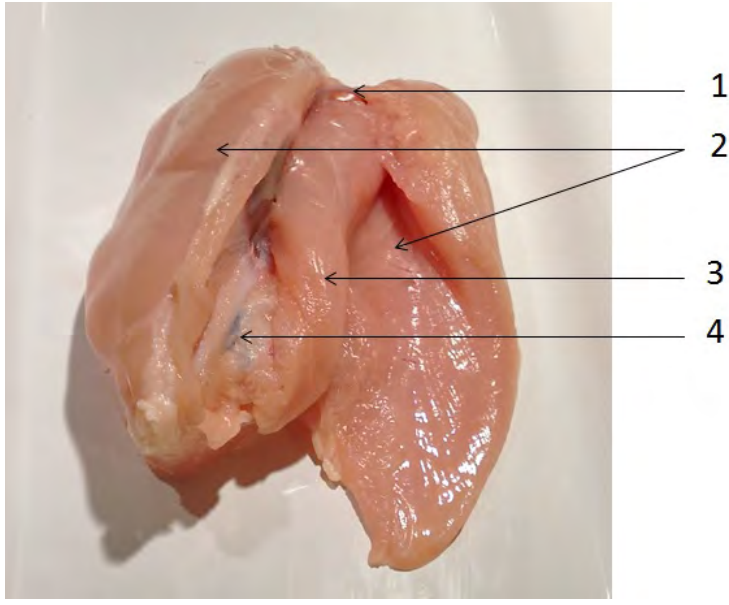


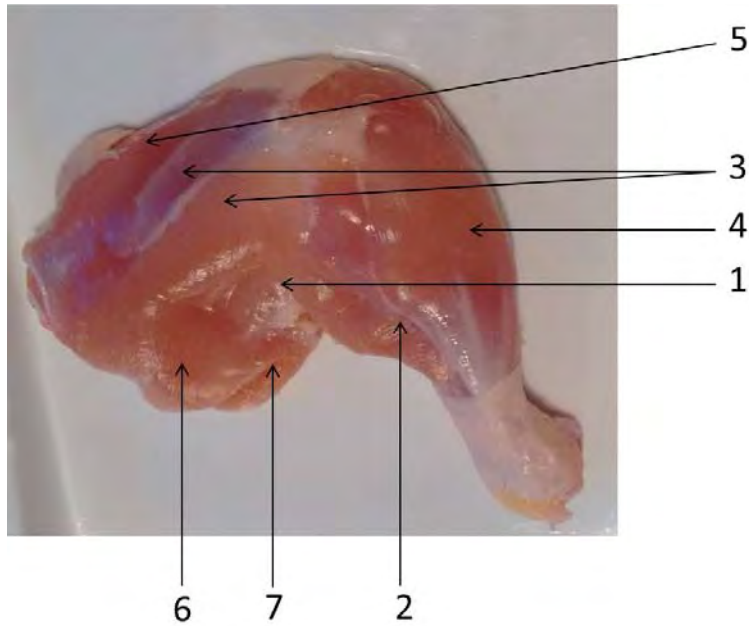
Figure 9.2.1.3 Poultry portions and their names in English and German. Courtesy of Emsland Frischgeflugel.

Another example is the Japanese Yellow Book which contains pictures (not shown here, but can be viewed on the internet) and very precise portion descriptions that serve as the basis of communication between sellers and buyers. The Japanese guide is used a lot within the country but also when dealing with companies exporting to Japan where it is common to sell cut up poultry to supermarkets in 2 kg bags (i.e., re-packaging can take place at the supermarket according to changing market needs). Overall, this case is different from the European and North American markets where final packaging is usually done at the plant level.

Figure 9.2.1.4a illustrates the muscles included in the breast meat portion of poultry (e.g., chicken, turkey, duck). As mentioned in Chapter 3, there are differences in the type of fibers in these muscles: migratory birds such as wild ducks have a high proportion of red fibers, while non- migratory birds such as chickens have a high proportion of white fibers that are ideal for short flights (see also Swatland, 1994). Figure 9.2.1.4b shows the leg muscles after the skin has been removed.

a)





b)

Figure 9.2.1.4 Major muscles and bones included in the breast meat portion (a), and in the leg meat portion of a broiler (b), shown after skin removal. For breast meat portion: (1) clavicle bone, (2) *Pectoralis*, (3) *Supracoracoideus*, (4) sternum bone. For leg portion: (1) *Biceps femoris*, (2) *Gastrocnemius*, (3) *Iliotibials*, (4) *Peroneus longus*, (5) *Sartorius*, (6) *Semitendinosus*, (7) *Semimembranosus*. Based on Swatland (1994). See also illustration of muscles in Chapter 3. Photos by Barbut.

9.2.2 Traditional Manual Cutting

Manual cutting and deboning of poultry has been exercised for thousands of years and can still be observed in small operations or where labour costs are low. Deboning is commonly done on a cutting board, or on a deboning cone (Fig. 9.2.2.1). The cone can be stationary, where an employee positions and cuts one entire bird at a time, or on a moving line, where employees are responsible for making one or a few cuts. The deboning process usually starts by removing the wings and then the breast meat (with/without skin). This can be done by cutting the anterior ends of the *pectoralis* muscle (Fig. 9.2.1.4a) and pulling it away from the bone. This usually leaves the small *supracoracoideus* attached to both sides of the sternum, from where they can be manually pulled. These small strips are

often sold as broiler/turkey "tenderloins". Later, the thighs can be removed by first cutting the abdominal skin, followed by cutting through the femur-pelvis joint. If the final product is skinless, then the skin would be taken off prior to removing the leg. The leg section can be separated into the drumstick and thigh by cutting through the femoro-tibial joint (see Fig. 9.2.1.4b). Boneless thigh meat can be obtained by removing the femur bone as well as the major ligaments.



Figure 9.2.2.1 Cone system used to assist manual deboning of poultry meat.

9.2.3 Automation in cutting and deboning

Automated, high-speed cutting equipment (Fig. 9.2.3.1) has been gaining popularity with the increased demand for boneless poultry meat. The system shown in Figure 9.2.3.2 can debone 3,600 breast caps per hour. It is interesting to examine the history of these systems on the market, as the equipment shown here is a 5th or 6th generation machine. An important driver in the development of automated equipment is the imbalance in demand for light and dark meat. In places such as North America, there is a very high demand for light meat (Chapter 2), whereas in places like Japan the demand for dark meat is higher. Processors are often left with whichever is less popular.

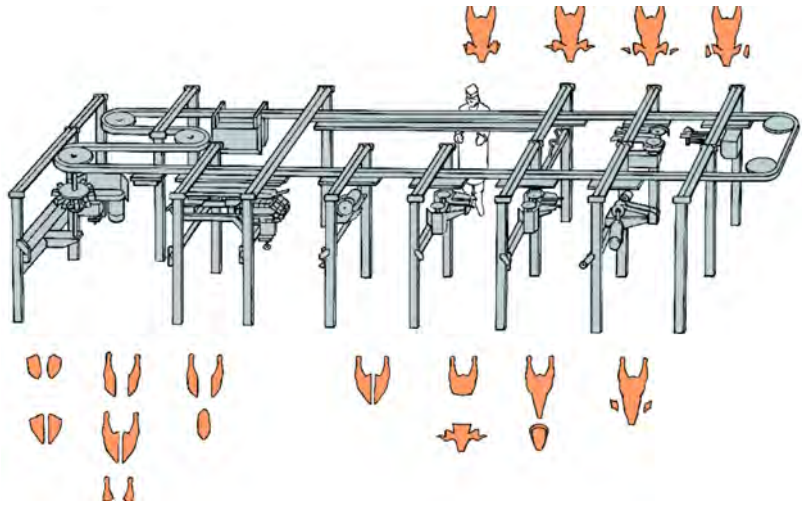


Figure 9.2.3.1 An example of a compact leg deboning system starting from back halves. Module parts include the following: back half feeding, anatomic leg cutting module, whole leg skinning module, right-hand thigh deboning module, left-hand thigh deboning module, left-hand thigh meat harvesting module, right-hand thigh meat harvesting module, drumstick cutting module, drumstick deboning module and drumstick meat harvesting module.
Courtesy of Stork.

In North America and Europe, deboning the dark meat and incorporating it in further processed or marinated products, or selling it as boneless meat, are important steps in obtaining a higher margin on dark meat. The equipment should provide high output and precise deboning (e.g., no/low occurrence of bone chips). The design of automated deboning equipment represents a significant challenge to the manufacturer because it should be capable of handling birds of different sizes and configurations with the same high yield. This is also the reason processors are looking for flocks with low variation among birds. It should also be mentioned that new modules are currently developed for new end products (e.g., tendon harvester and cartilage harvester, which were considered 'waste' a few years ago). A few examples of equipment and concepts currently used for cutting up and deboning poultry are provided in this section.

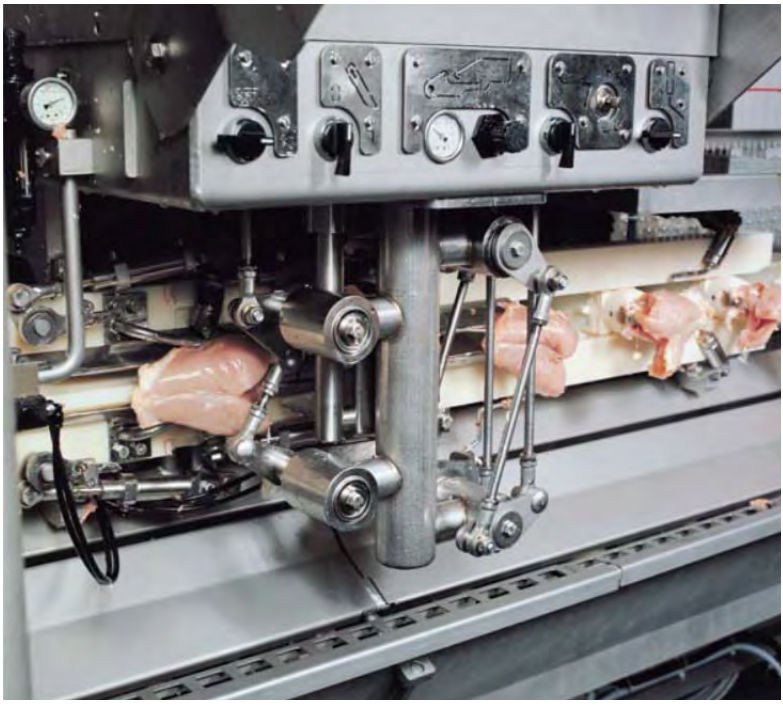


Figure 9.2.3.2 Automated breast meat deboning. Courtesy of Stork.

Figure 9.2.3.3 shows a leg quarter portioner used to cut the back half of poultry into leg quarters. A spring-loaded centric guidance assembly stretches and centers the back half (i.e., after the front half has been separated) and then a circular knife rotating in the opposite direction separates the back half into two quarters. Alternatively, the back can be cut out using double knives. The machine can process a few thousand pieces an hour. Usually, this operation is part of a larger process used to split the carcass into different portions.

Figure 9.2.3.4 shows an advanced whole leg automatic deboning operation. The different cutting steps are shown in the figure. Each operation mimics the activities of a skilled worker, but, according to the manufacturer, can accomplish the task ten times faster. A major consideration in the design and operation of the equipment is to minimize cartilage and bone fragments in the final product while still obtaining a high yield. To do so, the machine first measures the precise length of the leg bones and calculates cutting parameters before cutting the meat. This is an example of a high precision cutting machine that is mainly used to debone leg meat for the Japanese market where the customer is looking for a whole leg meat deboned

without a hole in the knee cap area. This obviously makes both the equipment and the final product more expensive. Such automated equipment also helps reduce "repetitive motion injuries" suffered by employees that perform the job manually.

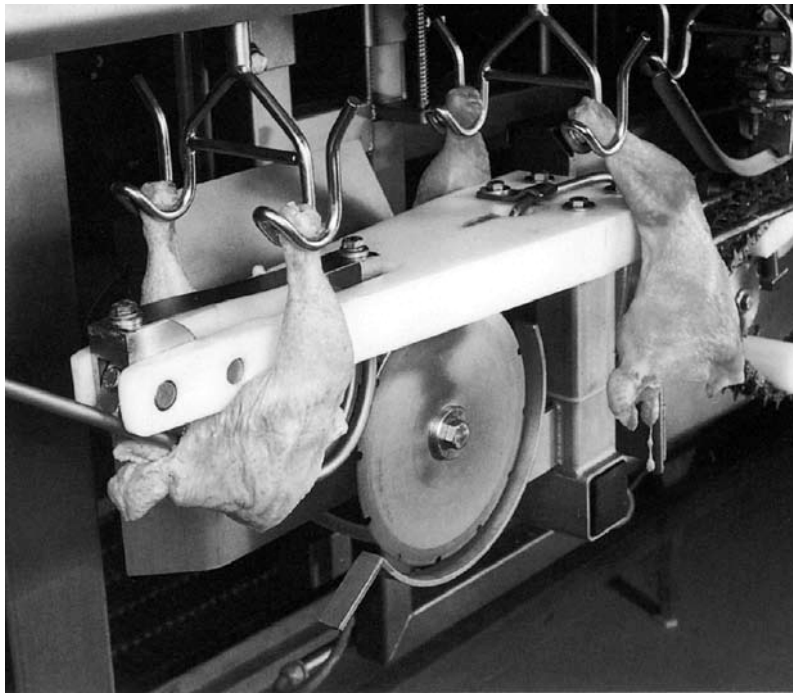


Figure 9.2.3.3 An automated leg quarter cutter. Courtesy of Baader/Johnson.

Figure 9.2.3.5.a shows an automated module system for drum stick deboning. Figure 9.2.3.5.b shows a whole leg automatic deboner which removes the meat from the thigh and drumstick in one piece (some trimming of the kneecap area is usually required). Overall, the concept of having different modules (e.g., drumstick, thigh, breast meat deboning) is gaining popularity and found in most large plants today. Birds can be sent to different cut-up modules depending on market needs (e.g., more deboned breast fillets), differential prices, the grade of incoming birds, etc. This allows high speed production and greater flexibility in processing birds for different markets. The modules shown in the figures are usually easy to adjust (e.g., raise, lower), so they can be positioned at various heights to facilitate handling different size birds, as well as provide improved inspection, cleaning, and repair (see hygienic design considerations in Chapter 15).

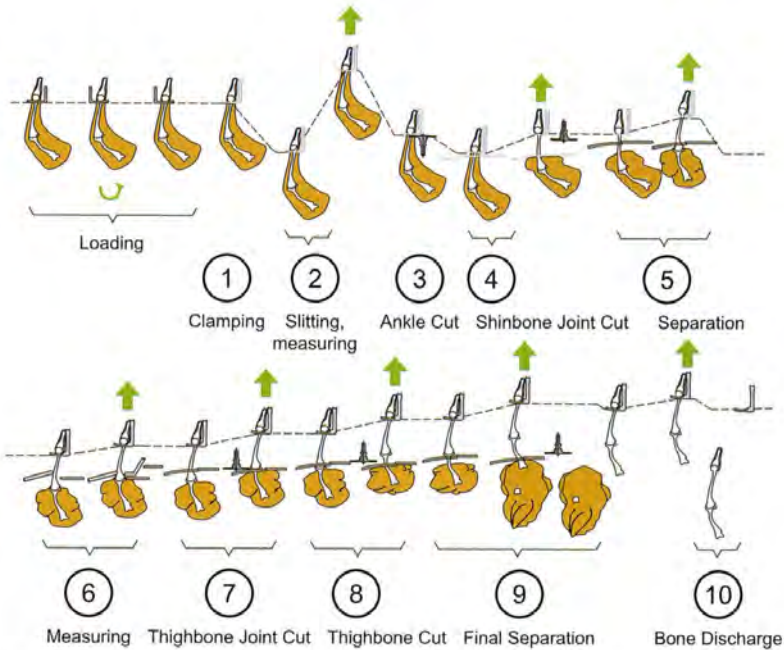


Figure 9.2.3.4 A whole broiler leg deboning operation. Courtesy of Mycom.



Figure 9.2.3.5.a Poultry drumstick meat deboner working by slitting and pushing the meat. Courtesy of Meyn.

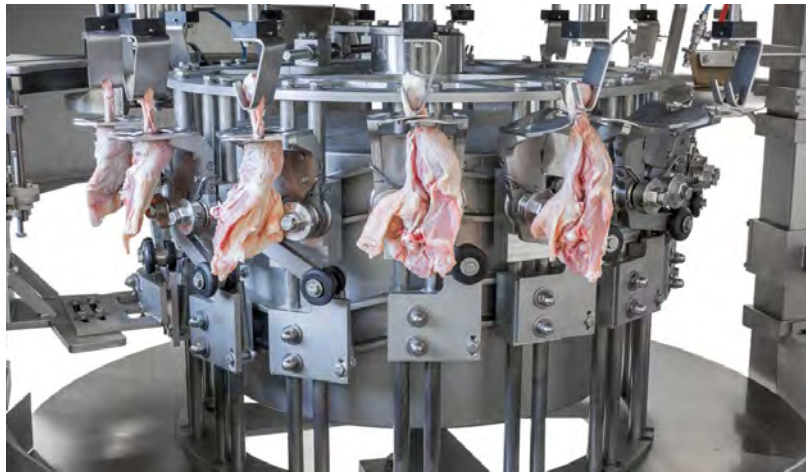


Figure 9.2.3.5.b An automated whole leg meat deboner. Courtesy of Foodmate.

Figure 9.2.3.6 shows a sophisticated breast meat deboner used by the Japanese market. This machine also starts with precise measuring (e.g., bone ends, width of the portion) and then calculates the best cutting strategy before cutting, while the breast cup is firmly secured on a moving carrier. Quality and presentation of the deboned meat are also very important features of this machine.

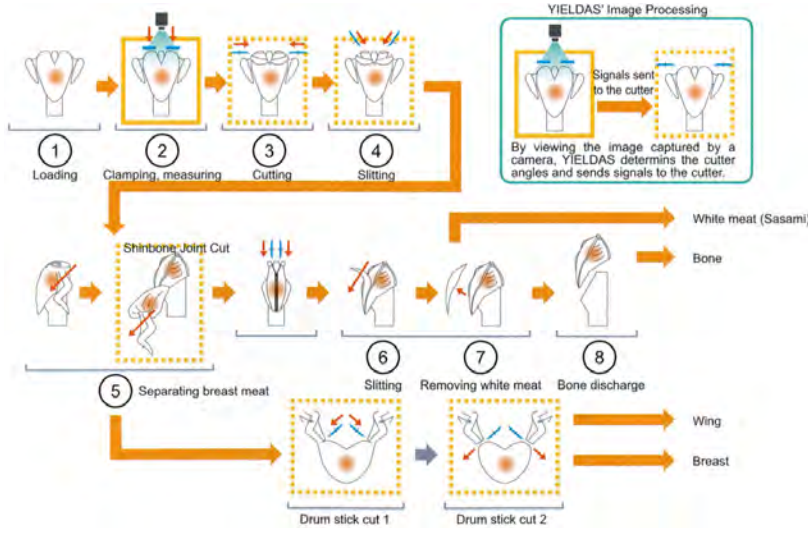


Figure 9.2.3.6 A very precise breast meat deboner used by the Japanese market. Courtesy of Mycom.

A very important factor in selling deboned meat is the guarantee that it is free of bones and bone chips (e.g., various large fast food chains require a letter of guarantee from the supplier). In order to ensure that the meat is bone free, various light tables and x-ray machines are used to inspect the meat. Light tables can be used to inspect the meat but are limited to thin skinless slices. Figure 9.2.3.7 shows an installation of an x-ray machine on a production line. The equipment has to be calibrated and a threshold set. High speed lines are also equipped with a device that can remove/kick out portions with bones so quality control staff can examine and remove the bone. The x-ray pictures can be saved and presented on a screen to help the operator quickly identify the bone location. The information can also be used for training. Modern software can identify foreign bodies in colour and display them on the screen (i.e., can also provide a smart solution for automatic positioning of affected meat cuts).



Figure 9.2.3.7 Installation of an x-ray machine. Courtesy of Marel.

9.3 Automated Portioning – Boneless Meat

The industry uses various methods to portion meat ranging from traditional manual cutting to fast, automated cutting by laser guided machines or water jet cutters. Figure 9.3.1 shows a fast moving blade capable of performing over 1000

cuts per min. While on a moving conveyor belt, the meat portion to be cut (e.g., chicken breast fillet, pork roast, fish) is first weighed and then scanned by laser to produce a 3D image. This information is analyzed and a computer calculates cut locations that achieve precise weight and shape specifications. Cutting the meat portion also occurs on the moving conveyor belt.

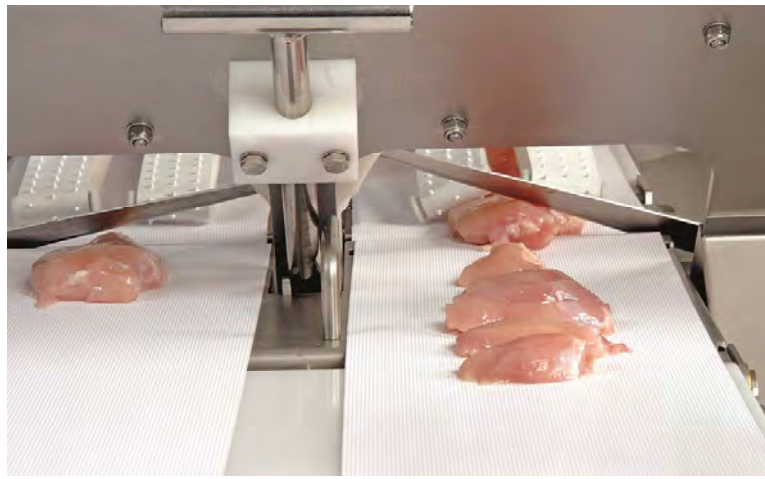
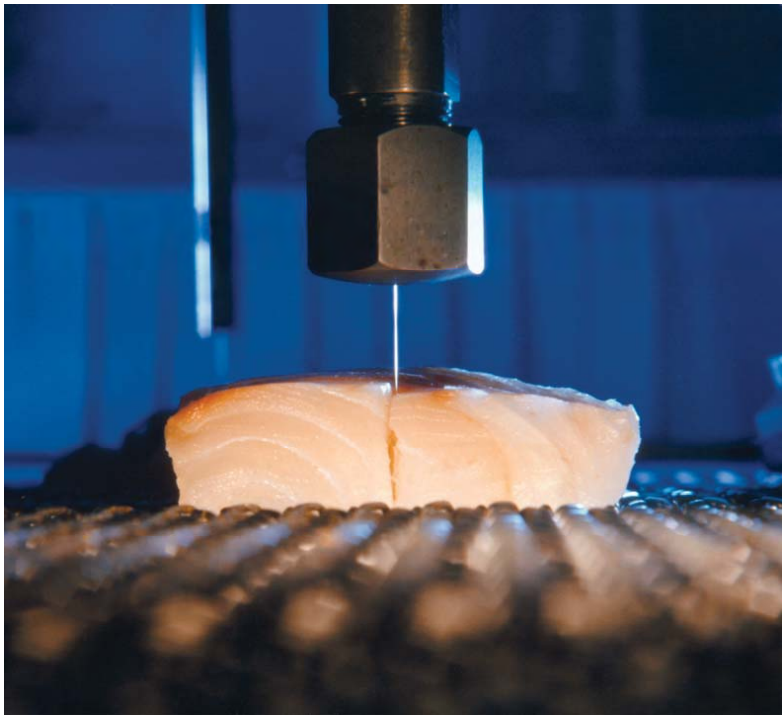


Figure 9.3.1 Laser guided high speed slicing machine. The meat cut is first weighed (on a high speed moving belt) then scanned by laser to determine the volume and then sliced according to pre-programed specifications. Picture showing meat cuts coming out of the machine. The machine is capable of performing a few hundred cuts per minute. Courtesy of Marel.

Figure 9.3.2 shows another portioning concept employed by the meat industry that utilizes a high-pressure water jet. While on a moving conveyor belt, the meat portion is first photographed from different angles to obtain a 3D image that is used for calculating cutting lines to meet weight and shape requirements. Then the meat portion is moved to a place where it is cut by one or more water jets positioned above the product. The processor has quite a few options in portioning (e.g., breast meat into nuggets, fillets and "butterflies"). The machine is computer controlled and information concerning meat and fat densities is used to calculate the appropriate volume needed to obtain a certain weight of each cut. The equipment can handle about 80 "butterfly" cuts per minute and provides accurate and high throughput performance. Capital investment and maintenance costs are much higher than the mechanical cutter described above because of the need to provide ultra-high water pressure, a very good water filtering system, etc.



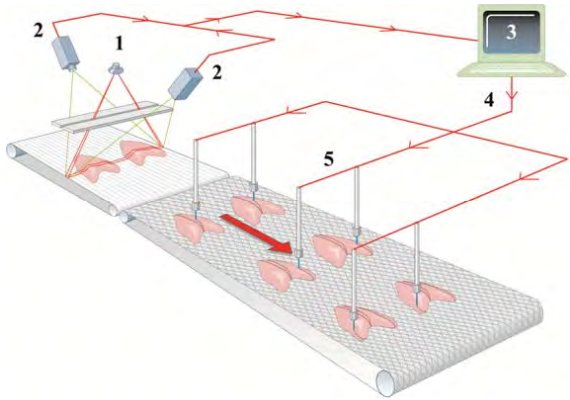


Figure 9.3.2 Water jet cutting of meat. Below is an illustration of the camera and jet directing systems. Courtesy of JBT.

Figure 9.3.3 shows an example of a machine used to cut uniform, pre-determined volume and shape portions commonly used by the fast food industry. The cavities shown on the moving belt can be different sizes and usually are also fitted with a vacuum option located at the bottom part (i.e., to allow better filling of the meat portion).



Figure 9.3.3 Machine to cut pre-determined portions by using a fixed mold approach. Courtesy of Stork.

9.4 Mechanically deboned meat

The large increase in the demand for cut-up poultry has resulted in leftover frames at the processing plant. Residual meat on the necks and backs of hand-deboned or automated-cut poultry is usually harvested by mechanical deboning equipment and the meat obtained is called mechanically deboned meat (MDM) or mechanically separated meat (MSM). Sometimes the species name is also included; e.g., mechanically deboned chicken/turkey/beef meat. The equipment is sometimes used for deboning whole spent hens or meat from parts that would not yield a high-priced product that would justify the cost of hand deboning (e.g., neck meat). However, in places where neck meat is praised (e.g., Japan) hand deboning is seen. The first mechanical deboner was developed in Japan in the early 1940s for fish meat (described further, below). Salvaging the meat after hand filleting can be of great economic importance, and the resulting minced meat is successfully used for making other further processed products (e.g., fish patties, poultry frankfurters).

Currently there are three basic types of deboners on the market:

a. A belt-drum system that was first developed for fish but later adapted for poultry and other soft tissue meats. The meat and bone particles are passed between a rubber belt and a perforated steel drum. The meat is squeezed through the holes of the drum while the harder bones and connective tissue remain outside. Pressure on the belts can be adjusted and sometimes pressure rollers are used to ensure an even distribution of tissue on the belt (Field, 1988). This is a mild separation method and usually results in higher muscle structure integrity than the two other methods.

b. A rotating auger system resembles the inside of a conventional meat grinder. First, bones and frames are pushed through a bone cutter to reduce particle size. Then the ground mixture is introduced into a screw-driven boning head where the material is pressed (i.e., with increasing pressure as it moves along) and the meat is squeezed out through holes in the perforated steel cylinder encasing the auger (Fig. 9.4.1). Hole size can be adjusted and is usually around 0.5 mm. Bone and connective tissue particles that cannot pass through the perforated cylinder are pushed forward and exit at the end.

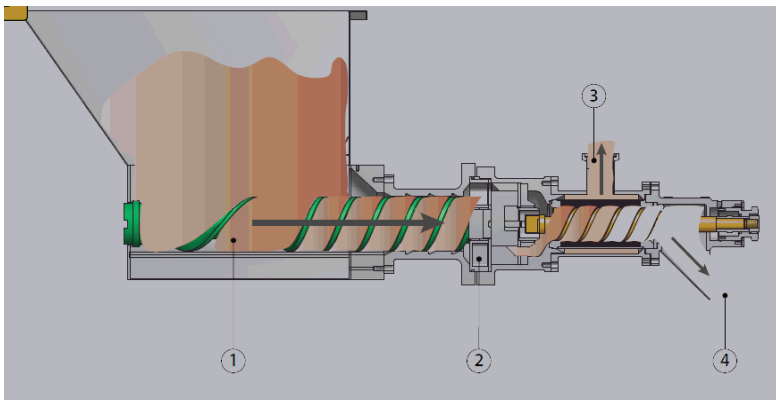


Figure 9.4.1 Illustration showing the principle operation of a rotating type auger used to harvest mechanically deboned meat. (1) auger pushing the material into the separator, (2) adjustment to head pressure, (3) meat exiting after going through the screen (4) residue exit point. Courtesy of Townsend.

c. A hydraulic press pushes the meat and bones against a perforated plate in a batch type system (Fig. 9.4.2). The bones can also be pre-cut prior to being introduced into a chamber. Inside, the material is forced against a stationary, slotted

surface/plate by a hydraulic-powered ram piston that squeezes the soft meat tissue through the cylinder openings (usually 1.0 – 1.5 mm in size). Later the residual bones and connective tissue are removed from the chamber.

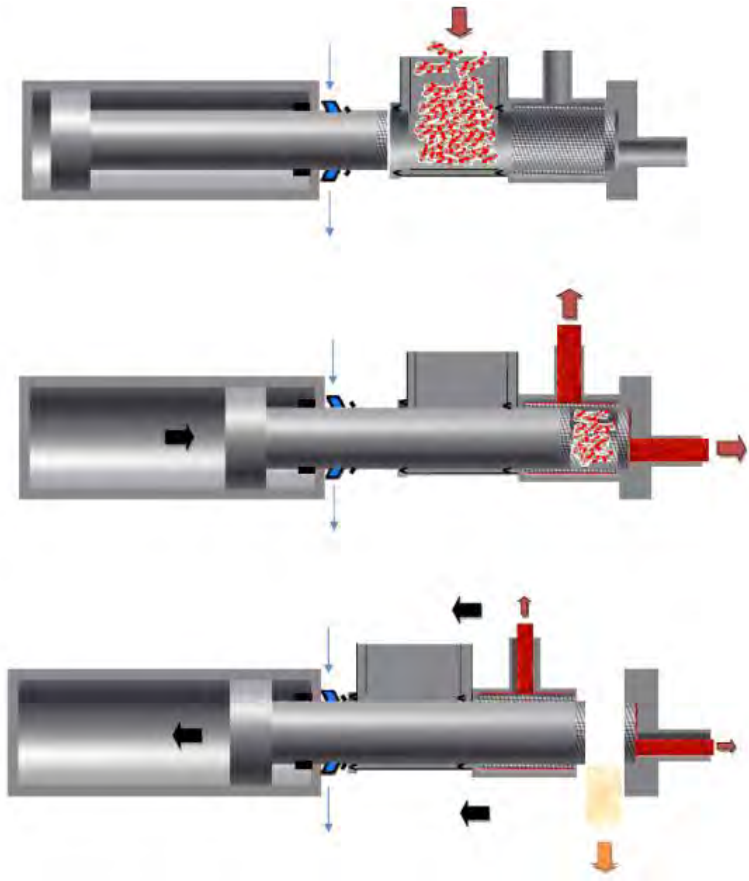


Figure 9.4.2 Illustration showing the principle of operating a hydraulic press type equipment for harvesting mechanically deboned meat. Top drawing shows meat going in; middle drawing shows compression phase and recovery of meat; bottom drawing shows release of bone residue. Courtesy of Townsend.

Because of the pressure used to separate the meat, the resulting texture of the MDM is that of a minced/finely chopped product (i.e., a paste-like consistency in which the myofibrils are quite fragmented). Under the microscope, breaks in the Z-line and distortion of the sarcomere can be seen. The paste-like texture is suitable for

finely chopped meat products such as frankfurters and bologna (see Chapter 13). The meat can also be used in a coarse-ground product where comminuted meat is used to fill the gaps and help form a cohesive matrix. An example is a smoked turkey sausage where coarse hand deboned meat pieces are embedded within a homogeneous, finely chopped meat matrix.

During mechanical deboning, cell membranes are broken, which makes the meat more susceptible to lipid oxidation as enzymes are released. In addition, oxygen exposure and heme and lipid extraction from bone marrow also makes the meat more susceptible to rancidity (Froning, 1981; Field, 1988; USDA, 1994; Daros et al., 2005). The meat processor's goal is to minimize oxidative rancidity and this can be done by oxygen exclusion (vacuum packaging), the addition of vitamin E to the diet of the animal, and/or the addition of antioxidants to the further processed meat product. The rate of lipid oxidation is also influenced by the pressure used during the deboning process. Higher pressures will result in higher yield (Table 9.4.1) but will also increase the amount of heme iron and the proportion of certain unsaturated fatty acids in the sample. The results reported here refer to using an auger-type deboner equipped with a 10 cm boning head, set at 1 mm spacing. A high pressure of 150 lb/in^2 almost doubled the yield, but it also increased iron content by about 70%. Most of the increase in iron content has been reported to be hemoglobin (Froning, 1981). It should be noted that heme content may also vary depending on age of the bird. Calcium also significantly increased when deboner head pressure was raised (Table 9.4.1). In many countries, calcium content and bone fragments in meat are regulated (Froning, 1981; Daros et al., 2005). In North America no more than 1% bone particles can be present in the product and machines should be adjusted to operate at these levels. Bone particle size is also important because large fragments can result in a gritty texture and, more importantly, can hurt the consumer. Therefore, bone size is included in the regulations where usually 90% of the bone particles cannot exceed 0.5 mm and no particle can exceed 0.85 mm. This ensures removal of bone particles that could cause problems (e.g., chip a tooth). However, large bone chips (> 1 mm) are sometimes found in regular hand deboned meat. In North America, MDM is usually not allowed in infant formulations, and some governments also limit the use of MDM in children's food (usually < 20%) because of concerns regarding excessive fluoride intake.

The meat's microbial quality is an important food safety issue as the meat can quickly deteriorate if the product is not handled properly. An important factor contributing to higher rates of microbial degradation is the mixing of exposed, more contaminated surface tissues with cleaner, internal muscle tissues. Overall, it is recommended that raw materials (backs, necks, and frames), be chilled to

4°C or below within an hour of the hand deboning operation. According to the USDA, they should be frozen at -18°C if they are not used within 72 hr. Recovered meat should be used within 24 hr of being separated; otherwise it should be frozen. During the mechanical deboning process, the temperature rises due to friction within the deboning head (e.g., 1–6°C during grinding and 5–7°C during deboning). To minimize microbial growth, effective chilling during and after the deboning process is required. Chilling is commonly done by mechanical refrigeration or cryogenic agents such as carbon dioxide snow or liquid nitrogen. Cryogenic agents can be added or sprayed directly onto the product; however, some reports suggest that CO_2 might contribute to lipid oxidation (i.e., due to some pH decline), especially if the meat is frozen more than six months.

Table 9.4.1 Effect of deboner head pressure on the chemical composition and yields of mechanically deboned whole roaster breasts (bone in, skin on) vs. composition of meat obtained by a hand-deboned meat operation. Adapted from Barbut et al. (1989).

Pressure (lb/in^2)	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Calcium (ppm)	Iron (ppm)	Palmetic[a] (%)	Yield (%)
Mechanically deboned								
40	69.82^{b}	20.65^{b}	8.13^{b}	1.05^{cd}	582^{c}	10.00^{c}	23.0^{bc}	45
75	70.37^{b}	20.76^{b}	7.88^{b}	1.04^{cd}	534^{c}	11.70^{c}	22.8^{bc}	44
120	70.28^{b}	20.10^{b}	8.47^{b}	1.12^{bc}	568^{c}	10.60^{c}	24.7^{bc}	42
150	71.05^{b}	20.68^{b}	6.78^{c}	1.23^{b}	764^{b}	17.85^{b}	27.3^{b}	82
Hand deboned								
	73.20^{c}	23.67^{c}	3.10^{d}	0.94^{d}	164^{d}	6.25^{d}	20.1^{c}	–

[a]Percent of total fatty acids.
[b–d]Means in the same column with different superscripts are significantly different ($P<0.05$).

Mechanically deboned meat is usually sold by fat and protein content. Fat content in the final, raw MDM is determined by the raw materials used (e.g., skin on or off). In the US, for example, the meat is marketed under two main categories. The first has a maximum fat limit of 30% and a minimum protein content of 14%, while the second does not have fat or protein limits.

During the past few years the industry has focused on creating MDM with a more meat-like texture. Texture preservation can be achieved by machines that cause less cellular damage (e.g., disruption) and leave more of the muscle structure intact. The industry is also looking into developing surimi-like products, based on the old Japanese technology that refers to washing minced fish meat (Dawson et

al., 1989; Daros et al., 2005). The washing process is designed to remove some of the enzymes, fat, and heme from the myofibrillar proteins. The final product is generally whiter and possesses good gelation and binding characteristics. In the fish industry, minced and washed meat is used to make surimi-type products (e.g., seafood analogues including imitation shrimp and crab leg). In that case, the initial raw material is not suitable for human consumption (e.g., small fish, high content of thin bones). After harvesting, the fish is mechanically deboned, washed, and processed in a special way to form a muscle-like texture (i.e., extruded in a string-like configuration and later twisted to form a rope-like structure). Dawson et al. (1989) studied the washing process of mechanically deboned poultry meat and investigated the application of different washing solutions (e.g., tap water, phosphate buffer, 0.1 M sodium chloride, and 0.5% sodium bicarbonate). Sodium bicarbonate was most effective in removing heme proteins and increasing the lightness of the washed meat. The washed meat was found to have very good gelation properties and had a light colour resembling white breast meat.

9.5 Meat Composition

Meat has been consumed as part of the human diet for thousands of years. It is a good source of high-quality protein, B vitamins, and minerals, whether the meat source is poultry, beef, pork, fish, or even insects. The fact that poultry is considered to be relatively inexpensive (e.g., compared to some other red meats) and a good source of lean meat has resulted in a significant increase in its consumption around the world (see Chapter 2). Overall, the dietary contribution of poultry meat is dependent on the culture, availability, and nutritional value. Table 9.5.1 shows the meat composition of selected poultry species. Turkey meat is usually lower in fat than chicken, while goose and duck meat are higher in fat. The presence of skin on a poultry meat cut will increase the fat level of the portion because skin includes subcutaneous (under the skin) fat. As fat content increases, moisture content decreases (Table 9.5.1). Therefore, it is commonly said that there is an inverse relationship between moisture and fat. Protein content, however, is not affected as much by this change. Higher fat also translates to a higher caloric value, but in general, poultry is considered a lean meat when compared to red meats. Another important difference is that poultry fat is less saturated than beef and pork fat (Table 9.5.2) and, therefore, has a more favorable image. Higher unsaturation results in a lower melting point of the fat (Table 9.5.2), which has implications regarding fat stability to lipid oxidation (i.e., a higher degree of unsaturation makes the fat less stable) and allowable chopping temperature when preparing a meat emulsion (see Chapter 13). Overall, poultry meat consumers can obtain a very lean product by removing the skin because, unlike red meat animals, most of the fat is

deposited subcutaneously rather than intramuscularly, which means that there is no fat marbling in chicken breast fillets.

Table 9.5.1 Composition and nutritional value of different raw poultry meats. From USDA (2011).

Source of Meat			Water %	Protein %	Fat %	Calcium (mg)	Iron (mg)	Calories (kcal)
Species	Meat	Skin						
Chicken	White	+	68.6	20.3	11.1	0.86	0.8	186
		–	74.9	23.2	1.6	0.98	0.7	114
	Dark	+	65.4	16.7	18.3	0.76	1.0	237
		–	75.9	20.1	4.3	0.94	1.0	125
Turkey	White	+	69.8	21.6	7.4	0.90	1.2	159
White		–	73.8	23.5	1.6	1.00	1.2	115
Dark		+	71.1	18.9	8.8	0.86	1.7	160
Dark		–	74.5	20.1	4.4	0.93	1.7	125
All		+	70.4	20.4	8.0	0.88	1.4	160
Duck	All	+	48.5	11.5	39.3	0.68	2.4	400
Goose	All	+	50.0	15.9	33.5	0.87	2.5	370
	All	–	68.3	22.7	7.1	1.10	2.5	160
Quail	All	+	69.7	19.6	12.1	0.9	3.9	192
Pheasant	All	+	67.7	22.7	9.3	1.3	1.1	180
Pigeon	All	+	48.1	15.7	20.2	1.0	–	250
Expressed on a 100 gram portion of meat with/without skin.								

The nutrient compositions of various poultry species and portions are shown in Table 9.5.1. This information was obtained from a very large database established by the USDA. The database contains information on many foods and is revised periodically (USDA, 2011). Overall, white chicken meat is very high in protein, 20% with skin and 23% without. When the skin is removed, the fat level drops from about 11% to 1.6%. More detailed nutrient composition data for raw light chicken meat with skin are provided in Table 9.5.3, which also relates composition to the cooking method. Cooking methods affect nutrient composition in different ways. While stewing results in the highest protein content, roasting and frying also elevate protein content as moisture and fat are lost. Stewing, which reduces cooking losses, results in a moister product compared to roasting. However, as discussed in Chapter 17, protein denaturation during the cooking process results in a lower water-holding capacity.

Table 9.5.2 Fatty acid composition of fat deposits associated with skin (poultry) and subcutaneous tissue (beef and pork). Adapted in part from Arberle et al. (2001).

Fatty Acid	Formula	% Fatty Acid in Fat		
		Chicken	Beef	Pork
Palmitic[a]	C16:0	26	27	28
Stearic[a]	C18:0	7	21	12
Palmitoleic	C16:1 (9c)	7	2	3
Oleic	C18:1 (9c)	20	42	47
Linoleic	C18:2 (9c, 12c)	21	2	6
Linolenic	C18:3 (9c, 12c, 15c)	–	0.5	0.7
Arachidonic	C20:4 (5c, 8c, 11c, 14c)	0.6	0.4	0.8
% Saturated		33	54	42
% Unsaturated		67	46	58
[a]Examples of unsaturated fatty acids. (Note: the other fatty acids are unsaturated; only major fatty acids are listed in the table).				

Frying the product, after it has been battered and breaded (22% coating in the example provided in Table 9.5.3), raises the carbohydrate content from 0 to 9.5%, the total fat content from 11 to 17%, and the proportion of saturated fatty acids. The cholesterol level remains similar to that of the roasting method because vegetable oil used for frying does not contain cholesterol. Heat-sensitive, vitamins such as ascorbic acid, can be significantly reduced by high temperature frying.

As reported in Table 9.5.4, yields are also affected by cooking method. Variations within the same cooking method can also be expected due to cooking temperature, time, previous treatments (e.g., marination), and processing history (e.g., freezing, chilling).

The composition of different poultry species can vary depending on the bird's size, breed, feed, etc. The composition of turkey meat (Table 9.5.1) is fairly similar to that of broiler meat but turkeys are bigger, produce more meat, and the ratio of skin to meat is lower than in broilers (i.e., proportionally, there is less skin per lean meat mass). This can be seen when comparing the skin-on light turkey meat (7.0% fat) and chicken meat (11.0%). The same is true for dark meat. Average cooking yields for young turkey hens and toms are provided in Table 9.5.4 and they are higher than yield for chicken because the ratio of bone to meat is lower in the larger turkey.

Table 9.5.3 Effect of three different cooking methods on the nutritional composition of light chicken meat with skin. From USDA (2011). http://ndb.nal.usda.gov/ndb/foods/

Nutrients and Units		Mean Values in 100 Grams, Edible Portion			
		Raw	Fried	Roasted	Stewed
Proximate:					
Water	g	68.6	49.4	62.51	53.01
Food energy	kcal	186	289	190	285
Protein (N X 6.25)	g	20.27	22.55	20.37	26.88
Total lipid (fat)	g	11.07	17.35	11.38	18.87
Carbohydrate, total	g	0	9.5	0	0
Minerals:					
Calcium	mg	11	18	10	11
Iron	mg	0.79	1.26	1.07	1.16
Magnesium	mg	23	18	17	17
Phosphorus	mg	163	132	155	153
Potassium	mg	204	157	180	155
Sodium	mg	65	250	75	62
Zinc	mg	0.93	1.46	1.23	1.50
Vitamins:					
Thiamin	mg	0.059	0.98	0.05	0.080
Riboflavin	mg	0.086	0.161	0.120	0.200
Niacin	mg	8.908	5.987	6.305	4.928
Vitamin B6	mg	0.48	0.264	0.29	0.212
Folacin	mcg	4	21	4	4
Vitamin B12	mcg	0.34	0.24	0.23	0.2
Vitamin A	IU	99	79	71	33
Lipids:					
Saturated, total	g	3.91	4.00	3.20	4.34
12:0	g	0.01	0.01	0.01	0.01
14:0	g	0.09	0.09	0.09	0.08
16:0	g	2.33	2.76	2.25	2.07
18:0	g	0.63	1.2	0.62	0.56
Monounsaturated, total	g	4.52	6.02	4.59	6.11
16:1	g	0.6	0.45	0.57	0.53
18:0	g	3.74	5.79	3.51	3.23
20:1	g	0.12	0.09	0.12	0.11
		2.34	3.48	2.48	3.59

Nutrients and Units		Mean Values in 100 Grams, Edible Portion			
		Raw	Fried	Roasted	Stewed
Polyunsaturated, total					
18:2	g	2.07	3.24	1.98	1.83
18:3	g	0.10	0.18	0.09	0.08
18:4	g	–	–	–	–
20:4	g	0.06	0.07	0.09	0.08
20:5	g	0.01	0.01	0.01	0.01
22:5	g	0.01	0.01	0.02	0.02
22:6	g	0.02	0.02	0.03	0.03
Cholesterol	mg	67	84	84	74
Amino Acids:					
Tryptophan	g	0.227	0.268	0.326	0.294
Threonine	g	0.839	0.963	1.202	1.084
Isoleucine	g	1.015	1.171	1.458	1.316
Leucine	g	1.477	1.723	2.119	1.91
Lysine	g	1.654	1.841	2.374	2.142
Methionine	g	0.541	0.616	0.776	0.699
Cystine	g	0.27	0.326	0.385	0.347
Phenylalanine	g	0.788	0.938	1.13	1.019
Tyrosine	g	0.655	0.762	0.94	0.848
Valine	g	0.985	1.147	1.412	1.273
Arginine	g	1.268	1.445	1.811	1.629
Histidine	g	0.597	0.682	0.858	0.774
Alanine	g	1.177	1.334	1.679	1.509
Aspartic acid	g	1.807	2.04	2.587	2.33
Glutamic acid	g	2.967	3.75	4.254	3.835
Glycine	g	1.291	1.466	1.823	1.629
Proline	g	0.973	1.238	1.381	1.238
Serine	g	0.714	0.869	1.021	0.919

Duck meat (Table 9.5.1) is fattier than broiler and turkey meat, partially because ducks are migratory birds that accumulate fat and the environments in which they live (i.e., water) require more insulation. Iron content (i.e., heme pigment) is also higher so the meat appears much darker than chicken and turkey meat. This is related to the fact that the breast muscle in wild ducks has a high proportion of red fibers to support endurance during long distance flying (see Chapter 3); however, in some more domesticated ducks fat content can be high, especially if skin is left on.

Table 9.5.4 Cooking yields for cooked poultry meat cooked under different conditions. From USDA (2011).

Product	Cooking Method	Meat	Part[a] with Bone	Meat[b] Only	Meat[c] and Skin
Chicken Broiler	Roasted	all	66	77	65
		light	68	73	68
		dark	64	75	63
	Stewed	all	75	79	73
		light	78	80	77
		dark	73	78	69
Turkey Young hen	Roasted	all	73	77	74
		light	76	81	78
		dark	70	72	70
Young tom	Roasted	all	72	72	71
		light	73	76	73
		dark	70	67	67

[a]As % of raw part with bone.
[b]As % of raw meat without skin.
[c]As % of raw meat, skin and separable fat.

It is also important to realize that diet of the monogastric birds can significantly affect meat composition. Fat content and composition are particularly sensitive to feed type. In general, high-energy diets and low-protein diets have been shown to increase carcass fat. It is also possible to modify the fatty acid profile in poultry meat by manipulating the fat source in the diet (Yau et al., 1991). Over the past decade, an increased interest in producing meat with an appealing nutritional profile has resulted in studying the effects of incorporating more unsaturated fat, particularly, omega-3 fatty acids in animal feeds. These fatty acids have been reported to assist in the prevention of vascular diseases and some immunological disorders and are also important in early neural development. Flaxseed and menhaden oil are commonly considered ingredients for trying to increase omega-3 fatty acids in chicken meat; however, α-linolenic acid deposition results from feeding chickens the former, while the omega-3 fatty acid level responds to the latter. Any omega-3 fatty acid deposition is usually proportional to its dietary concentration, although the incorporation of omega-3 fatty acids into poultry meat is a gradual process. Gonzalez-Esquerra and Leeson (2000) have shown that α-linolenic acid was

preferentially deposited in dark meat, and long-chain omega-3 fatty acids were preferentially deposited in white meat. Breast meat sensory quality was not affected in birds given 100 g/kg flaxseed for 14 days (treatment a), 7.5 g/kg menhaden oil for 14 days (treatment b) or 100 g/kg flaxseed + 0.75 g/kg menhaden oil for seven days (treatment c). In contrast, thigh meat sensory quality decreased in treatments b and c, which suggested that excessive levels can decrease sensory acceptability. Feeding flaxseed and menhaden oil to birds for just seven days prior to slaughter resulted in significant enrichment of omega-3 fatty acids, depending on their dietary concentrations. Overall, the α-linolenic acid and long-chain omega-3 fatty acids showed preferential deposition in dark and white meat, respectively, which may affect the sensory quality of various portions differently. This is an important difference from cows where feed material is fermented more in the stomach and modification of the fatty acid profile in the meat is much more difficult.

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10

FURTHER PROCESSING – EQUIPMENT

10.1 Introduction

The meat industry produces a large variety of meat products ranging from whole muscle to ground and comminuted products, each of which requires different equipment. This chapter explains the principles of operating modern meat processing equipment, which has evolved over the centuries to help processors and butchers perform different tasks (e.g., cut, inject brine, stuff, cook, slice). Variations exist in equipment design, size, and configuration, but most operate under fairly similar principles. Previously, equipment was designed for individual, single tasks (e.g., mixing) but today many processing lines are designed to accommodate continuous, automated operations.



Figure 10.1.1 Large scale fully automated lines producing nuggets. Courtesy of Townsend.

This is part of a large scale move towards automation (see Chapter 1), where fully automated lines produce thousands of nuggets/sausages per hour (Fig. 10.1.1), with minimal manual labour (i.e., employees might perform quality control functions or adjustments). Such continuous lines speed up manufacturing, move more product through a given plant, permit more centralized control, reduce potential cross contamination problems, and as a result, create cost savings.

The basic steps involved in meat processing are illustrated in Table 10.1.1.

Table 10.1.1 Unit operations used in meat further processing*.

Section	Activity	Action(s)
10.2	Cutting – Size Reduction	Grinding Chopping (coarse, fine) Flaking
10.3	Mixing/Blending (meat, salt, water, etc.)	Mixing (paddle, ribbon mixer) Brine Injection Massaging/Tumbling
10.4	Forming/Stuffing/Netting	Forming (patties, meat balls) Stuffing (regular casings, co-extrusion) Netting Equipment Cooking in Bag
10.5	Smoking	Smoking (smoke house)
10.6	Cooking/Heating	Water Cooking Hot Air Cooking (linear, spiral oven) Microwave Frying in Oil
10.7	Cooling	Air Chilling Water Chilling Cryogenic Chilling
10.8	Peeling	Sausage Peeling
10.9	Slicing	Slicing Cubing
10.10	Packaging	Flexible Packaging Rigid Packaging
10.11	Safety Checks	Metal Detector X-Ray Detector
10.12	Labeling	High Speed Labeling
10.13	Storage and Distribution	Cold/Frozen Storage Distribution Channels
* General sequence of production; not all activities are included in the manufacturing of an individual product		

Depending on the product (e.g., whole muscle roast, ground sausage), the operator will select steps to be used. Generally speaking, all processes performed prior to cooking are carried out at a refrigeration temperature to minimize microbial growth. In addition, good manufacturing practices and adequate HACCP programs are used to enhance the safety of the products (see Chapter 12).

10.2 Cutting/Size Reduction

Reducing the size of meat cuts is a common process involved in the manufacture of sausages and patties. Depending on the desired particle size in the finished product, different equipment can be used. The three basic procedures that are used include: grinding (coarse/medium/fine), flaking, and chopping (coarse/fine).

10.2.1 Grinding

Grinding is probably the second oldest method of reducing meat particle size; the first being manual cutting/chopping. In this process, meat is forced through a grinding plate preceded by a rotating blade. Grinding plates have different size openings and shapes (Fig. 10.2.1.1) and an auger is used to push the meat through a moving set of blades and a grinding plate (Fig. 10.2.1.2). The size of the equipment varies depending on volume and ranges from small, manual grinders that can process a few kg/hr to large electrically driven grinders capable of processing thousands of kg/hr. Pump driven grinders also exist where the meat is pushed by a pump (e.g., positive displacement) directly into the grinding head (Fig. 10.2.1.3). This kind of equipment has some advantages when it comes to maintaining particle definition in products such as dried salami, or when a "home style" grind appearance is required for retail sold ground meat. However, it should be noted that most grinders used by the industry are the auger type. In order to minimize heat build up, especially at the pressure building area of the head, the blades should be kept sharp and the plate maintained in good shape (e.g., not worn out). It is common to keep a blade and plate paired together. If, during production, the operator notices an uneven pattern of meat coming out of the grinder, the machine should be stopped and the connective tissue (or any other obstacle) trapped behind the plate removed. Some of the medium/large grinders have a special system that continuously collects and removes sinew, connective tissue, and bone residues through an opening in the center or the side of the plate. This material is carried away by a pipe or hose connected to the opening so it does not get mixed again with the ground meat. This is an important part of the operation as it can significantly reduce the time needed to open and clean the accumulating tough residues at the surface of the plate. In addition, it reduces heat build-up

(caused by friction of the material clogging the plate's opening), and eliminates fat smearing within the ground meat. In order to increase efficiency, some grinders are built with two or three sets of knives and plates (Fig. 10.2.1.2). The first set is for a coarser grind while the subsequent sets grind the product finer. By doing so, one can eliminate the need to move the meat mass to a second grinder for a finer grind. The size and number of blades, as well as the plates' openings, vary depending on the degree of grinding required. In a single set grinder, the meat is usually first ground through a large opening plate (e.g., kidney plate with openings of about 50 × 20 mm), followed by a smaller plate (e.g., 5 mm holes). Regrinding meat that has been mixed with spices (in a mixer), is also common practice in products such as summer sausages where a good mixing of the spices and starter culture is desired.



Figure 10.2.1.1 Rotating blades, grinding plates with different size opening and shapes. Courtesy of Speco Inc.

An important aspect of the grinder operation is preventing "back-up", which can happen when too much meat is driven towards the plate. Back-up results in an inefficient operation, overheating of the meat mass, and fat smearing. In a small, manual operation this is controlled by the operator, but on a large scale line automatic controls should be set to avoid this problem.



Figure 10.2.1.2 Main parts of a meat grinder. Note that the auger's pitch is changing from large to small. The blade and plate have to be kept sharp at all times to result in good grinding, avoid smearing and temperature build up. Some grinders have a set of 2-3 blades and plates on the same shaft; i.e., meat is gradually moved to a smaller plate. This configuration can save time and labour, but requires a bigger motor to drive the system. In some models sinew and bone particles can be collated, from the inner surface of the grinding plate, and removed from the side/center of the grinder. Photo by S. Barbut.

Pre-breaking frozen meat blocks is also considered part of size reduction and grinding. There are two general approaches. The first is a 'chipper' type, which is a rugged grinder that can handle frozen blocks without damaging the texture of the meat. It usually comes with a powerful slow speed rotor that chips away pieces from the block. Size of the pieces can be controlled by using different size rotors. The second approach is employing a blade/guillotine type that moves down and cuts the frozen meat block to predetermined portions.



Figure 10.2.1.3 Meat grinder utilizing a positive displacement pump (on the left hand side) to push the meat to the cutting plate (on the right hand side). Courtesy of Marlen.

10.2.2 Chopping – Coarse and Fine

In chopping, the meat is passed through a set of cutting blades (Fig. 10.2.2.1). The size of the particles is controlled by the number of passes through the rotating knives and the distance of the knives from the bowl. The degree of chopping is controlled by the overall chopping time, the number of the blades and their speed. The chopping process can be designed to produce relatively large particles or very small ones. Chopping is commonly used for producing fine comminuted products, sometimes called emulsion-type products, such as frankfurters and bologna (see recipes and preparation procedures in Chapter 13). Fine emulsion-type meat products with coarse inserts can also be made by first preparing the fine emulsion and then mixing in coarse inserts by using the reverse motion of the blades (i.e., no cutting is applied). Two common chopping devices used by the meat industry are the bowl chopper (Fig. 10.2.2.1) and the emulsion mill (Fig. 10.2.2.2). In a bowl chopper, meat is placed in a cutting bowl, which moves around at a relatively slow speed [15 to 30 revolutions per minute (rpm)] while the meat is chopped by a set of sickle-shaped knives (3 to 15) at a speed of a few thousand rpm. In order to speed up the process, some new designs have two sets of cutting heads. An emulsion mill, sometimes referred to as an emulsifier, combines the principles of grinding and chopping. The pre-ground meat is fed to the mill and passed through

fast, rotating blades and later pushed through a perforated plate. The blades and plate are arranged in a similar configuration as seen in a meat grinder, and can be positioned vertically or horizontally. An in-line vacuum system can also be included to remove trapped air, which is beneficial in minimizing problems such as lipid oxidation (e.g., associated with off flavour, colour fading) and pockets or ”holes” in the final cooked products (see Chapter 13). Vacuum application in bowl choppers is also popular in the industry. In that case a dome/cover is used to enclose the chopping area while a vacuum is applied (Barbut, 1999).





Figure 10.2.2.1 Meat chopper - meat is passed through a set of high speed cutting blades while the bowl is turning and moving the meat to the blades (top); the meat can also be just mixed by reversing the direction of the blades. An old meat chopper/mixer; note the belt drive mechanism (bottom). Photos by S. Barbut.

Emulsion mills operate at a very high speed (particle size is controlled by plate aperture size) and the meat is subjected to considerable friction, which results in a fairly quick increase in temperature (e.g., 5 to 8°C in a few seconds). Therefore, special care should be given to operating such equipment. A discussion on the risk of exceeding certain chopping temperatures (usually 8-12°C) during the preparation of finely comminuted meat products is provided in Chapter 13. Emulsion mills are advantageous when considering automating a production line because they can process large volumes in a continuous manner while quickly achieving a high degree of meat tissue disintegration. If air is not removed at this stage, it can be done during the stuffing operation as will be discussed later in the chapter. However, it is best to remove air during both the chopping and stuffing operations, as is done in most large plants to ensure quality.

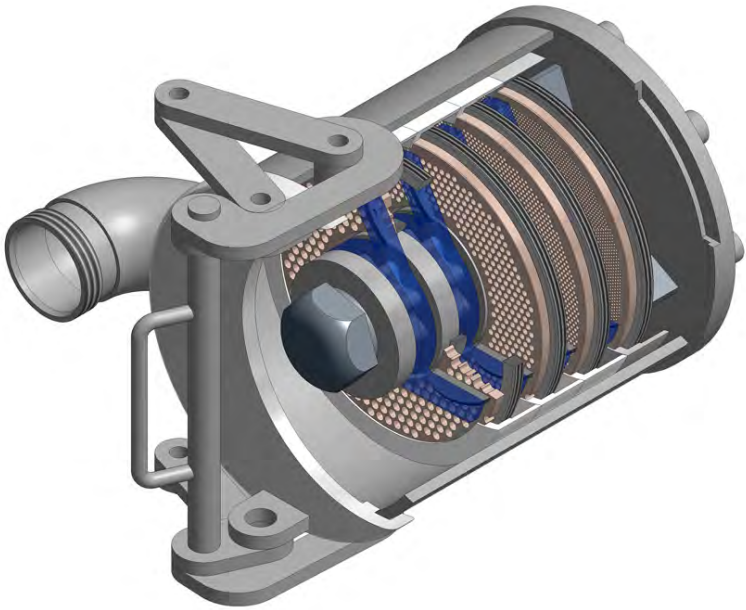


Figure 10.2.2.2 Illustration of a horizontal emulsion mill used to prepare finely comminuted meat products. Courtesy of Cuzzini.

10.2.3 Flaking

Shaving off or flaking small pieces from partially frozen meat cuts or blocks can also reduce the size of meat cuts. The equipment (Fig. 10.2.3.1) has a circular cutting head and an impeller that spins at a high speed and pushes the meat, by centrifugal force, close to the knives. The size of the flakes is determined by the spacing within the vertical knives of the cutting head. This method eliminates the mechanical squeezing of muscle fibers seen in a conventional grinder, which can sometimes result in moisture release from the meat. However, one should also consider that the partial freezing required to keep a stiff structure might also create problems with moisture loss during thawing. The meat obtained from flaking machines has a large surface area and can serve as a good ingredient in restructured meat products where a muscle-like texture is reconstructed from small pieces of meat.

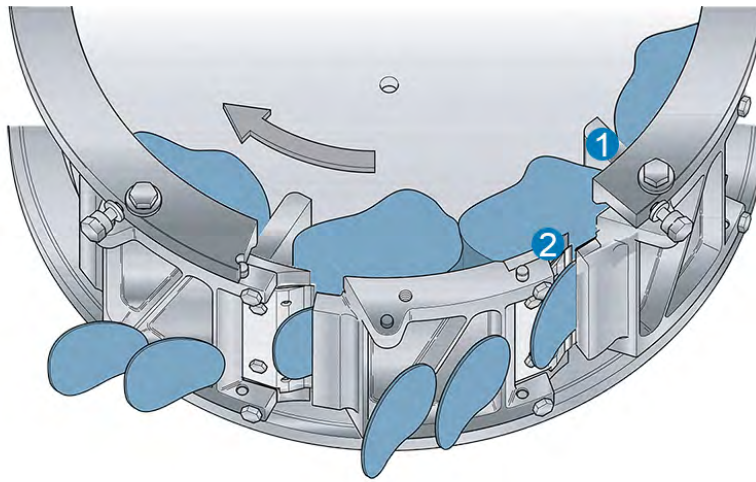


Figure 10.2.3.1 Illustration of flaking equipment. Cutting head spins at high speed and meat/food is pushed towards the blades by centrifugal force. Particle size can be determined by the size and spacing of the blades. Courtesy of Urschel Inc.

10.3 Mixing/Blending

Mixing and blending are essential steps in producing most further processed meat products as they incorporate ingredients (flavouring agents, and binders), extract myofibrillar proteins (e.g., by salt; see Chapter 13), and blend different meats.

The mixing method depends on the size of the meat particles/chunks and the desired characteristics of the final product, etc. When the meat particles are small, dry ingredients can be added to a paddle/ribbon mixer while brine injection and massage are used for large muscle portions (e.g., turkey breast, ham).

10.3.1 Mixers

Ground meat products such as sausages and meat patties are processed in a paddle/ribbon mixer that provides:

a. good mixing of meat and non-meat ingredients (e.g., salt, spices)
b. good uniformity when different meat sources are used
c. absorption of a brine solution into the muscle structure
d. extraction of salt soluble proteins from muscle by mechanical agitation.

There are different blender/mixer designs on the market. A paddle mixer (Fig. 10.3.1.1) employs paddles to mix the meat in a chamber. The blades are usually mounted on a horizontal shaft and the mixer provides a fairly gentle mixing. Another type is the ribbon blender where the diameter and pitch of each ribbon is designed to achieve maximum mixing. This type of blender usually works the product more than the paddle mixer and results in more effective protein solubility. With any mixer, blending should be precisely controlled to ensure uniform mixing action. When using a new formulation or changing the mixing schedule, uniform mixing can be checked using food colouring, mustard seeds, or small ice cubes placed at one corner of the mixer. To ensure proper mixing, the mixer should be filled according to the manufacturer's specifications as under or over filling will not achieve optimal blending. Over-mixing should also be avoided since it can result in too much muscle fiber separation and/or fat smearing.

Coarse-ground products (e.g., breakfast sausage, salami) are prepared in a mixer after grinding the raw meat to the desired size. A mixer can also be used to distribute meat and non-meat ingredients to be chopped by an emulsion mill. This ensures a uniform distribution of ingredients prior to the emulsion mill process where very little mixing takes place during a single pass through the machine.

In several cases pre-blending is employed to mix in the salt prior to product creation. It usually takes 12 to 24 hrs to achieve optimum benefit from pre-blending. This allows additional time for the salt to solubilize some of the meat proteins (e.g., actin, myosin) and thereby improve the water holding capacity and binding of the individual meat particles. In some cases, salt is added only to the lean meat so the processor can obtain a high salt concentration (see Chapter 13).



Figure 10.3.1.1 Meat mixer with paddles for continuous mixing and opening the meat dough structure. Photo by S. Barbut.

10.3.2 Brine Injection

Adding salt and spices to a whole muscle product can be time consuming and expensive (e.g., rubbing dry salt on large hams), so it is only justified for high end products. Therefore, injection equipment is used to quickly introduce the brine (water, salt, and flavourings) into large, whole muscle products. Before equipment development, the two major curing methods for large muscle products were dry curing and brine soaking. While both of these methods are still used today for selected products, brine injection is most popular. A simple injector consists of a single needle operated manually. More sophisticated injectors have a few dozen needles automatically controlled to deliver a precise volume of brine (Fig. 10.3.2.1).

A composition of a generic brine solution is:

Cold Water	75%
Salt (NaCl)	18%
Sugar/Starch	3%
Phosphate	4%
Sodium Ascorbate	0.5%
Sodium Nitrite	0.16%



Figure 10.3.2.1 Brine injector used for bone-in and boneless meat products. See text for more explanation. Photo by S. Barbut.

Delivery of the exact amount of brine is very important in meeting flavour requirements (e.g., saltiness, sweetness) and government regulations (e.g., precise nitrite level). The following examples of injection rate provide an illustration of flavour problems that might arise if mistakes occur in the delivery system:

- Intended injection of 10% pump results in 1.63% salt in the product
- Low injection of 5% pump results in 0.81% salt in the product
- Over injection of 15% pump results in 2.45% salt in the product
- Over injection of 20% pump results in 3.26% salt in the product.

A problem with under-delivery due to, for example, clogged needles, can result in lower than expected salt and nitrite concentrations. Delivering only 5% will result in half the salt flavour, but more importantly only half of the required nitrite, which can represent a serious safety issue. In the case of over-injection (e.g., 15 and 20%), the product will be too salty and also have higher than legal nitrite content. Over injection can also cause separation of the muscle bundles and the formation of pickle pockets. Uniform temperature of the injected product is also critical (e.g., previously frozen raw materials should be completely defrosted). Special care should be given to the uniformity of the injection process to prevent high salt and/or nitrite concentrations in localized areas where bones are present. This is commonly achieved with special sensors attached to the needles that can gauge

pressure and needle movement (i.e., stops movement and injection of the needle when it hits a bone). If injection continues next to a bone, high concentrations of salt and/or nitrite can cause flavour defects and some even claim nitrite burns in the final product; however the latter is extremely rare. Injectors should be constantly monitored during operation and quality control checks of pumped product should be routinely performed. The calculation for percent pump and percent yield are shown below:

Example:

Green weight (initial meat weight) 500kg

Pumped weight (meat + brine) 560kg

$$\% \text{ Pump} = \frac{(\text{Pumped weight} - \text{Green weight})}{\text{Green weight}} \times 100 = \frac{60 \times 100}{500} = 12\%$$

Example:

Finished weight = weight after cooking, smoking and/or drying 480kg

$$\%\text{Yield} = \frac{\text{Finished weight} \times 100}{\text{Green weight}} = \frac{480 \times 100}{500} = 96\%$$

If finished weight is: 520kg

$$\% \text{ Yield} = \frac{520 \times 100}{500} = 104\%$$

The finished product weight is used to calculate the actual salt, sugar, phosphate, and nitrite concentrations injected into the raw meat. During cooking, moisture evaporates (unless cooked in moisture proof casings), but added salt, sugar, and nitrite do not. Salt and sugar are concentrated in the product while some nitrite turns into nitric oxide gas. Therefore, knowledge of all processing parameters is crucial in developing a workable formulation and in achieving the desired concentrations of the different ingredients in the final product.

The physical shape and diameter of the needles used are also important and should match the meat. In the case of broiler breast meat (low connective tissue), the needles should be narrow enough not to cause damage to the muscle appearance. This is crucial when processing meat with a weak connective tissue structure (e.g., breast meat from large turkeys), as thick needles and/or high injection pressure will cause a lot of damage. In other cases, such as thigh meat, large needles or even small penetrating blades can be used for both injection and to tenderize (Fig. 10.3.2.2). It should be noted that the tenderizing operation can also be carried out by itself and there is equipment to do so independent of the injection process.

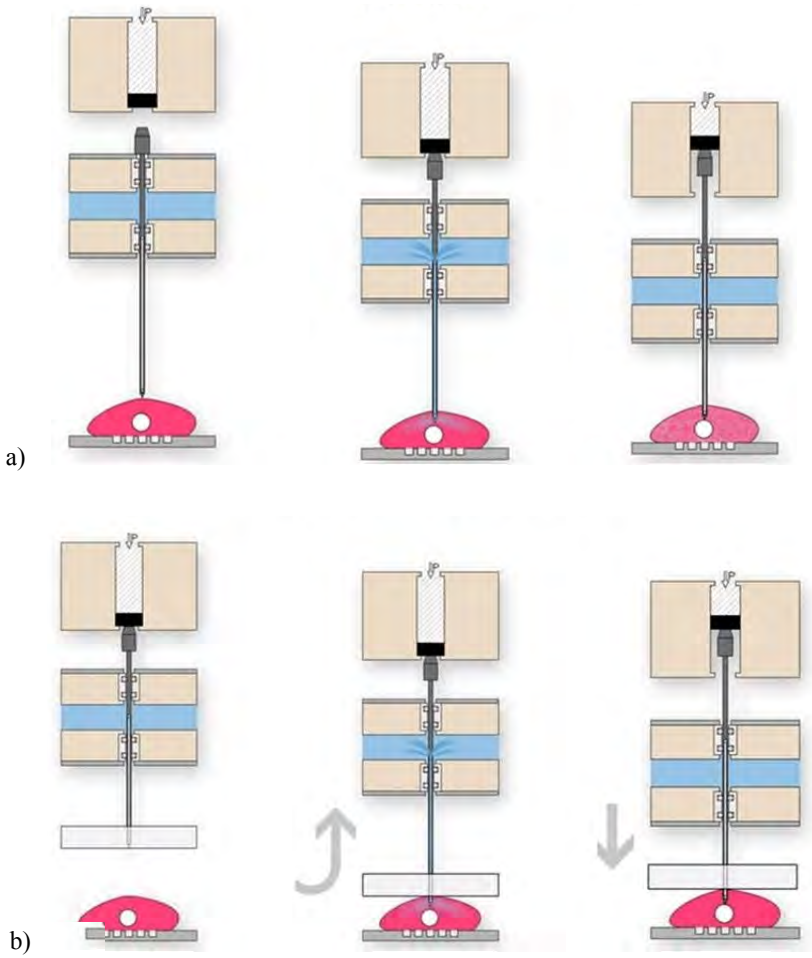


Figure 10.3.2.2 Illustration of brine injection principles (a) contact injection, and (b) forced injection. Courtesy of JBT/ Wolf – Tec.

After brine injection it is common to tumble the meat to achieve an even brine distribution, enhance absorption, and facilitate salt soluble protein extraction (Lin et al., 1991).

10.3.3 Massaging and Tumbling

Massaging and tumbling are procedures designed to help distribute brine into whole/large muscle chunks after injection, or to marinate small size meat strips in brine by tumbling. Both processes improve brine absorption and protein extraction, which later helps in binding (water added, particles' surfaces). In both processes the meat is subjected to a certain degree of agitation, which distributes the salt and other ingredients and solubilizes the myofibrillar proteins. Massaging is done in a stationary mixing vessel where a paddle(s) slowly moves the meat, whereas tumbling is done in a rotating drum that can have different baffles/ribbon designs on the sides (Fig. 10.3.3.1). The massaging action is considered gentler than tumbling since there is no lifting or dropping the meat. However, some tumbler manufacturers claim that gentle mixing, similar to a massage, can be achieved. For example, the two- and four-helical ribbon designs shown in Fig. 10.3.3.1 are claimed to provide gentler mixing than a tumbler equipped with horizontal baffles (located on the drum's side wall which help lift and then drop the meat during its continuous rotation). The helical ribbons slowly advance the meat towards the upper end of the tumbler and then gently move the meat towards the other side. This is important for meat cuts with inherently weak connective tissue structure. The capacity of tumblers and massagers ranges from a few kg (test kitchen models) to several tonnes. The degree of fill (ratio of meat volume to total volume) is also very important in adequate massaging/tumbling without damaging the meat structure. For example, low fill of a large tumbler can result in dropping the meat from a higher level and potentially breaking more connective tissue (note: this can be desirable when dealing with tough cuts, but is a problem with soft meat).

Temperature control during the operation is another important factor. Tumblers/massagers are usually placed in a refrigerated area and/or have a double wall construction that allows a fast cooling by a cooling agent. Removing the heat created by friction (moving meat pieces) and keeping the meat cold are important in protein extraction (i.e., studies show that 2-4ºC is ideal) and microbial growth suppression. Agitation/movement can be applied for one to several hours (e.g., slow or intermittent overnight; see recipes for oven roasted turkey breast products in Chapter 13), and help extract the salt soluble proteins that will serve to bind meat chunks together during cooking (i.e., the proteins will gel during heating). Protein extraction can be further enhanced if the mechanical action is performed under

a vacuum. Most commercial massagers/tumblers are equipped with a vacuum pump via a hose connected to the tumbler's lid so they can turn it on without any disturbance. This also helps to remove small air pockets created during injection. The processor should validate the performance of the tumbler.

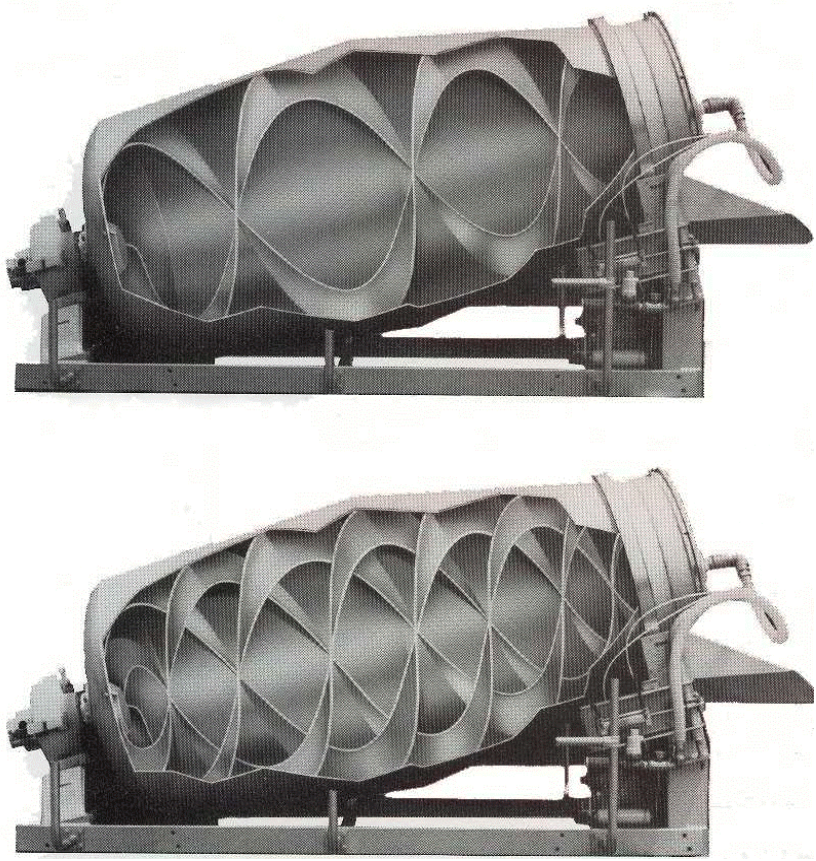


Figure 10.3.3.1 Illustration of a tumbler with a two and four ribbon configuration. Courtesy of Challenge Inc.

This can be done with the help of the equipment supplier and/or testing batches. Figure 10.3.3.2 demonstrates the effect of tumbling time (5, 10, 14 and 18 hrs) and the NaCl substitution with KCl (0, 15, 37, 60, 75%) on ham's elasticity, which

was measured using a texture profile analysis test. Elasticity increased non-linearly with increasing tumbling time up to 13 hrs, and NaCl replacement of up to 37% (i.e., dependent on tumbler type, temperature, meat source, etc.). The authors also illustrated multidimensional optimization and indicated that 15.6 hr tumbling at 12 rpm and 15% NaCl substitution maximized cooked yield and water holding capacity. For optimal sensory attributes the conditions were 12.4 hr at 17 rpm and 18% substitution (Lin et al., 1991).

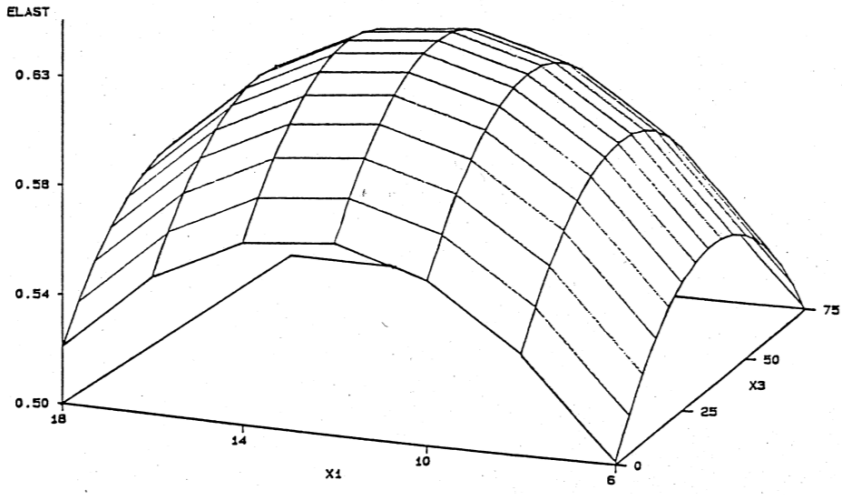


Figure 10.3.3.2 Response surface showing elasticity values for tumbled ham as a function of tumbling time (X1 in hrs) and NaCl substitution with KCl (X3 in %) at a tumbling speed of 17rpm. From Lin et al. (1991). With permission.

10.4 Forming, Stuffing, and Netting Equipment

Manual, semi-automated, and fully automated machines are used to form meat into various shapes (e.g., patties, meat balls) and sizes (small sized nuggets, large sized hamburger patties). Stuffing raw meat batter into casings is another way of shaping meat batters (e.g., traditional elongated cylinder type shape, curved sausages at different diameters; see also section on casings in Chapter 13).

10.4.1 Forming Machines

Equipment can be used to produce patties and nuggets that are commonly made from a mixture of ground and/or emulsified meat. The traditional forming machine is basically a press with different templates that can be used to form the desired shape. The meat is fed by a pump from a mixer/blender and is then transferred directly to the forming machine's mold. Alternatively, it can be first fed to a hopper on top of the forming machine (either by gravity or an auger) and later moved to fill the desired mold. The mold is usually made out of metal or hard plastic and can have a single or multiple cavity(ies) (Fig. 10.4.1.1).



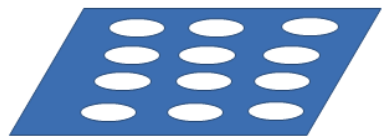


Figure 10.4.1.1 A small patty/nugget forming machine using a wheel based cavities (top; from www.birosaw.com), and a flat type mold used in high speed production lines (bottom).

In traditional forming machines there is a knockout mechanism that discharges the patties onto a conveyor belt. Common equipment on the market operates at 20-60 strokes/min and is capable of forming patties of 30-250 g. New generation forming machines have a gentler discharge performed by compressed air (Fig 10.4.1.2). This can be achieved by using porous metal at the back of the mold. This is also an example of using new technology from the metallurgy field to develop advanced equipment for the food industry. The new generation machines do not have a noisy knock out mechanism and do not exert high pressure on the meat patty.



Figure 10.4.1.2 New generation of low pressure forming machine with compressed air. Courtesy of Townsend.

The formed products do not usually hold together very well in the raw state, and are therefore "stabilized" by freezing or par frying for 30-90 sec. In some cases, battering and breading equipment is used just after the forming operation to uniformly coat products, such as chicken nuggets, prior to subsequent freezing or cooking. The equipment is usually connected via a series of conveyor belts, which carry the nuggets/patties to a battering and breading machine (see detailed description of equipment in Chapter 14).

10.4.2 Stuffing

Stuffers vary in size and their degree of automation, ranging from manual to fully automated piston/pump driven machines and co-extrusion systems. Traditional stuffers can be divided into two types: piston and direct pump stuffers (Pearson and Gillett, 1996). The piston is driven by manual energy or hydraulic fluid and forces the meat from a cylindrical barrel through a stuffing horn (Fig. 10.4.2.1). The diameter of the horn, the stuffing speed, and the pressure are controlled by the operator and should always match the size and type of casing used (e.g., high speed automated equipment requires strong, uniform casings such as manufactured collagen, plastic or cellulose casings). Different casings (e.g., natural collagen, manufactured collagen, cellulose, plastic; see Chapter 13) are also used for different types of meat products.



Figure 10.4.2.1 Piston type meat stuffer. A knee operating paddle can be seen at the lower part. On the back there is a knob to control the speed of the piston which is moving up and pushing the meat via the stuffing horn; different size horns can be used, depending on the size of the casings. Photo by S. Barbut.

A pump operated vacuum stuffer (Fig. 10.4.2.2) employs an impeller to move the meat forward. The impeller usually has feedback and pop-off connectors so a vacuum can remove trapped air within the meat batter as well as help draw the meat into the pump impellers. Applying a vacuum is optional and vacuum stuffers are more expensive. However, most if not all, large meat producers use vacuum as it enhances the product's appearance. Air pockets left in the meat batter might later show as empty voids in the cooked product. The voids can also be filled with gelatin (melted collagen), or melted fat during the cooking operation and it is advantageous to minimize their presence because they are unattractive. In addition, evacuating trapped air (specifically the oxygen) will minimize oxidation problems and prolong shelf life. Figure 10.4.2.2 shows equipment where air exclusion starts in the hopper (note: this feature is not found in all vacuum stuffers). Later, a feed screw (see vertical shaft) transfers the meat to a pump where it continues to be subjected to vacuum. The single vane of the pump rotates through 270 degrees before reversing direction and starting another sweep cycle. At the end of each sweep, a combination of inlet-outlet valves rotate, which directs the flow of the meat from the top hopper into the cavity that is formed as the vane discharges the product. In general, finely comminuted/emulsified meat products and fine ground products are commonly processed via pump-operated stuffers. When it comes to coarse ground sausages or products with large particles such as meat/fat/cheese/pimento, some processors prefer a piston-type stuffer because of potential damage to the structure when a rotating pump is used. However new rotary vane pumps and elliptical gear type pumps are now designed to handle delicate products such as dry sausage mixes. In any case, prior mixing and blending can be also done under a vacuum.

Fully automated co-extrusion systems are now becoming popular in medium and large meat processing plants. A conceptual breakthrough has been the idea of coating the meat coming out of the stuffer's horn with a semi-liquid casing that can later be cross linked (i.e., to form a strong casings directly on the product), rather than using pre-made casings (Barbut, 2014). With this new concept, plants can now switch from a batch operation, where the processor needs to stop each time a casing bundle is filled, to a continuous, fully automated operation (see Chapter 1). An example of a co-extrusion process using a collagen gel to form the casings is shown in Fig. 10.4.2.3. The meat is pumped out of the stuffing horn at a constant rate and immediately covered with a thin layer of collagen gel (usually 5% collagen, but can also be a hybrid gel of collagen and alginate, or alginate by itself). The co-extrusion head is divided into inner and outer cones that spin in opposite directions. This design allows the collagen fibers to be aligned on the product and increases the casing strength. The product is then submerged in a salt

brine to remove some of the water from the newly formed film/casings. Later, the long meat rope is portioned/crimped and then moved through an air drying cabinet. This is followed by a spray or a bath of liquid smoke that cross links the collagen fibers with aldehydes (see Chapter 13). The product can then be fully cooked, frozen, or sold raw. When alginate is used, calcium salt is used to cross link the hydrocolloid gum (see Chapter 13).

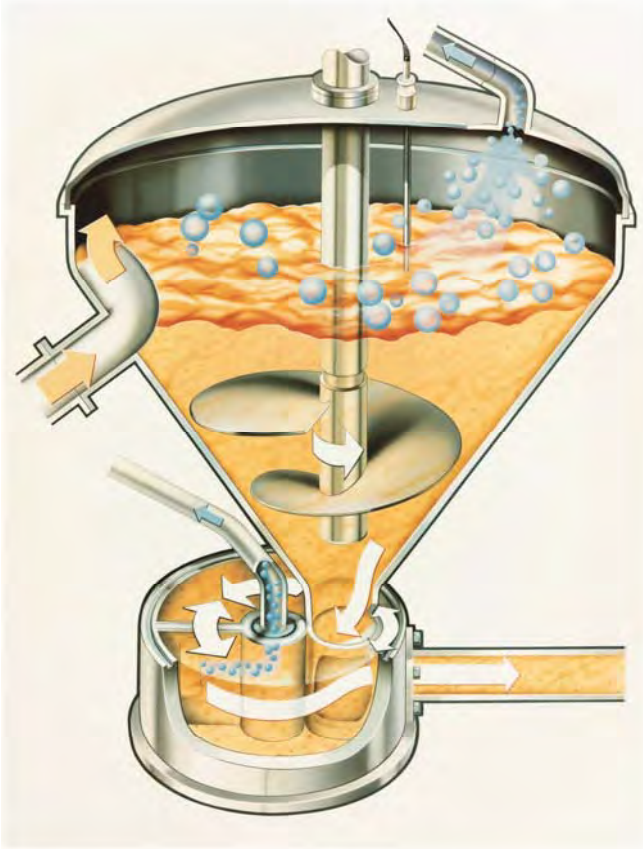




Figure 10.4.2.2 A vacuum meat stuffer (colour illustration), and details of the rotary vane pump mechanism (black and white picture). Courtesy of Handmann.

When using conventional casings, tying the ends or segmenting the product into individual links is performed after stuffing. This can be done by twisting links of small sausages by hand or using special equipment, tying the ends with a thread in the case of medium sized products, or using metal clips for large diameter/heavy products. Large diameter sausages are usually tied or clipped at one end with a hanging loop and then placed on a smoke stick or a hook so the entire surface is free from contact with the equipment or other products. This permits good airflow around the sausages in the smokehouse and prevents touch marks and spotting due to contact with adjacently hung products. In the case of very large, heavy products (e.g., bologna stuffed into 1 – 2 m long cellulose casing), the so called "logs" are placed on metal screens or put into large molds. This horizontal processing helps retain a uniform, cylindrical shape. In general, 25-30% more products can be placed in the smokehouse horizontally as compared to vertically (the degree of smokehouse fill also depends on air flow as well as heating capacity). Processors can choose from various types of fully/semi-automated stuffing machines. Lines that stuff a high volume of sausages (e.g., few hundred frankfurters per min) are now common. Some high-speed stuffing lines are fully automated and the whole line is integrated, synchronized, and computer controlled. In the case of a small

diameter product such as frankfurters, an automated arm can be used to hang the links on a continuous moving line that takes the product directly to the smokehouse. Overall, the high-speed linkers and high volume co-extrusion operations currently set the production economics of the sausage industry.



Figure 10.4.2.3 Co-extrusion head showing meat batter extruded from the stuffing horn and immediately covered with a gel that is de-watered by salt application (blue hose discharging a concentrated salt solution, and then sausage immersed in brine). Later cross linked by smoke. See text for explanation. Courtesy of Townsend.

10.4.3 Netting

Placing large whole muscle products (e.g., turkey breast, ham) or chunked products in nets is advantageous when the product is processed in a smoke house as it allows products to hang next to each other, helps maintain shape, and provides a nice appearance on the products' cooked surface. The product can also be placed in some type of a forming mold to result in a desired shape. The basic equipment consists of a narrowing funnel through which the product is pushed out into a pre-stretched netting sleeve (Fig. 10.4.3.1). There are several options to mechanize the process and often a large diameter pipe (fed via a pump) is used. There are many options for netting including opening size, pattern, strength, coating (protein and/or fat for fast release after cooking), etc.

10.4.4 Cook-in-Bag

Cook-in-bag technology is used to heat different products in a sealed bag. The cooked product can then be removed from the bag and sliced at the plant or by the consumer/retailer (the latter can increase the product's shelf life). The equipment used to fill the bags is similar to that used for netting, but the packaging bag is usually made of a stronger, more durable plastic (see Chapter 11 for more discussion on packaging films). Usually the bag is placed in some type of a forming mold or screen to produce a desired shape.



Figure 10.4.3.1 Raw whole muscle product stuffed into netting. Photo by S. Barbut.

10.5 Smoking

Many meat products are smoked before consumption. Smoking raw meat is done by exposure to traditional smoke, liquid smoke, or by adding smoke extracts. The product can then be sold to the consumer for cooking at home. Smoked raw products can appear cooked on the outside because of colour development during smoking (reactions between carbonyls, reducing sugar, and proteins), so an adequate label is important to alert the consumer. In other cases the processor cooks the products at the plant (e.g., frankfurters, bologna, ham). Quite commonly, processed meat is heated following the smoking process and this is often done in the same chamber. However, it should be realized that these two processes are different. In general, smoking is usually applied prior to heating, however some processors prefer to apply smoke at the end of the cook cycle.

Smoking is one of the oldest methods used to preserve meat. Both the drying and the deposition of numerous antibacterial compounds found in smoke (e.g., aldehydes, acids) help prevent spoilage. Today, smoking is done in dedicated commercial smoke houses (Fig. 10.5.1) and while it is based on the same principles, much less smoke and drying are applied today, mostly to provide unique flavour notes and colour. In such an application, limited amounts of the bacteriostatic compounds found in smoke are deposited on the surface (i.e., penetrating no more than a few millimeters into the product). During the smoking operation the temperature stays low while smoke generated in another area (outside the smoking chamber) is circulated. Alternatively, liquid smoke produced at specialized plants can be used.

Liquid smoke is produced by using small water droplets to capture smoke compounds moving up a long chimney. Traditional and liquid smokes are derived from various hardwoods (e.g., cherry, hickory, oak) that are used to generate the smoke by burning moist sawdust/wood shavings. Softwoods are sometimes used, but special care should be taken to avoid bitter flavour formation. Overall, more than 300 individual compounds have been identified in wood smoke (Maga, 1989; Toledo, 2007).



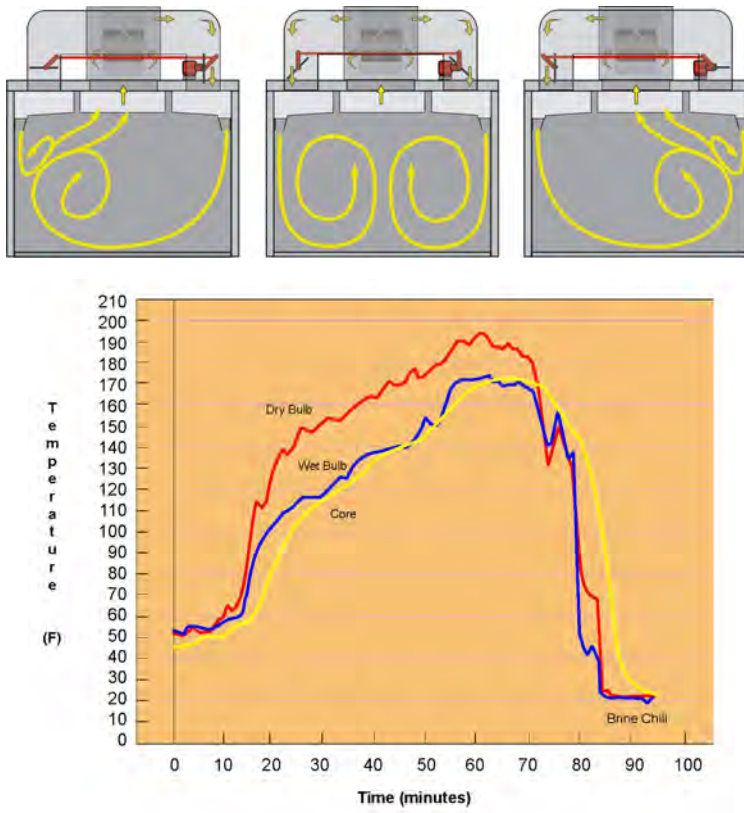


Figure 10.5.1 Illustration of a smokehouse with an air circulating unit, heater and humidifier located on the roof. The smoke unit is placed on the right side (first drawing). Changing air circulation pattern, using dampers, to achieve good heat distribution (second). Example of heating profile of 24 mm diameter wieners (third). Courtesy of Alkar.

Smoking and cooking are considered two separate processes; however, as indicated above, they are usually discussed together because they often occur in immediate succession or even simultaneously in the same location (Rust, 1987). Modern smokehouses are equipped with heat elements and fans so no product movement is required. To achieve the best smoke application the product should be in its raw state because the denatured protein film formed during cooking will reduce smoke migration into the product. Thus, smoking is commonly done at low temperatures, even though some heat is often applied to dry the product's surface. The latter is done to ensure that the smoke will not be washed off the product (e.g., condensation on the cold surface of the product can be a problem).

When liquid smoke is used, the product is dipped or sprayed prior to cooking. In all cases, smoke permeable casings (e.g., collagen, cellulose) should be used. If smoke flavourings are to be added directly into the raw batter, however, a special preparation (e.g., smoke components precipitated on sugar or dextrose carrier; sold as a dried ingredient) is used and the casings need not be permeable.

Modern smokehouses have specialized heating and ventilation systems (usually located on the top) that include fans, dampers, heating elements, and a steam supply. Many systems are computer controlled so the operator can program and save all parameters required for a specific process (e.g., heating, smoking, relative humidity, air flow).

10.6 Cooking/Heating

There are several ways to heat meat products. A brief discussion is provided below and additional information is provided in Chapter 11. Overall, heating can be done in water, oil, by hot air, or by infrared or microwave energy. Cooking produces various flavour/aroma compounds and results in distinct textural changes due to the denaturation of different muscle proteins (see Chapters 16 and 13, respectively).

a. Heating with hot air – using an oven/smoke house is one of the most common ways of cooking sausage-type products. The products are placed in a chamber or moved through a long tunnel while hot air is generated by gas burners, electrical elements, or thermal fluid. An example of a modern spiral oven that employs hot fluid to heat the air that cooks the meat is shown in Fig. 10.6.1. The main determinants of heating rate are the temperature difference between the product and air (also known as "ΔT"), air speed, relative humidity, product size, and oven capacity. Relative humidity (expressed as a percent of maximum moisture that can be held by the air at a given temperature) is particularly important as water is a good conductor.

b. Heating with water – is a faster way of transferring heat than hot, dry air. Water baths and steam kettles are used for cooking sausages and whole muscle products stuffed into moisture proof casings, glass jars, or metal tins. In other cases, unpackaged meat cuts are directly immersed in water/soup. The latter is commonly done when prolonged, moist heat is required to tenderize tough connective tissue (e.g., mature poultry/beef meat).

c. Frying – uses hot oil at a temperature of 180-195ºC. This is a fast and efficient way of transferring heat because the ΔT is high. Frying also results in a crisp outside

texture and is desirable in products such as chicken/pork nuggets. A detailed description of the frying operation, including an illustration of a continuous deep fat fryer, is provided in the Chapter 14.

d. Microwave heating – uses electromagnetic waves to vibrate water molecules in the product, and is therefore one of the fastest cooking methods. Heating results from friction of water molecule rotation due to rapid fluctuation in the electromagnetic field (915 and 2450 MHz are usually allowed for commercial microwaves, so there is no interference with communication wavelengths). As heating occurs throughout the product, this rapid process often does not allow enough time for surface browning. Therefore, other cooking methods, such as infrared, are also commonly used together to both cook and brown the product. Low microwave energy is also used to defrost meat. However, special care should be taken since there is a large difference between the heating coefficient of water and ice (see Chapter 11).

e. Infrared heating – uses a special lamp that produces a high level of infrared radiation to heat up the surface of the product. The heat is then gradually transferred, by conduction, towards the center of the product. Infrared heating is mainly used to warm up cooked products, keep products on a display counter hot, and brown the surfaces of microwave cooked products.

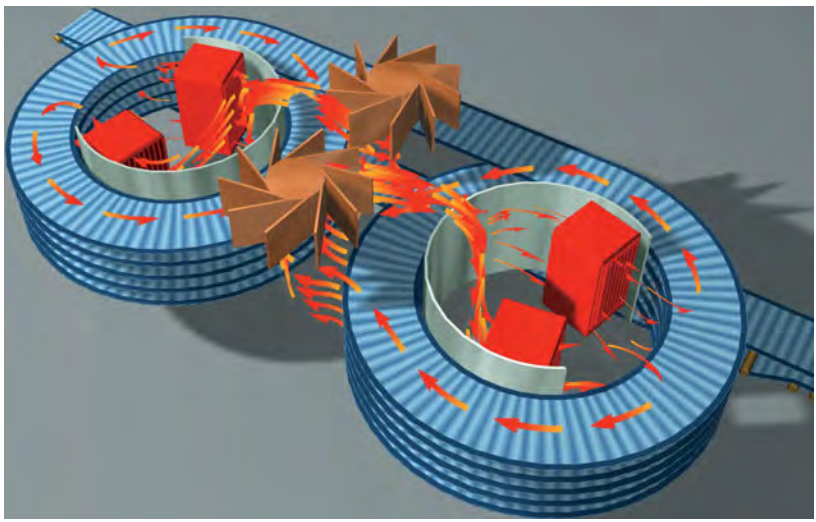


Figure 10.6.1 A spiral oven utilizing hot air for cooking meat and other food products. This oven has two separate towers/zones and each can operate under different conditions (e.g., temperature, humidity, air speed). Courtesy of Marel.

10.7 Cooling

Cooling of the heated meat products is required if the product is not consumed right away. The time to cool the product to a safe, refrigerated storage temperature is usually government mandated (see example in Chapter 12, dealing with HACCP) and can affect food safety (see example of *C. prefringens* in Chapter 15).

Cooling can be done using different mediums and methods. The most common include:

a. Water chilling by applying a cold shower to sausages in a smoke house or by immersing products packaged in moisture proof casings in cold water. When immersion is used, a counter current should be applied such that the product and water flow in opposite directions.
b. Air chilling by using cold air (e.g. -5 to 5°C) in specially designated refrigerated areas. Air speed, temperature, and humidity are major factors in establishing cooling rates.
c. Contact plate chilling for uniformly packaged products where they come in contact with very cold plates that serve as a large "heat sink" that quickly remove the heat from the product. Some of the plates are hollow and a cold fluid can be circulated inside.
d. Cryogenic chilling is used when very fast cooling is required. In this case carbon dioxide snow or liquid nitrogen are used. The boiling point of these materials is very low and therefore heat removal is fast. Figure 10.7.1 shows a cryogenic chilling/freezing operation.



Figure 10.7.1 Cryogenic chilling/freezing operation.
Courtesy of Praxair.

10.8 Peeling

The casing can be peeled at the plant or by the consumer. In the case of small diameter products such as hot dogs/frankfurters, peeling is often done at the plant by automated equipment. The products are passed through a short steam tunnel to help loosen the casing and then a small blade is used to cut open the casings along the moving product. The machine can strip off hundreds of casing links per minute. In such products, so called "easy to peel" cellulose casings are used (see micrographs of such casings in Chapter 13) to prevent excessive adherence. When large diameter products are prepared for slicing (e.g., bologna), the thick cellulose/plastic casing is removed by hand or semi-automated equipment.

10.9 Slicing

Cooked sausages and products such as whole muscle roasts/hams are often sliced and packaged in the processing plants. This provides the consumer with a convenient, easy to use product. The industry has developed high speed, automated slicing equipment with precise portion control. The introduction of computerized weighing equipment has had a significant contribution on the development of modern slicing equipment. Figure 10.9.1 shows an example of a high speed slicing line that also has a packaging module. The slicer has a large circular blade that slices the product at a predetermined thickness. The products sliced by this machine are usually long rolls (e.g., 1 – 2 meters) and the machine can later stack the slices at a predetermined number and orientation (e.g., shingle arrangement). Stacks are then placed on a conveyor belt and moved to an automatic packaging machine. The equipment can also be programmed to stack products with or without the insertion of paper/film in between individual slices or stacks. A number of new machines on the market today can self-correct weight variations using a fast feedback control mechanism that increases/decreases slice thickness. This is done by continuous computer monitoring of the weight of each stack of products.

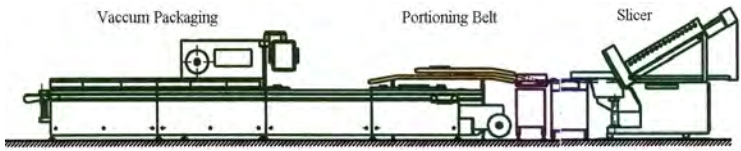
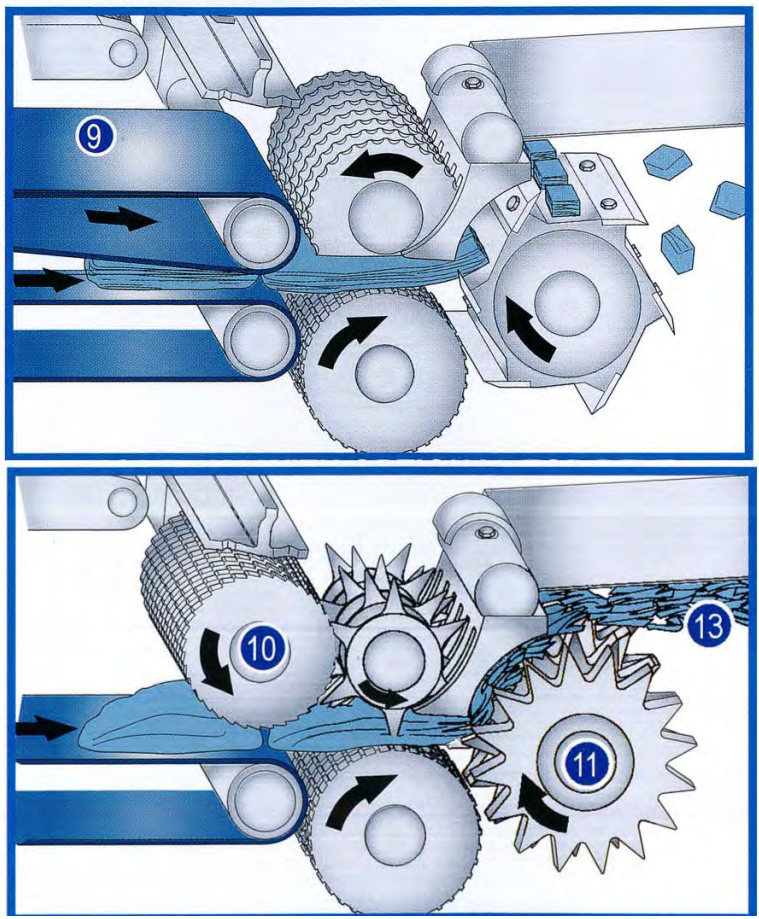


Figure 10.9.1 Illustration of a high speed slicing line. Courtesy of Dixie Inc.

Producing cubes, strips, or diced product is done for a variety of reasons. Whole muscle strips can be used in tacos by the fast food industry or consumers at home. The machine shown in Figure 10.9.2 can also be used to cut frozen or tempered fresh meat. Feed rollers hold the product flat while a moving belt advances it towards the cross-cut knives, which slice the product into strips (thickness can be changed by inserting more/less knives). The process can be terminated at this point or continued to dice the strips by a second set of circular knives. Overall, different cube sizes and shapes can be produced by spacing the knives at different distances from each other.



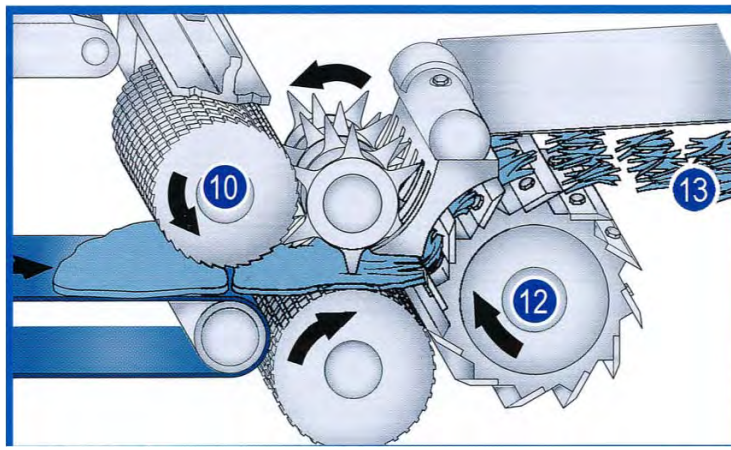


Figure 10.9.2 Principle operation of different dicing devices to produce cubes and strips. Courtesy of Urschel Inc.

10.10 Packaging

Most meat products are packaged prior to being shipped from the plant. The packaging material protects the product from physical damage, recontamination, and can also serve as a marketing tool (e.g., company logo, advertising, cooking/serving suggestions). The diversity of packaging materials and equipment used by the meat industry is beyond the scope of this book and the reader is referred to textbooks such as Robertson (2013). However, an illustration of two basic meat packaging concepts (vacuum packaging and skin packaging) are provided here and the properties of common packaging films used for food/meat are provided in Chapter 11. Figure 10.10.1 illustrates the use of a vacuum chamber to package a meat product. After the lid is closed, a vacuum is applied and air is evacuated from the chamber. The plastic bag is then sealed by applying heat to a special polymer that melts in the seam area. The process can be done manually or automatically on a high speed line. The manual operation is a batch process (i.e., each package is placed and removed manually from the chamber) while the automated process is continuous line where the product is placed on a special platform, covered with the lid, the air is pulled out, and the bag is sealed. This is commonly done in a round table configuration (to gain space), where enough time is allowed for air removal from this specially designed platform. Packaging films are usually composed of different layers, each contributing a specific function (e.g., oxygen barrier, heat sealant, strength; see Chapter 11).



Figure 10.10.1 Illustration of a vacuum packaging machine. Bags are placed with their opening facing the vacuum nozzles side and on top of the heat sealer strip (gray strip). When the cover is lowered vacuum is pulled (degree adjusted on the front panel). When the required level is reached, the upper heating sealer is lowered and forms a permanent seal. Note: the bag must have an inner layer of heat sealing polymer which allows this to take place. Photo by S. Barbut.

Skin packaging of sliced or unsliced meat products is also common. The process involves placing the product on a piece of soft or rigid cardboard or plastic film, which is then covered by a flexible film (Fig. 10.10.2). In the sealing station, heat is applied at the seams and the special polymer sealant is fused together (from both sides) to provide a complete integral seal. The packages are then separated automatically by cutting around the seal's perimeter, labelled, and moved to the boxing area.

Special ridged plastic packages filled with inert gas are also used for fragile products that might stick together and deform, such as pre sliced luncheon meats.

Meat processors can select from an assortment of different packaging materials that include single and multilayer films. As indicated before, most packaging films are composed of several layers in order to achieve desired characteristics in a cost effective manner, while still obtaining a relatively light, workable film. Saran, which has low gas and water permeability, is a popular film used in multi-layer film production, together with other materials such as polypropylene, which

provides high stretchability. Modern packaging films can have up to a dozen layers that include printed material, coating to protect the print from smearing, and layers to minimize dust collection, oxygen transmission, and provide a UV barrier.

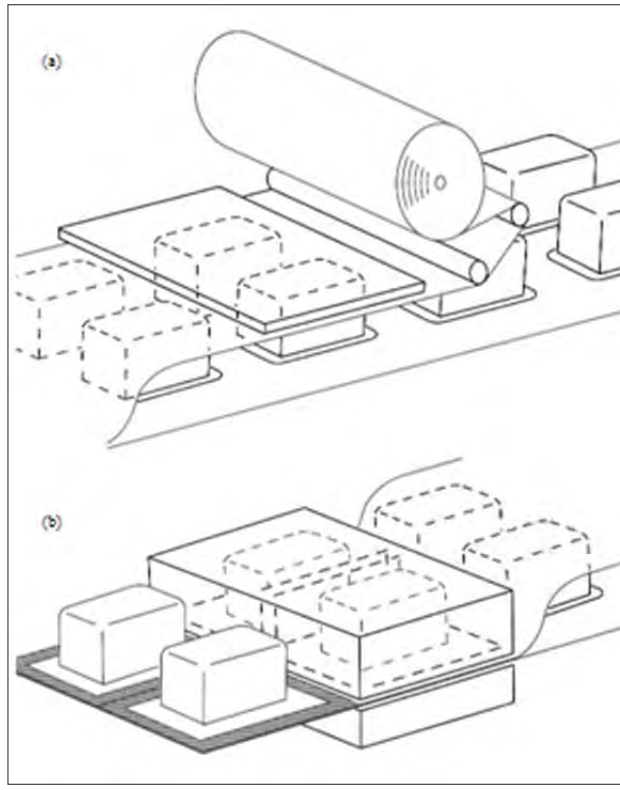


Figure 10.10.2 Illustration of the skin packaging concept showing entry to the sealing station (a) and the sealing section (b). Courtesy of Dixie Inc.

10.11 Safety Checks (foreign objects, seal integrity)

Various checks are performed by quality control personnel on random samples. In addition, all products go through metal detectors, which are mandatory in many countries and are now installed in most processing plants. Regulatory bodies such as the USDA have indicated:

> *"The extensive exposure of some products to metal equipment such as grinders, choppers, mixers, shovels, etc., causes the possibility of metal contamination ... therefore the use of electronic metal detectors is highly recommended ..."*

In addition to meeting regulatory requirements, the detectors can also help the processor:

a. Prevent damage to processing equipment
b. Comply with quality standards of various retailers
c. Avoid the cost of consumer complaints and recalls

The most common types of metallic contamination in the food industry include ferrous (iron), copper, aluminum, and various types of stainless steel. Of these, ferrous metal is the easiest to detect, and relatively simple detectors, or even magnetic separators, can perform this task well (Anonymous, 1996). Stainless steel alloys are extensively used in the food industry and are the most difficult to detect, especially the common, non-magnetic grades such as 316 (EN58J) and 304L (EN58E). Non-ferrous metals such as copper fall between these two extremes. To detect other materials, such as hard plastic or glass, x-ray machines can be used.

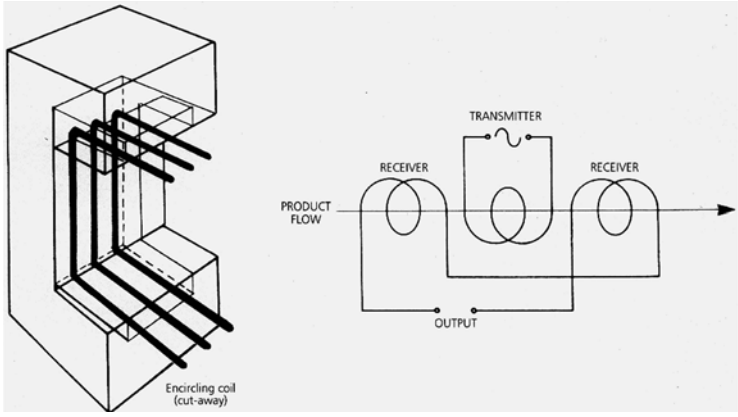


Figure 10.11.1 Illustration of the principles used in constructing a metal detector. Courtesy of Safeline Inc.

Metal detectors that employ a balanced, three-coil system are common since they have the capabilities to detect small particles of non-ferrous and stainless steel. The three coils are wound on a non-metallic frame or former, each exactly parallel

with the other (Fig. 10.11.1). The center coil is connected to a high frequency radio transmitter and the coils on either side of the center coil act as radio receivers or aerials. As these two coils are identical and the same distance from the transmitter, they pick up the same signal and an identical voltage is induced in each. When the coils are connected in opposition, they cancel out and result in zero output but when a metal particle passes through the coil arrangement the high frequency field is disturbed and the state of perfect balance is lost and the output is no longer zero. The resulting signal is processed, amplified, and used to detect unwanted metal (Anonymous, 2014). To prevent airborne electrical signals or nearby metal items and machinery from disturbing the detector, the complete coil arrangement is mounted inside a metal case with a hole in the center to allow for product passage. For suggested installation points, such as after packaging fresh meat or after freezing fried products, see the HACCP generic models in Chapters 6 and 14, respectively.

An x-ray detector, shown in Figure 10.11.2, can also be used at the end of a line. The x-rays that go through the product reveal items with different densities within the food matrix (i.e., same as used for medical imaging or security checks at airports). The equipment scans each package and materials reflecting x-rays are seen on a computer screen. A computerized image analysis system can be used to sound an alarm, take a picture, and/or kick the product out of the line. Many fast food and supermarket chains require that their suppliers use such equipment.



Figure 10.11.2 An in-line x-ray detector system. The system can be programed to detect and automatically eject products with foreign objects (e.g., bone fragments with a minimum size of 2 mm). Images and data are saved to assist employees to determine the location and quickly deal with rejected samples. Courtesy of Marel.

10.12 Labeling

Package labeling is usually done at the plant, as it is not difficult to customize labels for each supermarket/grocery store. High speed weighing equipment and printers place exact information (e.g., weight, price, best before date) on each package. This is usually done on top of pre-made colourful labels/stickers that are placed on the product. Figure 10.12.1 shows the concept of high speed automated labeling at the end of the line.

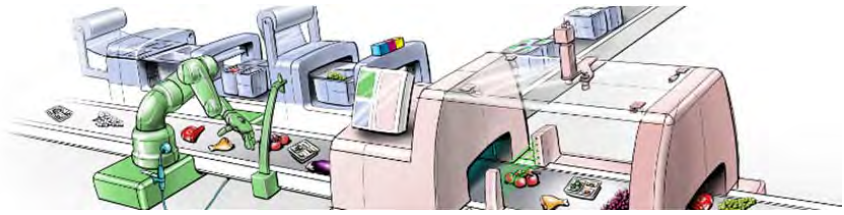


Figure 10.12.1 Concept of high speed labeling using image analysis and automatic robotic system. From www.picknpack.com.

10.13 Storage and Distribution

After the product has been packaged it can go directly to the store (i.e., put on a truck) or be stored at the plant/warehouse for a certain period of time. Freezing can be used as another option to extend the product's shelf life. As both raw and cooked meat products are susceptible to spoilage (unless canned or fully dried), they should be stored at a low temperature. Today, meat companies and supermarkets invest a lot of money to maintain and improve their cold chain distribution channels. In addition, government agencies monitor and inspect the distribution system and ensure consumer safety.

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11

HEAT PROCESSING, COOLING AND PRESERVATION METHODS

11.1 Introduction

Food preservation has played a very important role in human development. Cultures that could gather/grow food and keep it during harsh times survived, while those that could not, died, or had to go to war. Some foods are easy to process and preserve while others, like fresh meat, present a challenge to processors, retailers, and the consumer. Meat is a perishable item because it contains most nutrients required for bacterial growth, the pH is not prohibitive to most bacteria, and it has abundant amounts of free water. If proper storage conditions (e.g., refrigeration) or preservation treatments (e.g., salting, heating, irradiation) are not employed, the meat will spoil within a matter of hours or days. In areas where refrigeration is not available, a live market is very popular. In other places, special procedures are used (e.g., HACCP; see Chapter 6) to ensure low microbial counts during processing and to guarantee consumer product's safety. The latter is also very important because meat, as well as other foods, can carry pathogens that could harm the consumer. Today, all countries employ rules and regulations to supervise food production and guarantee wholesomeness.

Some of the most prevalent preservation techniques used today were established thousands of years ago, before scientific knowledge about microbial/chemical spoilage and pathogens was available. Our ancestors preserved food by drying, heating, cooling, freezing, fermenting, and adding ingredients (e.g., salt). Scientific development has helped us learn more about the processes involved in food preservation. Today we can even use molecular biology to select strains of microorganisms to produce antimicrobial compounds that inactivate pathogens during the fermentation of meat and dairy products (e.g., bacteriocins, discussed later in the chapter). Scientific advancement has also contributed to the development of equipment such as microwave ovens and to mathematical

models that can be used to optimize heating (Fig. 11.1.1), cooling, and other processes. In this chapter you will find more examples and descriptions of the main processes used by the industry.

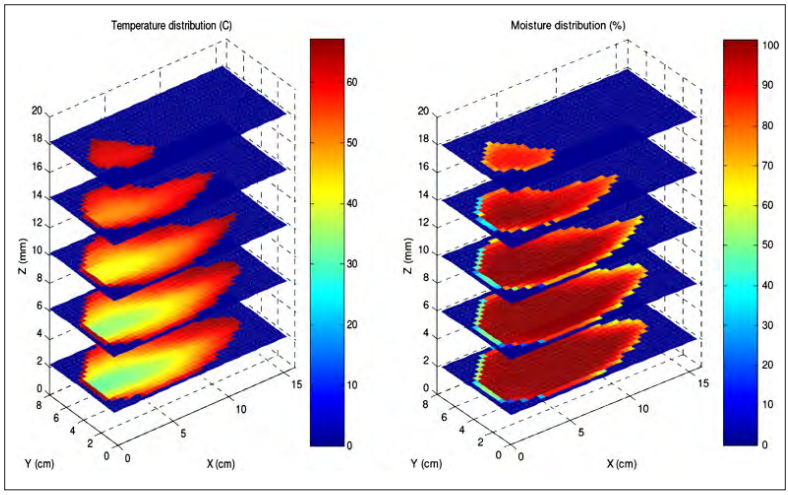


Figure 11.1.1 Visualization of simulation results showing the temperature (T) and water mass fraction (y_w) distribution in various horizontal cross sections of a chicken filet. Experiments were performed at T_{oven} = 170°C and T_{dew} = 90°C (see text for more information). The snapshot is taken after 28 min of heating. From van der Sman (2013).

As indicated above, food preservation by humans has a long history. Historians describe two major periods in terms of food consumption. The first is called the food-gathering period, which spans from the time of human origin, over one million years ago, to eight to ten thousand years ago. The second is called the food-producing period, which continues until today (Jay et al., 2005). It is believed that food spoilage problems were encountered early in the second period when people started to produce and store their own food for extended periods of time. Spoilage and disease problems caused by improper storage required innovations and solutions. Drying was one of the earliest methods employed to store foods like grain and meat slices. Sun dried grain and meat could be stored for extended periods of time. Some cultures discovered that drying meat while smoking it over an open fire substantially extended the shelf life. Later, fermentation of grains resulted in the production of beer. This innovation can be traced back to ancient Babylonia around 7000 BC. The Samaritans are believed to have been the first great livestock breeders as well as dairymen who were among the first to make butter around 3000 BC. They were also known to use salted meat, fish, and dried skins.

The early Egyptians in 3000 BC were known for their knowledge in fermenting dairy products and making cheese. Salted meat was also known to be used by the Israelites, the Chinese, and the Greeks; the latter also passed it to the Romans. Evidence of sausage fermentation by the ancient Chinese and Babylonians go as far back as 1500 BC. While it is certain that people did not understand the nature of food preservation by fermenting microorganisms, they used fermentation fairly successfully. This was probably done by "seeding" new batches with material from a successful previous batch (known today as transferring the "right culture"). Advances in understanding food poisoning and spoilage are believed to have been made within the first millennium AD (Jay et al., 2005). Concern over butchering practices is mentioned for the first time in documents regarding Swiss butchers handling marketable and non-marketable meat in 1156. In 1276, a compulsory slaughter and inspection order was issued in Augsburg. Although people were aware of quality attributes at that time, it is doubtful that there was any substantial knowledge of the actual causal relationship between meat and microorganisms. A monk named A. Kircher was one of the first to suggest the role of bacteria in food spoilage and carcass decay. He referred to "worms" that were invisible to the naked eye but his observations did not receive wide acceptance. In 1765, L. Spallanzani showed that beef bouillon that had been boiled for an hour and sealed, remained sterile and did not spoil. His experiment was designed to disprove the theory of spontaneous generation but it did not convince critics since they thought oxygen was vital to the process. A hundred years later, Schwann repeated a similar experiment, but allowed sterile air to be supplied (by passing it through a heated coil) and demonstrated no spontaneous generation.

Pasteurization, developed about 200 years ago, was one of the most important events in food preservation. Francois Appert succeeded in preserving meat in glass jars after keeping it in boiling water for extended periods of time. His discovery of the canning process happened in 1795 as a result of the French government prize offer for discovering a practical method for food preservation. In 1810, Appert was issued a patent for his process. This discovery actually preceded Lois Pasteur by about fifty years. Pasteur, who is considered the father of modern microbiology, demonstrated the role of bacteria in wine spoilage and suggested ways to prevent contamination/recontamination and thus prevent spoilage. The process developed by Pasteur is now known as pasteurization.

Below are the origination dates of common food preservation processes:

1774 – first extensive use of ice in transporting meat by sea (Jay et al., 2005)
1810 – commercial canning started

1878 – first successful cargo of frozen meat from Australia to England
1890 – commercial pasteurization of milk started in the US
1890 – mechanical refrigeration for fruit storage began in Chicago
1908 – sodium benzoate was given an official sanction as a preservative in the US
1916 – quick freezing of food was developed in Germany
1920 – first publication describing spores and heat resistance at 100°C
1923 – "general method" for calculating thermal processes was published
1928 – first commercial use of controlled-atmosphere storage for apples in Europe
1929 – patent from France proposing high energy radiation for processing foods
1943 – first application of ionizing radiation to preserve hamburger meat
1950 – D-value concept (for microbial lethality) came into general use
1954 – nisin patented in the UK for use in certain processed cheeses
1955 – sorbic acid approved for use as a food preservative in the US
1967 – first commercial food irradiation facility in the US (the second became operational in 1992 in Florida)
1967 – nisin accorded GRAS status in the US
1990 – irradiation of poultry approved in the US

This chapter discusses various means of preservation and equipment used by the meat industry. The reader is also referred to Chapter 15, which discusses interventions during primary processing (e.g., evisceration, cut up of meat) and microbiology. Combining different technologies is known as the Hurdle Technology and is discussed in Chapters 6 and 12.

11.2 Heating

11.2.1 General

Heating is one of the most common ways to prepare food items (e.g., meat, baked goods, jams). It is used for a variety of reasons that include texture modification, the creation of flavours and colours, and the inactivation or destruction of microorganisms. The latter is also used in other industries (e.g., medical), and the degree of microbial inactivation depends on the temperature and exposure time. Generally speaking, two levels of heat are used for microbial inactivation in food.

a. Pasteurization at a moderate temperature of about 60-90°C is designed to inactivate some of the spoilage and most of the non-spore forming food poisoning microorganisms. Pasteurization extends the product's shelf life but the product must be refrigerated or preserved by other means (e.g., reducing water activity).
b. Sterilization at temperatures > 100°C achieves "commercial" sterility, whereby food products (e.g., canned food at 121°C) can be stored at room temperature for long periods of time. This process results in inactivation of all spoilage and food poisoning microorganisms and their spores.

It is important to note that both heat treatments will result in changes to the texture, flavour, odour, and microbial load of the product. The extent of change increases with temperature and exposure time.

Cooking methods vary from cooking the meat in its own juices (usually at < 100°C) to frying in oil (usually 180-195°C) and grilling (BBQ temperature can be 350°C). Heat can be transferred to the product by:

a. Conduction – heat transfer between substances in direct contact. Heat is conducted from an outside source and is directly transferred from one particle to the next with relatively no mixing and no movement of the product (Fig. 11.2.1.1). This is usually true for solid and very viscous foods.
b. Convection – heat transfer by the mixing and moving of fluid particles. Heated particles are less dense and move up to the top, whereas colder particles are denser and sink to the bottom in a so called natural convection (note: forced convection is also possible by using a fan in an oven or a pump in a circulating water bath). Convection is more efficient than conduction because it results in mixing hot and cold particles through heat currents. Agitating, pumping, or steering can achieve additional mixing during heating. When a commercial sterilizer is used to heat food cans, it is important to determine and place thermocouples at the coldest point(s). In liquid food (e.g., a can of chicken soup with small particles), the coldest point in the can is approximately one-third up from the base. In solid food, however, the coldest point will be in the geometrical center of the can.
c. Radiation – heat energy is transferred through space, where a hot object gives up heat. For food applications, electrical heating elements and infrared lamps are commonly used to emit energy, which is absorbed by the product's surface.

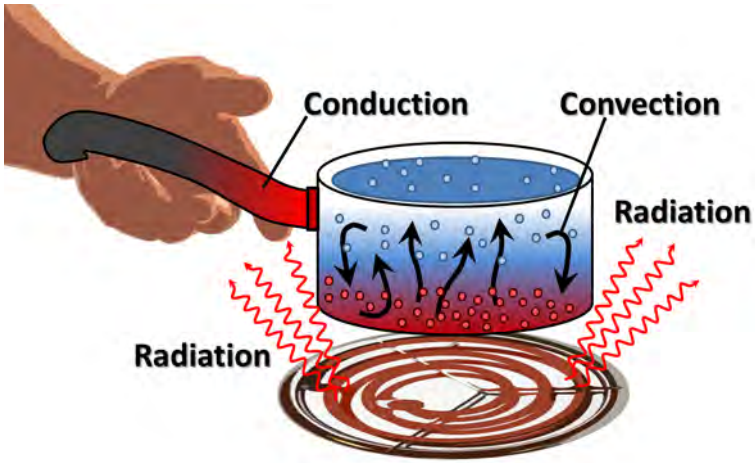


Figure 11.2.1.1 Heat transfer into food via conduction, convection and radiation. From NASA http://www.ces.fau.edu/nasa/module-2/correlation-between-temperature-and-radiation.php.

Heat transfer depends on factors such as the temperature difference between the heat source and the product (ΔT), the length of heating, the food's composition (e.g., moisture to fat ratio), and the heat transfer medium (e.g., water, oil). Thermal conductivity is the term used to express the rate of heat movement through a material (i.e., movement can be by conduction or convection). The other term needed for the calculation is the specific heat, which quantifies the amount of energy (heat) required to change the temperature of one gram of material by 1°C. Lean meat has more moisture and thus has a higher specific heat than fatty meat, meaning that it required more energy to heat up identical quantities.

Heating meat and other foods is done in hot air ovens, microwave ovens, water, and oil. The different methods provide certain textural and flavour characteristics to the product. Choosing one method over another is usually based on factors such as the desired product identity (e.g., crust on a fried product), equipment available, operating costs, and government regulations. Part of a meat cooking operation can also include a smoke application, which takes place in specially designed ovens. The effect of smoking on preservation is discussed later in the chapter.

11.2.2 Use of Hot Air Ovens

Hot air is frequently used to heat and cook different food products including meat. Small, home type ovens are designed to handle a few kilograms of product

whereas industrial ovens can handle a few tonnes of product every hour. In home type ovens, the air is usually heated and dried by electrical elements. This is not the best medium to transfer heat but is commonly used because other characteristics can be developed (browning of the surface, crust formation, etc.). In general, when moisture is added to the air, heat transfer is improved. This option is commonly used in industrial ovens where yield is a critical factor. Air heating can be done in several ways and can include passing the air over a hot surface (e.g., metal surface heated by electricity or hot oil) or using a flame to directly heat the air (e.g., a gas burner inside an oven). The hot air is then circulated around the product and heat is transferred by convection to a solid piece of meat. Figure 11.2.2.1 shows an industrial hot air oven. There are different configurations that include stand-alone heating cabinets, linear ovens that use a belt to move food through, and spiral ovens that have a smaller foot print than linear ovens because the product is moved to different levels. The climate inside the oven can be controlled by adjusting air speed, relative humidity, and air temperature. Controlling these parameters allows the operator to estimate the required cook time, yield, degree of microbial inactivation, colour, texture, etc. To optimize conditions and determine microbial inactivation, the operator needs data from the oven and the products. Sensors to measure temperature, relative humidity, air speed, colour, and weight can be positioned at different places inside the oven. The most common sensor is the thermometer, which shows temperature changes and can be used for HACCP plan validation. Monitoring the heating profile of a specific product is also done to obtain important information that can help optimize cooking conditions. Table 11.2.2.1 shows six heating conditions used to treat chicken breast fillet samples and Figure 11.2.2.2 shows the temperature profiles of the skin (surface) and core.

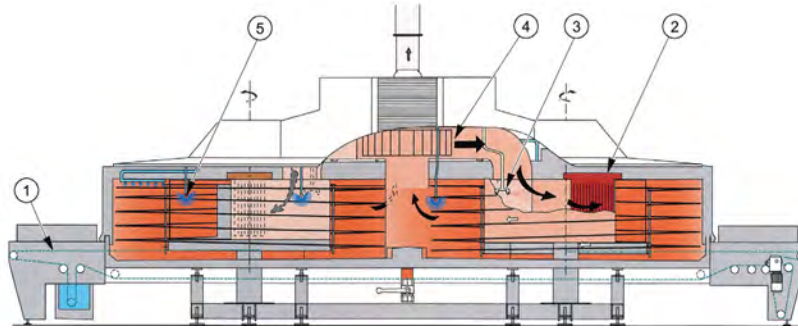


Figure 11.2.2.1 An example of a large scale industrial hot air oven with two compartments/towers: (1) conveyer belt, (2) heating elements, (3) steam injection, (4) fans, and (5) a cleaning in place system. Courtesy of Townsend.

Table 11.2.2.1 Setup of the cooking experiments showing six heating conditions used to treat chicken breast fillet samples. Adapted from van der Sman. (2013).

Index	T_{oven} (°C)	T_{dew} (°C)	v_{air} (m/s)	t_e (min)	Mass (g)
Heat 0	45	45	10	160	192
Heat 1	45	45	10	80	164
Heat 5	60	60	10	60	174
Heat 7	60	60	10	40	142
Heat 10	80	70	10	40	196
Heat 12	80	70	10	20	156

Data were obtained from a linear industrial tunnel oven where chicken breast fillets were placed on a grid (note: the grid might have caused slight differences in air flow compared to a linear oven without a grid; however all treatments were subjected to the same tray configuration). Oven temperature (T_{oven}), dew point (T_{dew}), and air velocity (V_{air}) were all controlled in this relatively closed environment. The results are typical of meat heated in an oven and the graphs show that the surface and core temperatures reach a steady value after 20 min. This steady value is equal to the so-called wet bulb temperature, which is quite near the dew point of the air flowing over the chicken fillets. The author (van der Sman, 2013) also presented data for heating at 55, 70, and 100°C where similar behaviours were observed. The time to reach this steady state value depends on the airflow velocity, which determines the external heat transfer coefficient and thus the time scale of the energy transport. During extensive cooking the surface temperature starts to deviate from the wet bulb temperature because water activity at the surface drops below unity. In that case, local equilibrium at the surface demands that the surface temperature rise. The surface temperature will then approach the air temperature. After a lag time, the core temperature will also start to rise. At air temperatures below boiling the core temperature will also move towards the air temperature. At air temperatures above boiling, internal evaporation will occur and the core temperature will remain at the boiling point.

As indicated in the introduction, modeling of the heating process is becoming more popular. This procedure allows for simulations that can help predict the product's temperature and optimize oven conditions. An example of a model developed for oven heating and how it was created is provided below. Figure 11.1.1 shows simulation results from the experiment with the chicken breast fillets mentioned above.

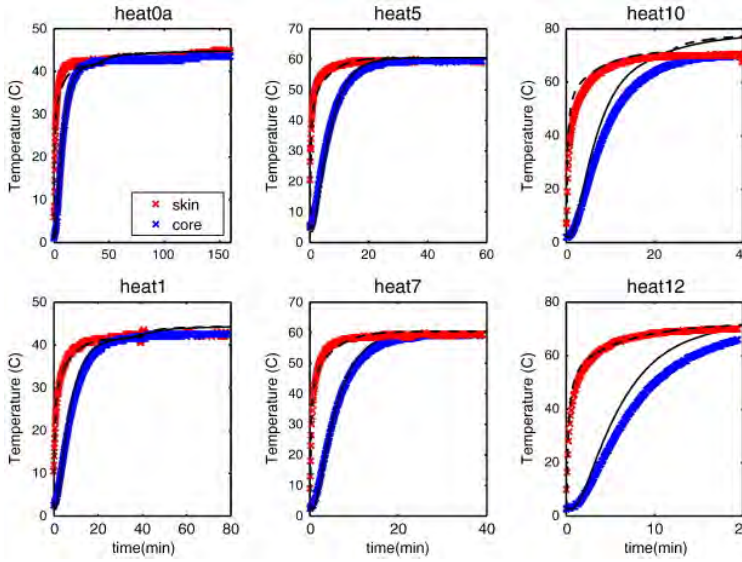


Figure 11.2.2.2 Comparison of experimental (symbols) and numerical (lines) values of core and skin temperatures for experiments heat0a to heat12. From van der Sman (2013).

To simulate moisture content, the authors obtained experimental data for water holding capacity as a function of temperature, together with a fitted sigmoid function (Fig. 11.2.2.3). Such curves have also been published by other groups in the past. In order to do the simulation, good data regarding the shape and volume of the sample was required. Figure 11.2.2.4 shows a line scan obtained for a chicken fillet. This was used later on for the heating simulation at 170°C (Fig. 11.1.1). The simulation shows temperature and moisture distribution after 28 min where the surface temperature is near boiling point and the product is drying out. A step gradient in moisture content is also seen. The model predictions (some presented in Fig 11.2.2.2) were obtained after fitting the model to the experimental data via least squares. The parameter estimation was done via trial and error, as the non-linear parameter estimation, using Levenberg–Marquardt, did not converge. By comparing the model predictions and the experimental results (Fig. 11.2.2.2), the author concluded that the evolution of temperature is well predicted in the majority of the experiments, which were characterized by cooking times $\leq$ 40 min (i.e., common cooking time used by the industry and consumers under such climate settings). For these experiments, cooked yield prediction was reasonably good (within 5% of the experimental data). However, for some experiments there

was poor quantitative agreement between the model and the experimental results. For temperature, the predictions started to deviate when cooked times were longer than 40 min, which is about the end of the constant drying rate regime. For these experiments, the model also failed to accurately predict the final mass of the cooked meat. It appeared that, after reaching the falling drying rate regime, the model's prediction for moisture transport was too low. There was too little evaporative cooling effect and the core temperature rose too quickly to the oven temperature. However, the author observed that the model predictions were qualitatively in agreement with the temperature behaviours shown in the experiments. In the constant drying rate regime the surface temperature was at the wet bulb/dew point and in the falling rate regime it gradually rose towards the oven temperature.

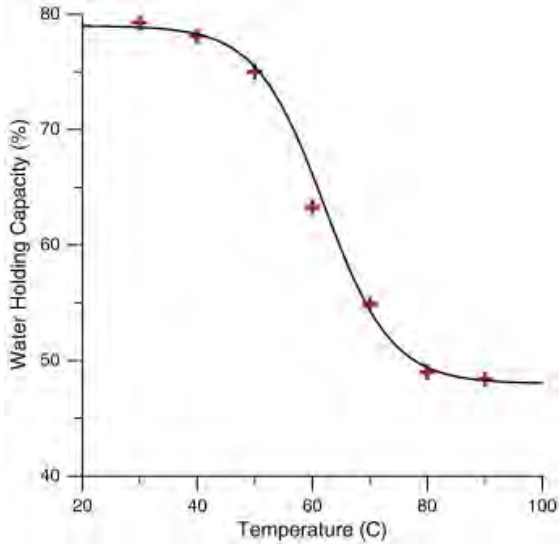


Figure 11.2.2.3 Water holding capacity as a function of temperature T, as obtained from cooking loss experiments. The WHC is expressed in mass fraction of water. From van der Sman (2013).

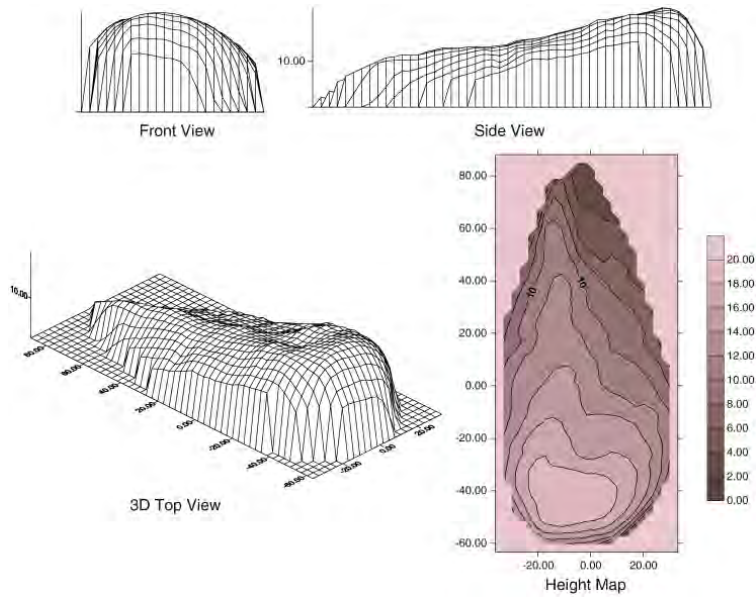


Figure 11.2.2.4 Line scan of a chicken fillet of 104g. All dimensions are in mm. From van der Sman (2013).

11.2.3 Use of Water Heating (Boiling, Canning)

Water is a better medium than air for transferring heat to a meat product. The meat industry uses water to heat different types of meat cuts and further processed products. The meat can be heated outside or inside packaging. When cooking without a package, the meat interacts with the cooking medium where liquid/flavour compounds can be transferred into or out of the product. This is usually done by cooking raw meat in boiling water or broth. Processed products such as sausages and marinated cured muscle products are usually packaged in moisture proof casings prior to putting them in a kettle filled with hot water (e.g., 80-100°C).

For high temperature heat processing of canned food, water is also used as the heat transfer medium. Because temperatures of 120°C are usually used in canning operations, high pressure equipment is employed (i.e., need to suppress the boiling temperature of water). High pressure vessels come in a variety of sizes and forms. Small pressure cookers are often found in homes, whereas large scale cookers are used by the industry.

The canning process achieves so called "commercial sterility" and is commonly done in a retort (a large metal chamber capable of operating under pressure). The high temperature (120-122°C) helps reduce the time required to destroy heat resistant microorganisms that are capable of forming spores (e.g., *Clostridium botulinum*; see Chapter 15). Meat products that are processed in this way include canned soups, chunked meat in gravy, stews of meat cubes with vegetables, etc. These products are usually packed in metal cans, glass jars, or flexible retort pouches and can be stored at room temperature. As indicated above, the nature of the food dictates the way heat penetrates the product. For solid foods, such as chicken rolls, heat is transferred by conduction, and for liquid or particulate food, such as chicken soup with small particles, convection currents provide a faster heat transfer than for solid foods. Other factors that determine the rate of heat transfer are the container's packaging material (stainless steel containers have a thermal conductivity of about 20 $Wm^{-1}K^{-1}$ whereas glass and polyethylene containers have values of 0.52 $Wm^{-1}K^{-1}$ and 0.55 $Wm^{-1}K^{-1}$, respectively; Fellows, 2009), the size of the container, the temperature difference between the food and the heating medium, the shape of the container, and container agitation.

The rate of heat penetration must be measured so the required residence time for microbial destruction at the coldest point of the container can be calculated. As indicated previously, thermocouples are placed in sample cans, and the slowest heating point depends on whether the food is solid or liquid. The time-temperature calculations to achieve commercial sterility (also known as 12 log reduction or 12-D) can be found in Fellows (2009) and other textbooks.

Different types of retorts are available on the market and can be divided into batch and continuous operations. In a batch-type operation, cans/jars/pouches are placed in a large basket and lowered into a chamber that is then sealed. Then the temperature is raised by injecting live steam. In a continuous operation, the cans are moved through a system where a hydrostatic head is produced between two columns ("legs") of water. This allows for finer control over the processing conditions and, hence, produces a more uniform product. The first "leg" time is used to raise the temperature of the product gradually before it is transferred into the steam chamber. In the steam chamber the food is heated to the required temperature (usually 121°C) and kept at this temperature for a predetermined time. The second "leg" cools the product initially before it is further cooled by water sprays and cold water dips. Sealing the can prior to the operation is extremely important. The high temperature causes pressure build up inside the can and therefore the seams should be able to withstand pressure. Plastic polymer is usually placed within the seal groove (e.g., white plastic ring in a metal lid of a glass jar). Incorrect sealing or defects in the seam will cause leakage and suction of outside water or air, which will contaminate the food inside. Metal cans commonly have a double seam construction, which is done by a seaming machine. In the first step a roller forms

the cover hook around the body of the can. The second operation tightens the two hooks together to produce the double seam. A thermal plastic sealing compound is also placed between the can and the lid and melts during the heating process to fill the space and provide an additional barrier against contamination. Retort pouches are composed of various layers (e.g., aluminum foil, polyethylene) where one is a thermal plastic material that becomes semi-fluid when heated and sealed.

11.2.4 Use of Oil (Frying)

As a cooking medium, oil allows for a very high cooking temperature (175-195°C). The oil temperature is kept below the smoke point, where the oil starts to burn and degrades very quickly. Frying allows for very fast heating and the formation of a unique surface texture called a crust (note: crust can also be formed during hot air heating). Frying time is directly related to oil temperature: the higher the temperature, the faster the product will cook. Kovácsné-Oroszvári et al. (2005) examined the effect of pan temperature and meat patty diameter on heating rate and mass transfer of hamburgers prepared by double sided frying. Overall, pan frying is a process that involves simultaneous heat and mass transfer and the quality of the final product is influenced by cooking temperature, time, product shape, and the thermo physical characteristics of the food. Temperature profiles of patties prepared from brisket (fat content 39%) are shown in Figure 11.2.4.1 as a function of frying time [measured at the center (5 mm) and 2 mm below the surface] at 150 and 175°C. The heat transfer at 100°C (measured 2 mm below the surface) was slower than during frying. It also resulted in minimal crust formation compared to the frying treatment (visual observation).

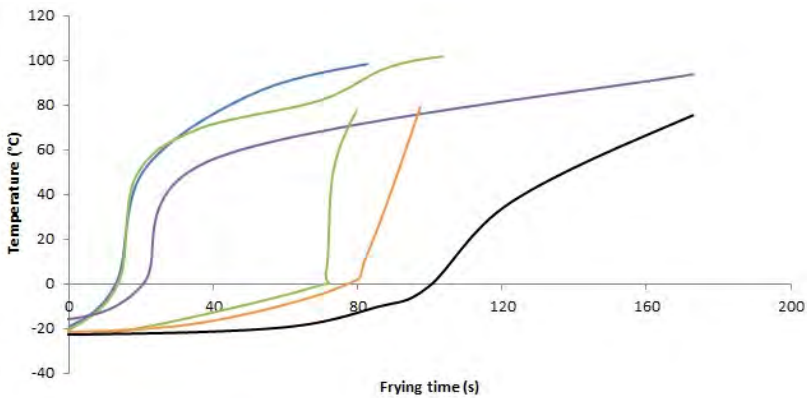


Figure 11.2.4.1 Measured temperature profiles (at the centre (5mm) and 2mm below the surface) of a beef burger (D = 10 cm) prepared from fat brisket as a function of the frying time. Three lines on the left are for 2 mm below surface (175, 150 and 100°C). Next three lines for 5 mm, in the same order. From Kovácsné-Oroszvári et al. (2005).

Water loss was related to the initial water content and increased with frying temperature and decreasing patty diameter (Fig. 11.2.4.2). At a pan temperature of 100°C the average water loss value for patties that were 10 cm in diameter was 33%, whereas it was 39% for patties that were 3 cm in diameter. After frying, the temperature 2 mm below the surface was about 88°C for all diameters, which was well below the boiling point of water. Therefore, it can be assumed that the water losses at the lowest cooking temperature occur mainly in the form of drip.

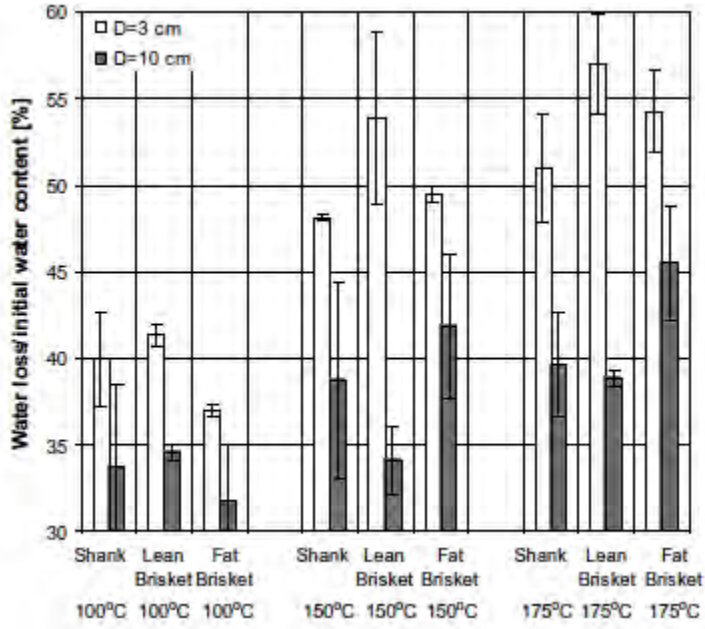


Figure 11.2.4.2 Water loss related to the initial water content expressed as a function of the frying temperature for fat brisket, lean brisket and shank. Mean values are shown with standard errors. From Kovácsné-Oroszvári et al. (2005).

11.2.5 Microwave and Radio Frequency Heating

Microwave and radio frequency energy belong to the non-ionizing radiation category (Fig. 11.2.5.1). In order to prevent disturbance with other communication bands, the frequencies that are permitted for use are 433, 915, 2450 and 5800 MHz for microwave, and 13.5, 27.1 and 40.6 MHz for radio (i.e., also depends on the

country). Frequency heating is based on inducing molecular friction within the water molecules of a food (e.g., lean meat 70% water). Water molecules consist of two hydrogen atoms attached to an oxygen atom and are considered to have electric dipoles because the oxygen atom carries a slight negative charge and the hydrogen atoms carry a slight positive charge as a result of the angle between them (107°). Microwave heating applies a rapidly oscillating electric field that reorients the water molecules. This realignment causes friction, which heats the product. There is a short delay of a fraction of a millisecond before the dipoles respond to the oscillating electrical field called the relaxation time. Relaxation time is affected by the viscosity of the media and depends on temperature. When water changes to ice, the dielectric constant (i.e., the ratio of capacitance of the food to the capacitance of air or, in some cases, vacuum) falls and continues to decrease as the ice is further cooled. This means that ice is more "transparent" to microwave energy than water, and can cause problems when food is thawed in a microwave, as will be discussed below.

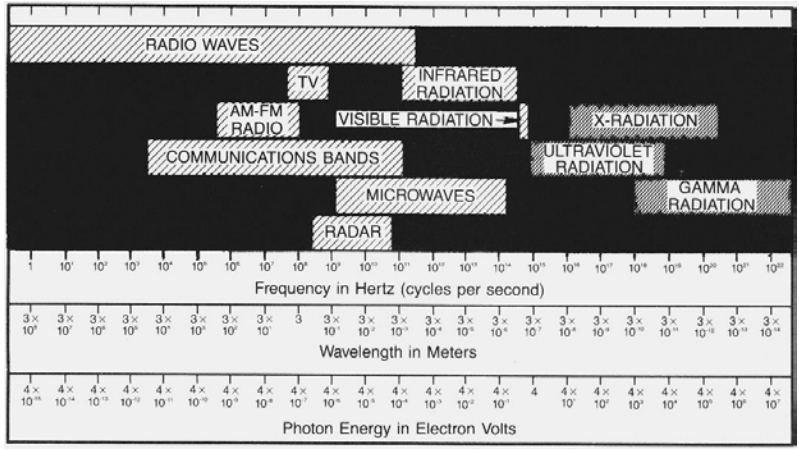


Figure 11.2.5.1 The frequencies, wavelengths and photon energies of the major part of the electromagnetic spectrum. The boundaries of the named segments are more or less arbitrary, and there is now some tendency to reduce the overlapping by defining the range between TV and infrared radiation as microwaves and the range between visible radiation and x-radiation as ultraviolet. From CAST (1986).

Microwave designs can vary but all have a power source called a magnetron (a cylindrical diode) and a waveguide to bring the radiation to the area where the product is positioned. The magnetron (power can range between 300 to 3000 W) consists of a ring of resonant cavities that form the anode, while the cathode is a

hot metal cylinder capable of producing free electrons; the cathode is positioned inside the anode ring. When a high voltage is applied, the electrons give up energy to form rapidly oscillating microwave energy, which is directed to the waveguide by electromagnets. The food in the heating chamber may rotate on a turntable, or a rotating antenna can be used to evenly distribute the energy (Fellows, 2009) in order to reduce "shadowing" or areas not exposed to radiation.

A radio frequency oven is equipped with a generator coupled with a pair of electrodes, called the RF applicator. For industrial equipment there are two different applicators on the market. The first is conventional RF equipment where the electrodes and generator are closely connected. The second is 50Ω RF equipment where the electrodes and the generator are connected with a high power coaxial cable and are controlled by a matching box. Each system has advantages and disadvantages and selection depends on the application (Aymerich et al., 2008).

High frequency heating, especially in the microwave, tends to create hot and cold spots as a result of product geometry, composition, dielectric properties, and packaging. A way to control the generation of hot and cold spots is to insert vapour into the oven cavity to help distribute the heat (Aymerich et al., 2008). These designs require trained staff, good maintenance, and must be done in collaboration with equipment producers.

Radio frequency heating can result in more even cooking and a better penetration depth than microwave heating because of the lower frequency. However, there are some challenges related to the physics of radio frequency heating (Tornberg, 2013) such as arching, which occurs when electric field strength across the sample is too high and thermal run away heating, which is the formation of hot spots in a heterogeneous medium.

Microwave heating is not dependent on product thickness, takes less time than conduction in a conventional oven, and is sometimes referred to as "heating from the inside". However, the rapid heating usually does not allow enough time for browning on meat cuts. Therefore, some new commercial and residential ovens include both microwave and convection heating to speed up cooking and provide browning.

Microwave heating is also used to thaw meat, where fairly large blocks of frozen meat can be tempered fairly quickly. However, as mentioned before, water has a higher dielectric constant than ice and, as a result, heats faster than ice. This can result in non-uniform heating where some portions of the food may be cooked, while others remain frozen. To overcome this problem, microwave power should

be reduced during thawing to allow enough time for temperature equilibrium. When the meat industry uses microwaves to temper meat (i.e., raising the temperature from -25° to -3°C), there is a limited phase change and overheating does not present a major problem. Tempered meat blocks can then be easily sliced or boned. Using microwaves for defrosting is advantageous in reducing thaw time (e.g., minutes instead of days for large meat blocks), drip loss, and microbial counts, since very little time is allowed for microorganism recovery and growth. High frequency heating can also be used to inactivate microorganisms. For example, Apostolou et al. (2005) reported a 6 log reduction of *E. coli* O157:H7 in chicken portions exposed to 2450 MHz, 650 W for 35 sec. However, attention to sample size, uniformity within the microwave, and temperature are critical.

Packaging material should be transparent to microwave energy as materials such as metal will reflect microwave energy and result in arcing as well as excessive heating of the packaging material. Therefore, various plastics, glass, and paper with low dielectric loss are commonly used (Fellows, 2009).

11.2.6 Infrared heating

Infrared heating is mainly used to heat food surfaces, keep food hot on a display, and to dry food. There is no contact between the lamp and the food. The technology employs electromagnetic radiation that is emitted by hot objects and absorbed by the food. Infrared heat is less controlled and has a wider useable range of frequencies compared to microwave heating (Fig. 11.2.5.1). In addition, penetration depth is lower and heat transfer actually relies upon conduction from the surface to the interior of the food. The rate of heat transfer depends on factors such as the distance from the heat source, the food's surface property, and the temperature difference between the food and the heating lamp. Equipment includes quartz/halogen tubes fitted with electric filaments, ceramic heaters, and metal heaters. The temperature of the heating element can range from 900°C for a quartz tube operating at a medium wavelength, to 2,200°C for a heat lamp operating at a short wavelength. Infrared radiation is frequently used by the industry to keep display food hot and to dry products such as cocoa, pasta, and flours. Drying is mentioned here because solar energy (indicated earlier as a historic was of drying meat) consists of approximately 48% infrared energy.

11.2.7 Ohmic Heating

Ohmic heating is based on the resistance of food to convert electrical energy into heat and is also known as electro-heating. The rate of heat generation depends on the voltage gradient and the electrical conductivity of the food (Yildiz-Turp et al.,

2013). Ohmic heating is used more often for liquid processing, as solid food is more heterogeneous. Overall, the energy conversion is very efficient as most of it (e.g., 90%) can be converted to heat.

Meat products commonly have heterogeneous structures, which affect the uniform distribution of heat. Ingredients with poor conductivity (e.g., fat) do not generate heat at the same rate as lean muscle and thus create cold spots. In order to be effective, product conductivity should be in the range of 0.1–10 S/min (Piette et al., 2004). In animal fat the electrical conductivity is low (0.1 S/min) compared with that of processed meats (0.5 to 3.5 S/min). Ohmic heating also inactivates microorganisms through its thermal effects and electroporation. Piette et al. (2014) reported on the treatment of bologna inoculated with *Enterococcus faecalis* processed in an enclosed heating unit. Heating the core temperature to 80°C within 14 min resulted in a 9.0 $\log_{10}$ CFU/g reduction. When core temperature was reduced to 70°C it took 31 to 40 min to achieve the same inactivation rate. The authors also demonstrated that product size and shape were important when using this technology. Flat meat patties and plate heating were suggested to ensure good contact between the sample and the electrode surface.

Another advantage of ohmic treatments over conventional methods is the departure from the limiting heat transfer coefficient and the need for high surface temperatures. As compared to conventional heating, ohmic cooking results in shorter processing times and higher yields, while still maintaining the colour and nutritional value of the food. With the development of solid-state power supply technology, it is now possible to use ohmic heating in pulse mode, to economically control electrolytic effects to innocuous levels. Ohmic systems are now better engineered, more sophisticated, and far less expensive than their predecessors and currently four manufacturers produce ohmic heating equipment for general food processing (Yildiz-Turp et al., 2013).

11.3 Cooling

The practice of cooling meat and other perishable food products has been used for thousands of years, although most improvements in chilling and freezing technologies for large scale operations have occurred in the past century (Leygonie et al., 2012). The global meat industry uses chilling and freezing to preserve meat during primary processing, transportation, and marketing (e.g., large refrigeration and frozen storage cabinets in a modern supermarket). In addition, many customers

own smaller units to keep meat cold/frozen. This section focuses on methods used to chill, freeze, and later thaw meat.

11.3.1 Chilling

Chilling is the most common way of extending the shelf life of fresh meat. At the processing plant meat is chilled by cold water or air immediately after evisceration (see Chapter 5). The process decreases the heat of the product from 37-39°C to about 5°C within a few hours. The rate of temperature decline depends on factors such as carcass size, chilling medium, temperature differential, amount of insulating fat, capacity of the refrigeration unit, and the amount of product moving through the system. A number of countries regulate the time allowed to reach a certain final temperature (e.g., 8 hr to reach ≤ 5°C after poultry slaughter). Chilling the meat quickly prevents/slows down microbial growth but can also be associated with cold-shortening (see Chapter 3). Chilling times for different animal producing species are designed to allow sufficient time to eliminate toughening associated with cold-shortening, while some processors also apply electrical stimulation to speed up the rigor process. In some operations of large animal processing, meat is only deboned 24 hrs after slaughter, while in small meat producing animals (e.g., broilers), carcasses are cut and deboned within 4-6 h after slaughter. In such a case, care should be taken to minimize toughening and allow even cooling of all parts. It is important to reduce the meat temperature to discourage the growth of mesophilic bacteria (e.g., *Salmonella*, *Staph. aureus*). The dangerous temperature zone where food should not be kept is shown in Figure 11.3.1.1, as well as the safe ranges to store food. The shelf life of refrigerated fresh meat, including poultry carcasses or parts, is generally limited to 1-2 weeks and depends on factors such as initial contamination load, storage temperature, temperature fluctuation over the storage period, and packaging conditions including modified atmosphere (see additional discussion below). Storing the meat at low temperature (-2° to 0°C) will significantly prolong shelf life compared to storing the meat at 4° to 6°C. Additional discussion on microbial growth during storage can be found in Chapter 15.

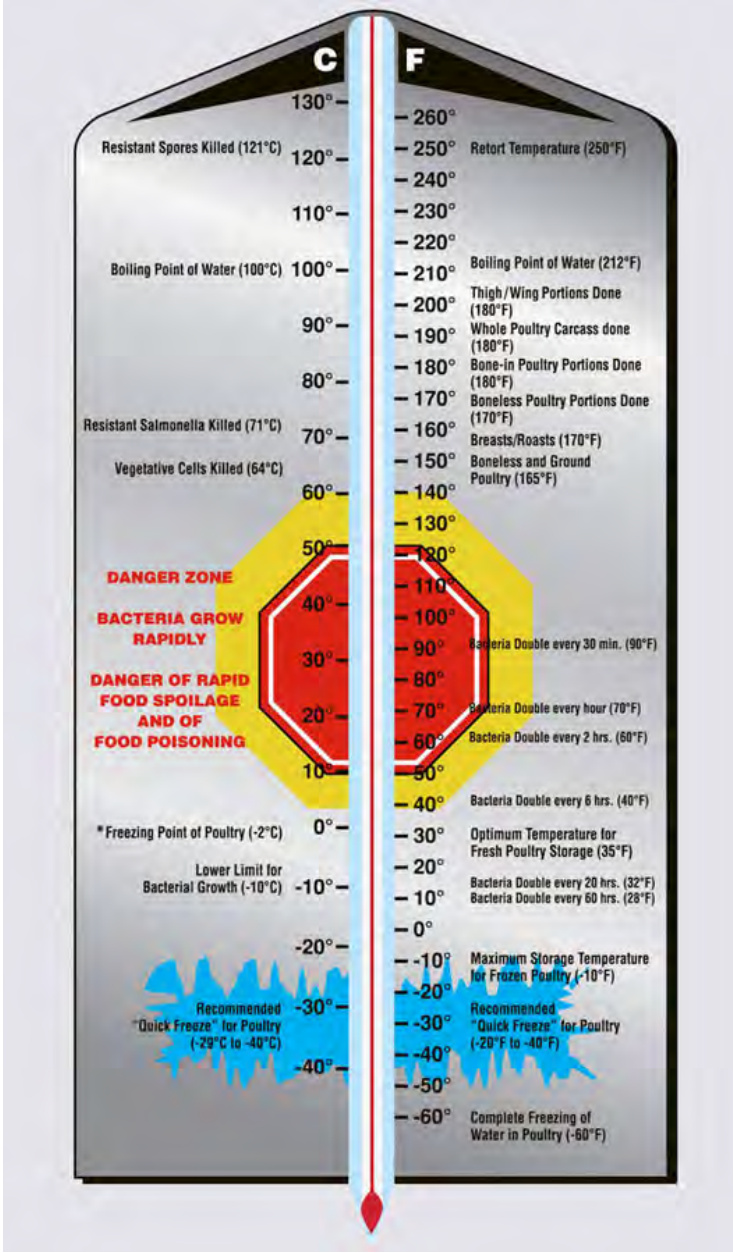


Figure 11.3.1.1 Microorganism growth and recommended poultry meat storage temperatures. http://www.strogoff.nl/content/594/download/clnt/27449_The_Meat_Buyers_Guide.pdf.

11.3.2 Freezing

Freezing is used to store meat for extended periods of time (weeks, months), but does result in physical and chemical changes (e.g., ice crystal growth, lipid oxidation) that limit the storage life of the product. Even under optimal conditions, meat should not be stored for more than one year. It should be mentioned that the global meat trade (export and domestic) heavily depends on frozen storage for keeping and shipping meat (Leygonie et al., 2012).

Although freezing is a good method, it requires added cost and planning. In terms of maintaining quality over an extended storage time, temperature is key. Examples of recommended storage times for poultry are 2 months at -12°C, 4 months at -18°C, 8 months at -24°C, and 10 months at -30°C (Aberle et al., 2012). Storage times are longer for beef, which has more saturated fat, and shorter for fish, which has more unsaturated fat.

Overall, lower temperatures reduce the rate of chemical deterioration, mainly oxidative rancidity, which results in off flavour development (e.g., described as old, stale, and cardboard-like). Other changes might result from dehydration (e.g., freezer burn if the product is not packaged correctly). Freezing rate has a significant effect on texture as slow freezing results in large ice crystal formation, while fast freezing results in small crystals. Such ice damage is only seen later, during the thawing phase, where drip loss is increased in products that were slowly frozen because large crystals are more damaging to the cellular and membrane structures of muscle tissue. Fast freezing refers to a process where the temperature is lowered to about -20°C within an hour. This can be achieved by direct immersion in a very cold medium (e.g., liquid nitrogen), direct contact of the meat with a cold plate, or air blasts with very cold air. On the other hand, slow freezing refers to a process whereby the desired temperature is achieved within 3-72 h. Fast freezing is advantageous in maintaining the product's quality but is substantially more expensive. From a microbiological standpoint, quick freezing does not allow microorganisms time to adapt to the fast decline in temperature and can cause a greater thermal shock as opposed to slow freezing. However, in some cases, slow freezing can be more damaging to microorganisms because they are exposed to injurious factors for a longer period of time as well as the phenomenon known as freeze concentration of certain components in the cell.

The meat industry uses a number of freezing methods including air (still or blast) and plate freezing, liquid immersion/spray, and cryogenic freezing. Figure 11.3.2.1 illustrates the relative freezing rates of various methods. The time it takes water at 0°C to change to ice is referred to as the latent heat removal period. At a

low freezing temperature, the time required to change physical states (liquid to solid) is shortened and ice crystals are actually formed at a lower temperature, which results in smaller ice crystal formation. Water has a high specific heat (4,200 J $kg^{-1}K^{-1}$) and a high latent heat of fusion (335 kJ kg^{-1}). The energy required to freeze the material is either supplied by an outside source such as melting carbon dioxide snow or by circulating cold air (i.e., produced by electrical energy). Figure 13.3.2.1 shows a characteristic curve when food is first cooled down below its freezing point (around -2°C for lean meat). This is known as super cooling and, at this point, the water is still liquid. Then the temperature slightly increases (to the freezing point, or only slightly below) and ice crystals are formed as the latent heat of crystallization is released. At this point, the temperature remains almost constant until the product is frozen. During slow freezing, a smaller number of large ice crystals are formed compared to a larger number of small crystals during fast/cryogenic freezing. The rate of ice crystal growth is determined by the rate of heat transferred during the freezing period.

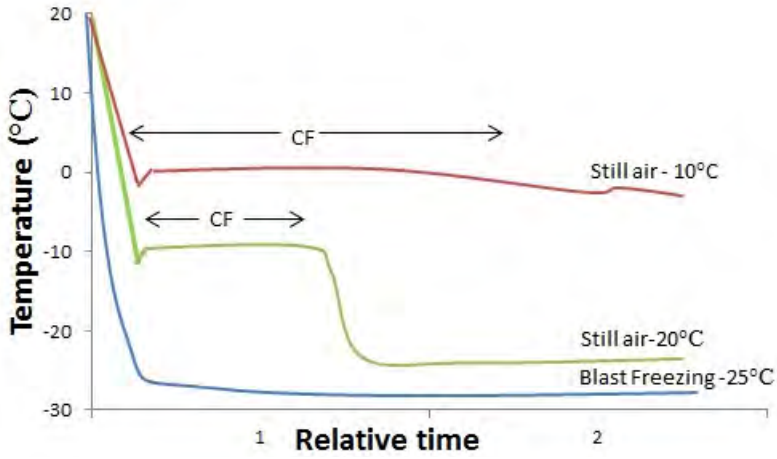


Figure 11.3.2.1 Effect of freezing method on the relative freezing time.
CF = crystallization period.

Another drawback of a slow freezing rate is the formation of a eutectic solution. This is the result of solutes (e.g., salt) becoming super saturated in certain areas while the water around them freezes. This can create areas with high solute concentration (eutectic temperature for sodium chloride is -21°C), which will depress the freezing point. However, it is difficult to identify individual eutectic

temperatures in a complex system such as meat. Most foods are not totally frozen even at a temperature where all water seems to be solid (e.g., about 10% remains unfrozen in meat kept at -20°C).

Overall, the most common freezing methods used by the meat industry are:

a. Plate freezing – usually used for individual meat patties and patties packaged in wrapped trays. Products are placed in direct contact with very cold (e.g., -12°C to -35°C) metal freezer plates or shelves. Plate freezing can also be used for thinly packed meat (fillets). Heat transfer is by conduction. The thermal conductivity of the freezer plates is much higher than circulating air and therefore used to quickly freeze meat. Using plates from both sides as well as colder plates can increase the freezing rate.

b. Liquid immersion/spray – used for smaller products (e.g., cut up meat, cubes, nuggets) and, sometimes, larger trims. If liquids such as a sodium chloride brine, glycol, or propylene glycol are used, the products are first packaged in a plastic bag. The product can also be conveyed on a belt through a freezing tunnel where it is continuously sprayed with a cold liquid. The length of time the product is exposed to the liquid, its temperature, and the size of the meat cut determine the extent of freezing. In the case of large parts it is common to freeze the outside and form a so-called "crust" prior to transferring the meat to an air blast freezer to complete the process. After the product is removed from the immersion tank or freezing tunnel, the freezing liquid must be rinsed off. The integrity of the packaging material is important to avoid any leakage problems. The freezing liquid must be non-toxic and approved by the local food inspection agency.

c. Cold air freezing – can be done by still/slow moving air (home freezer) or in a blast freezer where air movement is very rapid. Using still air is a relatively slow method, which is sometimes employed in refrigerated rooms in a meat processing plant. The air temperature is usually -10° to -25°C and removes heat slowly from the product. Blast freezing refers to using high-velocity cold air that is circulated by large fans. Figure 11.3.2.1 shows that, in blast freezing, the rate of heat transfer is greatly improved over that of still air and the freezing rate is higher. Air velocities commonly used in commercial air blast freezers can range from 1.5 to 6.0 m/s and the temperature from -15° to -50°C (Aberle et al., 2012). Adequate spacing among units is very important to allow proper air movement. In other cases, air blast tunnels are used where meat is moved on a conveyor belt. In the case of a large bird, this is done to freeze and harden the surface, and form a crust that later provides a lighter appearance; the product is then packaged and moved into a regular blast freezer to complete the process.

d. Cryogenic freezing – a very fast method using very cold gases. Gases such as nitrogen (N_2) and carbon dioxide (CO_2) are liquified or condensed and then used. The freezing rate is rapid, since the boiling points are very low (liquid N_2 and CO_2 are -196°C and -78.5°C, respectively). When liquid N_2 is sprayed onto food, about 48% of the total freezing capacity is taken up by the latent heat of vaporization needed to form the gas (Fellows, 2009). The remaining 52% of the heating capacity (enthalpy) is available in the cold gas and the gas is therefore recirculated to achieve optimum use of its freezing capacity. Carbon dioxide has a lower enthalpy than liquid nitrogen and its lower boiling point causes less severe thermal shock. Most of its freezing capacity (85%) is available from the sublimating solid. Therefore, it is usually sprayed onto the product as a fine snow that sublimates on contact and the gas is not recirculated (Fellows, 2009). CO_2 consumption is usually higher than liquid N_2 consumption, but storage losses are lower. The choice between the two is usually determined by cost, the nature of the product, and available equipment.



Figure 11.3.2.2 A schematic illustration of a cryogenic freezing tunnel used for chicken breast fillets. Courtesy of Praxair.

Figure 11.3.2.2 shows a freezing tunnel where either CO_2 or N_2 can be used for packaged or unpackaged food moving on a perforated belt. When liquid N_2 is used the food can either be sprayed or immersed. An initial exposure of the food to the gas itself can somewhat reduce the thermal shock. A very cold medium that results in fast freezing can cause stress (e.g., cracking or splitting) to the food. Therefore, it is common to use cryogenic freezing with small particulates (cubes, nuggets), which are less susceptible to stress. This type of process is called individual quick

freezing (IQF). In both N_2 and CO_2 freezers, the meat's temperature is allowed to equilibrate at the desired storage temperature (commonly below -20°C) before the food is discharged. Liquid N_2 and CO_2 snow are also used in spiral freezers (Figure 11.3.2.3), where the main advantage is employing a higher freezing rate at a smaller footprint (see also the spiral oven cooking concept in this chapter). Liquid N_2 or CO_2 is sprayed down the perforated belt to maximize efficiency. An example of a popular product that goes through such a process is par-fried chicken nuggets (battered, breaded and fried for about 30 sec; see Chapter 14) that are sold to fast food outlets. Cryogenic freezing provides the best way to preserve the fresh-like characteristics because of the small ice crystal formation (see explanation above). However, low storage temperature maintenance during storage and distribution is critical in preserving the quality. Otherwise, the ice crystals will grow (recrystallization), rupture cell membranes, damage the texture of the food, and diminish the benefit of quick freezing. Many consumers are familiar with the phenomena of getting a "sandy" texture in an ice cream that was stored for a few weeks in a home type freezer that fluctuated in temperature.

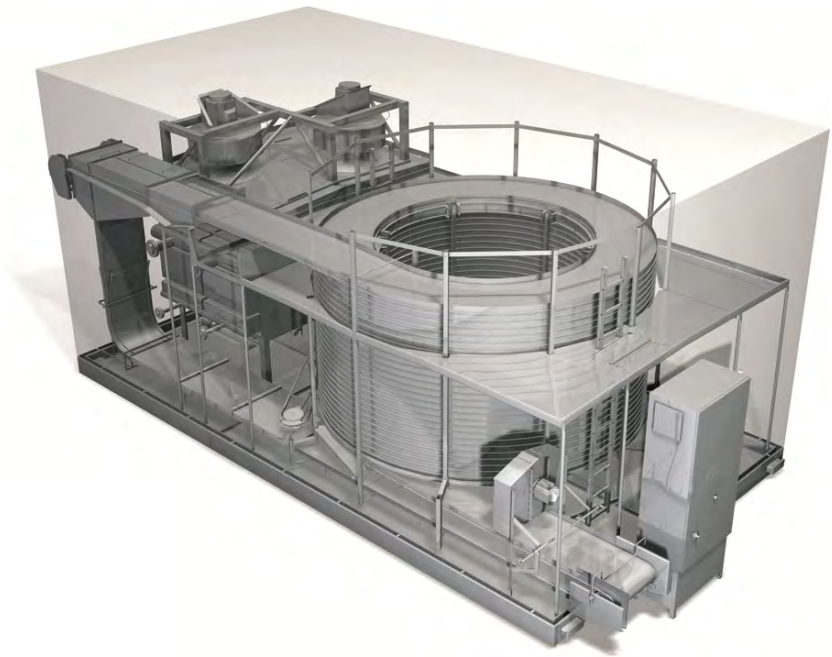


Figure 11.3.2.3 A large-scale cryogenic freezing unit. Courtesy of JBT Food Tech.

Liquid N_2 and CO_2 snow are also used to maintain cold temperatures as meat is mechanically deboned and there is a corresponding rise in temperature due to high pressure. However, some reports indicate that CO_2 can affect the pH (CO_2 can dissolve and form carbonic acid), and in a sensitive product such as mechanically deboned meat, increase lipid oxidation during frozen storage.

Protecting the product's surface during and after freezing is another important issue, as air exposure will dry the product during freezing or result in freezer burns during storage. If freezing time is short, no extra measures are taken. However, if freezing is a long process the product must be protected/packaged. Packaging material must be approved by the appropriate regulatory agency. In addition, it should have good moisture barrier properties and strength (see packaging section below). When meat is going to be stored for a long time, vacuum packaging and oxygen impermeable films are often used. Air removal reduces insulation while oxygen removal decreases the rate of oxidation and the development of off flavours due to rancidity. The shelf life of frozen cooked meat products is shorter than for frozen fresh meat because some oxidation processes have already been induced by heating. The overall storage life also depends on factors such as cooking temperature and additives (e.g., salt, antioxidants). Aberle et al. (2012) provided a few examples for meats stored at -18°C: fried chicken nuggets in vacuum package - 3 months; steamed chicken nuggets - 9 months; the same product with tripolyphosphate (serves as a chelating agent that suppresses lipid oxidation) – 12 months. If these times are exceeded, the products will remain safe, but product flavours and odours will differ from a freshly prepared product.

The processor should also be aware of problems that might occur during freezing. For example, bone darkening is sometimes seen in young chickens after freezing. It shows as a dark/bloody appearance of the tips of the bones and the muscle area close to the bone. It occurs during freezing because as water expands, hemoglobin can be squeezed out of the bone marrow through the porous bone structure. When present at the bone surface, it will turn a dark colour during cooking and the product can become unacceptable to consumers though it is not a food safety issue. Most often, this is seen around the leg, thigh, and wing bones, and sometimes in the breast and backbone area.

11.3.3 Thawing

Thawing can occur under different conditions that affect the meat product's water holding capacity (Leygonie et al., 2012) and rate of ice crystal melting. There is a substantial difference in thermal conductivity between ice and water (e.g., 2.1 vs. 0.6 $W.m^{-1}.K^{-1}$), which is an important factor to consider when thawing food. During thawing, the temperature rises fairly quickly to the near melting point

(depending on the products' thickness) and remains there throughout the relatively long thawing process. This results in a longer thawing period (Fig. 11.3.3.1) compared to freezing and can allow more time for chemical and microbial changes. In general, thawing is inherently slower than freezing when conducted under comparable temperature differentials. At the beginning, a water layer starts to form on the outside of the product and this layer has a lower thermal conductivity and a lower thermal diffusivity than ice (or the frozen meat). This insulating effect actually increases as the layer of thawed water grows. Figure 11.3.3.1 illustrates how thawing is a substantially longer process than freezing when temperature differences and other conditions are similar. Initially, the thawing curve shows a rapid rise when there is still no significant layer of water around the food. This is followed by an extended zone when the temperature is near the melting point.

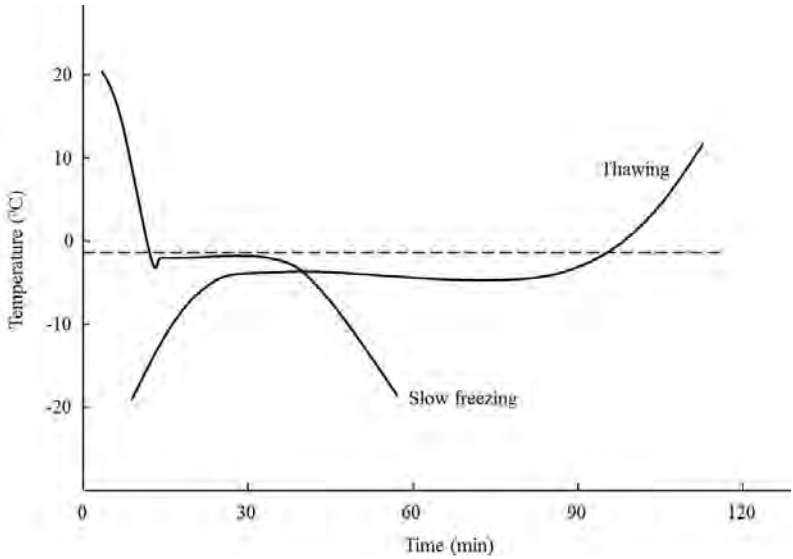


Figure 11.3.3.1 Temperature changes during freezing and thawing for similar size packages. Adapted from Fennema and Powrie (1964).

Commercially, thawing is done under different conditions:

a. Cold, running water (relatively fast)
b. Cold room (temperature should be cold enough not to encourage microbial growth; few hours to a few days)
c. Microwave at a lower level (fast)
d. During cooking (very fast)

Overall, the time required for thawing depends on the size of the meat cut, packaging materials, temperature differential, and air circulation. Thawing at room temperature should be avoided at all costs in order to prevent extensive microbial growth.

11.4 Use of Chemical Preservatives

11.4.1 General

Mankind has used various additives to preserve food for thousands of years. The most common additive has been salt, which, at a high enough level, can reduce water activity such that microorganisms cannot grow. Other chemical preservatives, such as smoke, have been used for centuries in conjunction with drying to produce shelf stable products. This is a primitive example of Hurdle Technology (more than one means of preservation is used to enhance microbial inhibition), which will be discussed later in the chapter. Fermentation is another example, where lactic acid (by bacteria) or alcohol (by yeast) production can inhibit pathogens and spoilage bacteria. Even though our ancestors did not understand what bacteria were they were still able to develop effective preservation methods for their food.

11.4.2 Salt

Sodium chloride (NaCl) is one of the oldest ingredients used to preserve meat. Preservation is achieved by lowering the water activity and hence reducing the water available for microbial growth. High salt concentrations can also interfere with the cell metabolism, since the salt draws water from the cell. Salt concentration in a living cell is around 0.90% and when the outside concentration is about the same, the cells experience an isotonic condition. When more salt is added to the surrounding environment, water moves outside the cell in an attempt to maintain equilibrium. This, in turn, results in a condition known as plasmolysis, and the withdrawal of water inhibits growth and possibly kills the cell. In order to make a food product shelf stable, a concentration of 10-15% salt should be used. This level is much higher than the 1.0-2.5% salt commonly used in most meat products (Barbut and Findlay, 1989; Sindelar and Milkowski, 2011), which is insufficient to preserve the product on its own but together with other additives and heating can significantly extend the shelf life. It should be mentioned that some microorganisms are actually inhibited by a salt level of 2.0%, but the high water activity (around 0.98-0.99) is insufficient to inhibit most bacteria, molds, and yeasts (see Chapter 15). It is also important to remember that salt is water soluble

and the calculation for salt concentration used for preservation should be based on lean meat portion (e.g., 2.5% salt added to a sausage with 30% fat will result in a salt concentration, as experienced by bacteria, of 3.6%). Other water soluble compounds such as sugar can also be added to reduce water activity but the high levels needed (e.g., 30-50%) are not commonly used in meat products but rather in fruit preservatives.

11.4.3 Phosphate

Different types of phosphate are used by the industry and the most common is tripolyphosphate (TPP). Phosphates can alter pH, cause a salt imbalance outside bacterial cells, and emulsify fat (i.e., affect cell membranes). Phosphate rinses and dips for decontaminating fresh meat were suggested over 50 years ago (Barbut and Findlay, 1989). Due to their detergent activity (i.e., resulting from their hydrophilic/hydrophobic structure), they have been successfully used as antimicrobial agents for removing bacteria from meat including from poultry skin. For example, in 1992, a commercial mixture of TPP and a few other ingredients was approved, in the US, for poultry skin decontamination and reprocessing (note that the level required is about 10% phosphate). See Chapter 15 for more information regarding phosphates.

11.4.4 Nitrite

Nitrite can be used by the meat industry as sodium nitrite ($NaNO_2$), sodium nitrate ($NaNO_3$), or as potassium salts. Nitrite is used in the curing process of different meat products (see also Chapter 13). Nitrite/nitrate is added for three main reasons:

a. inhibit the growth of harmful microorganisms such as *Clostridium botulinum* and other spoilage microorganisms
b. stabilize the pink meat colour in cured meats by forming the nitrosohemochrome complex
c. contribute to flavour development and inhibit oxidation e.g., the formation of the so-called warmed-over flavour.

The major reason for adding nitrite is to inhibit the growth of *C. botulinum* spores since they are not destroyed at temp < 100°C (i.e., most meat products are not cooked > 100°C). The active compound in nitrite is nitric oxide (NO), which inhibits *C. botulinum* by interfering with iron/sulphur enzymes such as ferredoxin that prevent adenosine-triphosphate (ATP) synthesis from pyruvate.

When sodium nitrate is used, it should be first reduced to nitrite, by microorganisms present in the meat (see also Chapter 13). Sodium nitrate is usually added to fermented meat products where a slow release of nitrite is required over a longer period of time.

Nitrite levels used in processed meat products are very low and usually range from 100-200 parts per million (ppm). Levels are regulated by government agencies because of the potential for nitrosamine formation, some of which are known to be carcinogenic. Nitrosamines can be formed by the reaction of nitrite and secondary/tertiary amines, under acidic conditions at high temperatures. In meat products that are processed shortly after nitrite addition (e.g., hot dogs), a reducing agent (e.g., ascorbate at a level of about 500 ppm) is commonly used to quickly convert most of the nitrite into nitric oxide and reduce the chance of nitrosamine formation. In certain products, where exposure to high temperatures is expected (e.g., fried pork/turkey bacon), lower levels of nitrite are allowed.

Sindelar and Milkowski (2011) reviewed the large volume of literature published on the use of nitrite and examined the risks and benefits. Overall, nitrite is recognized as beneficial in reducing food borne disease risk. Additionally, one should be aware that meat products are not the major source of nitrite in our diet. Certain vegetables (e.g., celery) have nitrite levels in the range of 300 ppm. In addition, microorganism presence in the human gut produces a lot of nitrite within the body. As well, as meat products are heated, nitrite is converted to nitric oxide gas and nitrite levels are substantially reduced. During storage, there is further reduction in the amount of measurable nitrite, and by the time the product is consumed, the nitrite level can be as low as 10-30 ppm (initially ~150 ppm). In the past few decades several attempts have been made to reduce or eliminate nitrite levels in meat productions, but none have gained wide acceptance. One example was the addition of 0.25% potassium sorbate to a product with 40 to 80 ppm nitrite. This combination inhibited *C. botulinum* but flavour problems were reported. Another patented alternative was the use of 35 ppm encapsulated dinitrosyl ferrohemochrome as a colouring agent and 3,000 ppm sodium hypophosphite as an antimicrobial agent in a nitrite-free curing formulation for wieners (Yun et al., 1987; Sindelar and Milkowski, 2011). However, that formulation is also not used today on a commercial scale.

11.4.5 Acids

Organic acids found in food (e.g., citric acid in citrus fruits), can be directly added to other products as marinades, sprays/rinses, or can even be produced within the product during fermentation (e.g., lactic acid during the fermentation of summer

sausages). Some acids can effectively reduce pH and inhibit microbial growth; the inhibition depends on the type and concentration of acid used. Acids are used as part of the Hurdle Technology system because relying only on an acid would require a high concentration that might negatively affect flavour, texture, and colour. Use of an acid rinse to inhibit/remove microorganisms during primary processing is also a common practice and is discussed further in Chapter 15.

Marinating meat cuts with ingredients such as lemon juice and vinegar is inhibitory to many pathogens and can also help extend shelf life. Marinated meat (e.g., chicken wings; see recipe in Chapter 13) is becoming very popular and many products are sold as convenience items that only require grilling. The antimicrobial inhibition of organic acids is due to both the reduction in pH (below the growth range of microorganisms) and metabolic inhibition by the un-dissociated acid molecules (see review by Theron and Lues, 2007). Overall, determining the inhibitory effect of a specific organic acid can be better measured by titratable acidity than by examining the pH alone. The latter is a measure of hydrogen ion concentration, as organic acids do not ionize completely. Measuring titratable acidity indicates the amount of acid that is capable of reacting with a known amount of base and is a better indicator of acidity (Jay et al., 2005). In the case of fermented/acidified meat products, lactic acid is produced within the product by lactic acid bacteria or added as an encapsulated acid to help reduce pH and preserve the product. Reports about the use of other encapsulated acids used in meat include citric and glucono-delta-lactone (Barbut, 2006). Lactic acid and its salts have also been extensively used by the meat industry to inhibit pathogens such as *Salmonella*, *Listeria* and *E. coli* in raw and cooked products (Aymerich et al., 2008). Sommers et al. (2010) reported on the beneficial effect of using potassium lactate and sodium diacetate together with ultraviolet light (i.e., Hurdle Technology) to suppress the growth of *Salmonella* and *Listeria* in packaged hot dogs stored at 10°C.

Sorbic acid is a preservative that is used as a fungal inhibitor (at a level of < 0.2%) and, more specifically, as an inhibitor of mold growth on products such as meat and bread. Sorbic acid can be used as a spray on fermented sausages as it works best below pH 6 and is not effective above pH 6.5. In general, catalase-positive cocci are more sensitive to sorbic acid than catalase-negative bacteria, and aerobes are more sensitive than anaerobes. The resistance of lactic acid bacteria to sorbate allows it to be used as a fungistat in fermented meat products (Jay et al., 2005). As mentioned in the nitrite discussion, a combination of sorbate and nitrite can be effective against *C. botulinum*, however, it can also cause flavour problems.

11.4.6 Spices and Extracts from Vegetables

Plants produce different compounds to protect themselves against microbial attacks. The antimicrobial efficacy has been attributed to various phenolic compounds, acids, alkaloids, quinones, flavanols and lectins (Gao et al., 2015; Gupta and Abu-Ghannam, 2012). There is a growing interest in using natural spices (Fig. 11.4.6.1) to improve the shelf life and safety of foods, but extracts are usually needed because spices are used at low concentrations. The antimicrobial activity of a specific spice depends on the chemicals found in the plant. Examples are:

- Oregano – carvacrol and thymol
- Cinnamon – sinnamic aldehyde and eugenol
- Cloves – eugenol
- Mustard – isothiocyanate
- Sage – thymol and eugenol



Figure 11.4.6.1 Spices that can be used for flavour and colour enhancement in food preparation. Showing here tyhme, red pepper, cardemon, etc.

More comprehensive lists can be found in Shelef (1983), Jay et al. (2005), and Gao et al. (2015). It should also be mentioned that several natural antioxidants that prevent lipid oxidation also possess antibacterial activity. The phenolic structure of antioxidants such as BHA and BHT are inhibitory to Gram-positive and Gram-negative bacteria, yeast, and molds at concentrations ranging from 10 to 1,000 ppm. Food borne pathogens such as *Salmonella typhimurium*, *Staphylococcus*

aureus, and *Bacillus cereus* are inhibited by BHA/BHT concentrations of > 500 ppm, while *Pseudomonas* spp are among the most resistant bacteria to BHA/BHT (Jay et al., 2005).

11.4.7 Smoke

Smoke has been used for centuries to preserve meat and other foods because burning wood releases various antimicrobial compounds. In general, there are four groups of compounds that have a bacteriostatic and/or bactericidal effect: phenols, ketones, aldehydes, and organic acids. Compound concentration depends on the type of wood and burning temperature. Phenols and organic acids contribute most to the preservative effect of smoke, but > 400 compounds have been isolated from wood smoke (see Chapter 13). In the past, when meat cuts were traditionally smoked over an open fire for an extended period of time, a high chemical concentration and the actual drying helped preserve the product. Today, however, most smoked meat products are only lightly smoked in order to enhance the exterior colour, contribute special flavour notes (hickory, oak), and provide some antimicrobial inhibition. This means that the smoke is only deposited on the surface of the product and penetrates to a depth of 1-3 mm. Consequently, the bacteriostatic/bactericidal effect is only on the surface of the product. Cold smoking can also be used to inhibit mold growth on uncooked, dry fermented sausages where a chemical spray such as sorbic acid (mold inhibitor) is prohibited for use (e.g., in Canada). Such a smoke application can be very effective.

11.4.8 Antibiotics and Bacteriocins

Microorganisms naturally produce antibiotics and bacteriocins to inactivate or kill competing microorganisms. Bio-preservation can also be applied to food where, for example, lactic acid bacteria can produce bacteriocins and lactic acid that inhibit pathogen growth during meat fermentation (e.g., preparation of salami). Bacteriocins usually have a narrow spectrum and only affect very specific groups of microorganisms. Castellano et al. (2008) reviewed the effectiveness and use of bacteriocins by the meat industry. Nisin was the most widely used bacteriocin in food preservation and is permitted for use in around 50 countries. It is also used by the cheese industry to prevent Swiss cheese spoilage by *Clostridium butyricum*. Nisin is naturally produced, heat stable, has an excellent storage stability, is destroyed by digestive enzymes in the body, does not contribute to off flavour or odours, is not toxic to humans, and it is not employed in human medicine. Nisin is considered to be a Class I bacteriocin. Like antibiotics, bacteriocins inhibit or kill other microorganisms, but only of closely related species or strains of the same species (Jay et al., 2005).

Antibiotics are also metabolites of microorganisms. One of the most familiar and useful antibiotics in human medicine (penicillin) is produced by the mold *Penicillium*. Antibiotics such as penicillin, tetracycline, and subtilin are strictly prohibited from use in meat producing animals. If any antibiotic is used for therapy during the growing period of farm animals, a withdrawal time is required until no residues can be found in the meat/milk/eggs. Tetracycline and subtilin were previously approved for use in meat in the US in the 1950s but were later removed due to concerns of having residues transferred to the consumer, and the development of antibiotic resistant bacteria (e.g., difficult to treat patients with bacteria resistant to tetracycline).

11.4.9 Sugars

Sugars preserve foods in the same manner as NaCl (i.e., reduction of water activity), but a main difference between them is the required relative concentration. To achieve the same inhibition effect, about six times more sucrose is required than NaCl (Jay et al., 2005). Most meat products are not preserved by high sugar concentrations, but there are some specialty products where high sugar content is used. More commonly, sugar such as dextrose is added to fermented meat products as a substrate for lactic acid bacteria and, thereby, indirectly assists in microbial inhibition. Dextrose concentrations of around 0.5-2% are commonly used and, by the end of the fermentation, most, if not all, of the dextrose has been converted to lactic acid.

11.5 Drying

11.5.1 General

Drying is one of the oldest methods of food preservation and drying thin slices of meat/fish over a fire or under the sun has been practiced since prehistoric times. The goal of the process is to reduce the amount of water in foods where the water content is 75-95% (considered highly perishable products). The scientific principle is based on reducing the water activity (A_w) to a level that will not support microorganism growth. Dried foods usually contain $\leq$ 25% moisture and have an A_w of 0.05 to 0.60. There are also intermediate-moisture foods, which contain between 15 to 50% moisture and have water activities between 0.60 and 0.85 (Jay et al., 2005). Overall, drying adds cost but also improves shelf life, reduces transportation costs, increases convenience, and allows out of season consumption of dried meats and produce that can be used in dry soup mixes, dried foods for camping, and food carried to space.

11.5.2 Air Drying

Air drying is one of the most common ways to reduce A_w. It is estimated that most industrial dryers (85%) are hot air or combustion gas ovens that are based on convective heat transfer. This is an energy-intense process, which accounts for up to 15% of all industrial energy expenditures. In an energy intensive industry like heating and drying, improving energy efficiency by 1% can result in as much as 10% increase in profit (Kumar et al., 2014). The most common way of drying meat is by circulating dry, hot air, inside a drying cabinet where small or thin slices are placed on trays. Open air drying is also used commercially for products such as raw fish, which are often salted prior to drying. Large meat chunks (e.g., Prosciutto ham) are also dried by air over a long period of time. In that case it is very important to avoid the so-called case hardening (i.e., fast water migration from the surface that causes the formation of a "shell" that prevents further drying). Attention should also be given to the final shape of the product, since drying may shrink, twist, or deform it. This is especially true for thin meat products such as beef/turkey jerky, which are later sold in flat packages. In addition, fat oxidation can be accelerated during drying due to the large surface area exposed to oxygen. In order to overcome this problem, anti-oxidants are usually added. The anti-oxidants may be synthetic (e.g., BHA and BHT) or natural such as rosemary oleoresin (see Chapter 13).

The state of the drying air affects the quality of the final product. Higher drying temperatures reduce drying time but may result in poor quality, heat damage to the surface, and a higher energy cost. On the other hand, mild drying may improve quality by increasing drying time and reducing cost. When product shape and texture are very important, freeze drying is used (see Section 11.5.3). Intermittent drying has also been considered as a technical solution to reduce drying time while maintaining quality (Kumar et al., 2014). According to this concept, drying conditions change over time by continuously varying air temperature, humidity, pressure, and, when needed, the mode of heat input. At the plant, ultrasound, infrared, and microwave energy can be used during certain parts of the drying cycle to help design shorter and more efficient processes.

11.5.3 Freeze Drying

Freeze drying is used for high-end, delicate food products that can justify the higher cost of the process, which removes moisture from the product while maintaining its original shape. The frozen product is placed in a freeze dryer chamber and vacuum is applied (usually 1.0-1.5 mm of Mercury). The ice sublimates from the product without passing through an intermediate liquid phase. In commercial freeze dryers, rapid sublimation is achieved by applying both a vacuum and raising the

chamber temperature while the product is placed on a colder surface (e.g., cooled by a refrigeration coil). The product maintains its original shape since the water is sublimated while the product is frozen and structural changes (shrinking, collapse) cannot occur. Preserving the structure is important in products such as soup mixes where fast re-hydration and the textural characteristics are better compared to air dried products. The final moisture content of freeze dried meat is usually $\leq 5\%$. Therefore, a good package is required to protect the product and prevent moisture entry. As with air dried products, the freeze dried products are susceptible to lipid oxidation because of the large surface area of the fat. Note that re-hydration of the product usually does not return it to its original moisture content. This can also result in lower flavour notes and usually flavourings and seasonings are added to enhance meaty flavour. Cooking the meat prior to freeze drying usually results in a more stable product compared to drying fresh meat, in part because enzymes have been inactivated. If the product is properly packaged, the overall shelf life of cooked, freeze dried products can be a couple years, which is 2-4 times greater than the shelf life of freeze dried fresh meat.

11.6 Packaging

11.6.1 General

Packaging is used to protect food from contamination during storage, shipping, and distribution, to delay spoilage, and to reduce evaporation/weight loss, freezer burn, etc. After processing, the product is packaged and usually stays there until used by the customer. This time period may be days (ground meat), weeks (vacuum packaged hotdogs), or even years (canned food). Therefore, it is very important to control the conditions inside the package. Packaging technologies today range from a simple non-barrier overwrapping film, to barrier film (e.g., oxygen, water vapor), to modified atmosphere packaging, and active packaging. The packaging material can also be pretreated prior to use to sterilize it (e.g., hydrogen peroxide, pulsed light) or active ingredients added to the film (e.g., antioxidants, oxygen scavengers) that protect the product during storage.

In the early 1950s, as stores began pre-packaging meats in refrigerated self-service display cases rather than serving customers on demand, advanced meat packaging materials and technologies were required (McMillin, 2008; Kerry et al., 2006). Initially, oxygen-permeable and moisture-proof polyvinyl chloride films were developed that would stretch around a polystyrene tray of raw, fresh meat. The oxygen permeability was important because consumers began to associate

the bright red colour (called bloom) of pre-packaged meat with meat freshness because this was the colour of the meat they saw at the butcher shop.

Later, the economies of carcass portioning in centralized processing plants and shipment of cut up portions (steaks, fillets) rather than whole carcasses, sides, or quarters to retail stores for cutting also propelled advances in vacuum packaging materials and equipment. Packaging was also influenced by the increased competition of retail stores and chains (e.g., the need to provide an attractive package), requirements for safe and wholesome products, shortages of skilled butchers, and the need for a fully stocked meat case with longer store operation hours. Case-ready or centralized packaging is the concept of fabricating and packaging of consumer-sized retail items in a non-retail location. The items are then transported to retail stores with minimal or no package manipulation after removal from the shipping box. Centralized packaging is done on a large scale and provides opportunities for automation as well as improvements in space and labour resource utilization, quality, waste reduction, and inventory control. Packaging ranges from flexible films to rigid packages and rigid packages covered with a flexible film (Fig. 11.6.1.1) where different high speed automated machines can be employed. A modern high speed packaging area is shown in Figure 11.6.1.2.

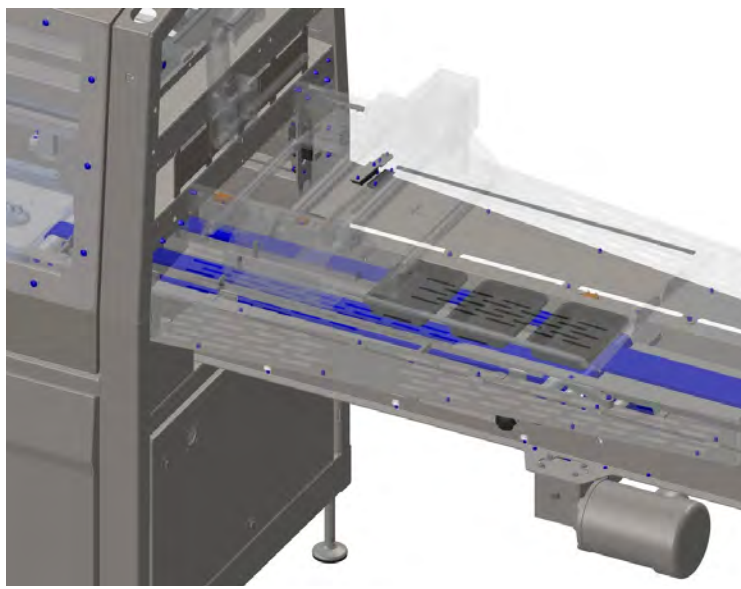


Figure 11.6.1.1 Packaging equipment for rigid trays that after filling are covered with a plastic film. Courtesy of Ross Industries.



Figure 11.6.1.2 Six sorting lines going to fresh meat packaging in a large meat processing operation. Courtesy of Marel.

11.6.2 Modified, Vacuum, and Non-Vacuum Packaging

This category of packaging actively changes the environmental conditions within the package. Plastic is used most commonly because it is highly suitable for food packaging, as it has a low density, breakage resistance, no sharp edges, ready sealability, fabrication flexibility, environmental durability, barrier and permeability properties, printability, and flexibility at low temperatures. Other important physical and chemical properties of plastic used for food applications are: glass transition temperature, crystalline melting point, flexural modulus, tensile strength, tear strength, impact strength, flex life, water vapour transmission rate, O_2 permeability, optical properties, heat sealing properties, and bonding strength. Table 11.6.2.1 provides examples of common plastic films used by the food industry. Each type of packaging film has advantages, disadvantages, consumer and marketing issues, environmental considerations, and cost. A single layer plastic generally does not have all required properties for a food package application. Therefore, lamination, coating, or co-extrusion are used to create layers of different plastic polymers to achieve the desired properties. Heat sealing and barrier properties are often improved by application of different coatings to the surfaces of plastic films.

Today most fresh and cooked meats are packaged to prevent contamination and moisture loss (weight) during distribution. Sometimes fresh meat is also aged in a plastic pack to permit enzymatic activity that enhances tenderness.

Table 11.6.2.1 Properties of major packaging resins used for meat and poultry. Based upon a thickness of 1 mil film. Data from multiple sources. Based on McMillin (2008).

Packaging resin	Abbrev.	Water vapor transmission rate ($g/m^2/24h$)	O2 transmission rate ($cc/m^2/24h$)	Tensile strength (MPa)	Tear strength (g/mL)	Impact strength (J/m)	Haze (%)	Light transmission (%)	Heat seal temperature range (°C)	Notes
Polyinyl chloride	PVC	1.5-5	8-25	9-45	400-700	180-290	1-2	90	135-170	Moisture impermeable; resistant to chemicals
Polyvinylidene chloride	PVdC	0.5-1	2-4	55-110	10-19	–	1-5	90	200-150	Vapor barrier; high hardness; abrasion resistant
Polypropylene	PP	5-12	2000-4500	35.8	340	43	3	80	93-150	Clear, readily processed
High density polyethylene	HDPE	7-10	1600-2000	38.2	200-350	373	3	–	135-155	Used for structure
Low density polyethylene	LDPE	10-20	6500-8500	11.6	100-200	375	5-10	65	120-177	Lidding film use; high strength, low cost sealant
Linear low density polyethylene	LLDPE	15.5-18.5	200	7-135	150-900	200	6-13	–	104-170	Superior hot tack; poor sealing through grease
Ionomer		25-35	6000	24-35	20-40	150	–	–	107-150	Metallic salts of acid copolymers of PE; broad heat sealant range
Ethylene vinyl acetate	EVA	40-60	12,500	14-21	40-200	45	2-10	55-75	66-177	4% improves heat sealability; 8% increases toughness and elasticity
Ethylene vinyl alcohol	EVOH	1000	0.5	8-12	400-600	–	1-2	90	177-205	Vapor barrier
Polyamide (nylon)	PA	300-400	50.75	81	15-30	50-60	1.5	88	120-177	High heat and abrasion resistance, clear, easily thermoformed; printable
Polyethylene terephthalate	PET	15-20	100-150	159	20-100	100	2	88	135-177	Polyester from terephthalic acid reaction with ethylene glycol; abrasion and chemical resistant; structure use
Polystyrene	PS	70-150	4500-6000	45.1	2-15	59	1	92	121-177	High impact PS (HIPS) for multilayer sheet extrusion; strong; structure use

When meat is overwrapped in packaging film, the initial environment is roughly 79% nitrogen (N_2), 20% oxygen (O_2), and 0.03% carbon dioxide (CO_2). Modified atmosphere packaging is the process of altering the normal mixture of atmospheric gases into an atmosphere that will discourage microbial growth. The process involves either the evacuation of all air (vacuum packaging) or an artificial increase of the concentration of one or two gases (modified atmosphere packaging, also known as MAP). Table 11.6.2.2 shows examples of the major packaging systems used for fresh meat, including MAP. It is interesting to note that modified atmosphere storage of plant material has been used since the early 1920s, where fruits such as apples and pears were stored in large rooms with an elevated CO_2 environment. This was done to retard fungal rotting and the gas concentration could be continuously adjusted. During the 1930s, meat was shipped from Australia and New Zealand to England in large containers enriched with CO_2 in order to extend the shelf life. This was a very successful development for the red meat industry as it extended the shelf life of unfrozen meat to 3-4 months (Jay et al., 2005). In his review, Genigeorgis (1985) discussed numerous findings showing that high CO_2 concentrations increased the shelf life of different meats. It is important to note that the packaging material should be of high quality and meet specific characteristics that maintain the desired conditions (e.g., good O_2/CO_2 barrier to prevent gas migration). Various gas mixtures ranging from 0 to 100% CO_2 with or without nitrogen and/or oxygen have been suggested as a means of prolonging packaged meat's shelf life. During a week of refrigerated storage the amount of CO_2 in vacuum packaged meat can accumulate and reach 30%. The increase in CO_2 is the result of the residual oxygen consumed by microorganisms and their resulting respiratory activity (Jay et al., 2005).

At the plant, modified atmosphere conditions can be achieved in several ways:

a. Evacuating air from the package with a vacuum pump, where pressure usually ranges anywhere from 10-200 mm Hg
b. Physically removing air by squeezing or placing the lower part of the package in water
c. Flushing the product with a gas mixture of choice using special equipment.

There are many similarities between vacuum packed and gas flushed meats, since the primary inhibitory effect is caused by CO_2. Overall, Gram-negative bacteria are more sensitive to CO_2 than Gram-positive, with *Pseudomonas* (a typical spoilage bacteria) being among the most sensitive and lactic acid bacteria and some anaerobes being among the most resistant.

Table 11.6.2.2 Major packaging types and characteristics for fresh retail meat. Based on information from different sources. Based on McMillin (2008).

Package	Air-permeable overwrap	Air-permeable overwrap in master pack	Vacuum skin packaging (VSP)	Low O_2 with CO_2 and N_2	Peelable VSP or low O_2 with CO_2: N_2	Low O_2 with CO	High O_2
System description	Air-permeable film overwrap of product on tray; product displayed in package	Barrier bag with single or multiple trays of product in air-permeable packaging; trays removed for retail display	Flexible film shrunk around product on a rigid base web; product displayed in package	Thermoformed or preformed trays with lidding film; may be a master pack for product in air-permeable packages	VSP or barrier tray with 2 layer lidding film; outer barrier film peeled from inner permeable film before product display	VSP; may be thermoformed or preformed tray with lidding film; product displayed in package	Thermoformed or preformed tray with lidding film; product displayed in package
Gases in headspace	Atmosphere air	Usually CO_2 and/or N_2 in master pack	No gas headspace	CO_2 and/or N_2	No headspace with VSP; CO_2 and/or N_2	CO_2 and/or N_2; no headspace with VSP	O_2 and CO_2; often 80% O_2:20% CO_2
O_2 scavengers	none	Recommended	Sometimes	Recommended	Recommended	Recommended	None
Meat color in storage	Red	Purple	Purple	Purple	Purple	Red	Red
Meat color for display	Red	Red	Purple	Purple; red after removal from master pack	Red	Red	Red
Whole muscle shelf life, d at 4 °C	5 - 7	10 - 14	60 - 90	30 - 60	30 - 45	35	12 - 16
Minced or ground shelf life, d at 4 °C	2 - 3	7 - 10	45 - 60	20 - 40	20 - 30	28	10 - 12
Display life, d	2 - 7	2 - 7	30 - 60	15 - 40	2 - 7	28 - 35	7 - 16
Drip loss, %	8 - 10	3 - 5	2 - 5	1 - 5	0 - 7	1 - 7	0 - 5
Advantages	Consumers familiar with packaging; high product visibility; lowest cost; multiple sizes on same equipment	Storage life extended before display	Long storage life before display; high product visibility	Long storage life before display	Long storage life before display; high product visibility with VSP	Long red color stability and no lipid oxidation; high product visibility with VSP	Moderate red color stability
Disadvantages	Short display life; leaky package if bottom sealed rather than tube sealed at ends	Double packaging costs; short display life; reblooming after air exposure may be inconsistent	Display with purple color	Purple display color in MAP; scavengers increase costs; bloom may be inconsistent on exposure to air after removal from MAP; increased cost with master pack	Film peeling at retail store; may be mottling or inconsistent bloomed color after air exposure; short display life; increased package and scavenger costs	Negative image by consumers; concern red products may be spoiled in other factors; scavengers increase costs; cooked meat color may be pink	Lipid oxidation; may be bone darkening or decreased tenderness; headspace required; may be premature browning of cooked meat

The main differences between the microflora of fresh and vacuum packed meat are the dominancy of Gram-positive bacteria and fewer yeasts in the vacuum packaged meats (Jay et al., 2005; Sebranek et al., 2006). Two main mechanisms have been offered to explain the inhibitory effect of CO_2 (Enfors and Molin, 1978). The first suggests that CO_2 blocks the enzymatic decarbonization system in bacteria such as *P. aeruginoxa*. The second mechanism suggests that CO_2 affects the permeability of the lipid bilayer within the cell membrane and increases its fluidity. At 1 ATM CO_2, Enfors and Molin (1978) showed that spore germination in *B. cereus* was inhibited. The same was reported for *P. fluorescence*. Other reports have shown that CO_2 inhibition increases as temperature is reduced. This concept is used today to enhance the shelf life of fresh and further processed meat products. Hotchkiss et al. (1985) reported that the shelf life of fresh chicken quarters could be extended up to 35 d at 2°C when packaged with 60-80% CO_2. Marshall et al. (1992) looked at further processed chicken nuggets and showed that competitive growth of *L. monocytogenes* and *P. fluorescence* was reduced by using a modified atmosphere (80% CO_2, 20% N_2) and 4°C storage.

Various reports have shown that the predominant organisms in spoiled vacuum packaged meats are *lactobacilli* and *B. thermosphacta*, although other microorganisms can sometimes dominate. Among the determining factors influencing the microflora are: whether the product has been cooked, relative load of psychrotrophic bacteria, the degree to which oxygen was excluded, and the product's pH level and nitrite concentration (Jay et al., 2005).

Many cooked meat products (e.g., bologna, salami, frankfurters) are vacuum packaged to minimize lipid and colour oxidation, extend shelf life, and suppress spoilage microorganisms. Neilson and Zeuthen (1985) examined the microflora of cooked, bologna-type sausage in vacuum packaging and showed that the normal flora restricted growth of *Y. enterocolitica* and *Salmonella*, but not *S. aureus*. The normal microflora also inhibited *C. perfringens* and all pathogens were inhibited by the lactic acid bacteria, with greater inhibition when storage temperature was lowered. Additional discussion on spoilage microorganisms is provided in Chapter 15.

11.6.3 Active and Intelligent Packaging

Active and intelligent packaging are fairly new categories that have become popular over the past few years. Active packaging refers to the incorporation of additives into the packaging system with the goal of maintaining quality and extending shelf life (Kerry et al., 2006; Aymerich et al., 2008). Additives may be selected for:

a. Absorbing/scavenging properties – oxygen, carbon dioxide, moisture, flavours, UV light
b. Releasing/emitting properties – carbon dioxide, antioxidants, preservatives, sulphur dioxide, flavours
c. Removing properties – catalyze a food component such as cholesterol
d. Temperature control – self-heating and self-cooling packaging, insulation materials, microwave susceptors, and modifiers
e. Antimicrobial and quality control – antimicrobial agents such as organic acids and chelators.

The second category, intelligent packaging, refers to sensors/indicators that can monitor the condition of packaged foods and provide quality information during storage. Sensors can be used to monitor integrity, freshness, time, temperature (e.g., detect temperature abused conditions), and provide radio frequency identification (Kerry et al., 2006). Currently, this area mainly involves physical sensors that can monitor the concentration of a certain chemical (e.g., O_2, CO_2, acid). However, the industry is also interested in biosensors such as enzymes, antigens, nucleic acids, and hormones to help monitor metabolite development during food storage.

While there is a lot of interest in intelligent packaging, it is not yet popular in the meat industry. It is expected that this area will grow substantially over the next few years and help the industry and consumers monitor condition changes within the package.

11.7 Other Non-Thermal Processes

11.7.1 General

Non-thermal processes can also be used to inactivate spoilage and pathogenic microorganisms. They are usually based on transferring some energy to the food without noticeably raising its temperature. In that sense, they are usually regarded as treatments that have a minimal effect on the texture and nutritional value of the product. However, some (e.g. irradiation) can initiate lipid oxidation and, therefore, measures should be taken to reduce such effects (e.g., low temperature/ freezing during application).

11.7.2 Radiation

Radiation, in general, is defined as the emission and propagation of energy through space or a material medium. Use of ionizing radiation as a preservation method has

already gained acceptance in various countries and is gaining acceptance in others. The wavelengths and photon energies employed are part of the electromagnetic spectrum and are presented in Figure 11.2.5.1; the shorter a wavelength is, the greater its energy. Electromagnetic radiation occurs in units called quanta or photons. When the energy in a quantum exceeds the energy that binds adjacent molecule atoms, the chemical bonds between atoms can be cleaved off, resulting in smaller fragments that may be electrically charged (ions) or neutral. Ultraviolet rays, x-rays, and gamma rays are capable of breaking fairly stable bonds and even expelling electrons from atoms. Therefore, they are known as ionizing radiation or ionizing energy. Ionizing radiation is defined as radiation with a wavelength of $\leq$ 2,000 angstroms (Å). Radiation particles of primary interest to the food industry are: gamma rays, beta rays, x-rays, and alpha particles. Their quanta contain enough energy to ionize molecules in their path. Ionizing radiation can destroy microorganisms without increasing temperature and is therefore also called "cold sterilization" (CAST, 1986; Ahn et al., 2006). It is important to point out that irradiated food is not radioactive. The radiation sources used by the food industry include machine-type and isotopic (Fig. 11.7.2.1) radiation. Machine-type radiation is produced by an electron accelerator that generates a high energy electron beam or high energy x-rays for treating food. Isotopic radiation uses isotopes such as cobalt-60 (^{60}Co) or cesium-137 (^{137}Cs) as a source of gamma rays. ^{60}Co is produced in nuclear reactors by neutron-induced transmutation of naturally occurring ^{59}Co. ^{137}Cs is a fusion product and is extracted from byproducts of nuclear reactor fuel elements. The "strength" of an isotopic source is commonly expressed in terms of the rate of disintegration of radionuclide. The standard unit for activity is the curie and is defined as 37 billion disintegrations per sec. In addition to activity, the frequency of gamma ray emission should also be described. In the case of ^{137}Cs, gamma ray emission is only 85% of its disintegrations, while ^{60}Co emits 2 gamma rays per disintegration. Another important characteristic is the isotopic half-life, which describes the length of time for the activity of the source to be halved as a result of decay. The half-life of cesium is 30 yr and for cobalt it is 5.2 yr. The majority of facilities use ^{60}Co because of its stronger gamma ray and water insolubility (Ahn et al., 2006; Aymerich et al., 2008).

The amount of radiation absorbed by the material (e.g., food) is known as the "dose" and can roughly be compared to the amount of heat a food product absorbs when placed in a hot oven. The process of measuring radiation absorption is called dosimetry and the unit is called a rad. A rad is equivalent to the absorption of 100 ergs/g of matter and a kilorad (krad) and megarad (mrad) are equal to 1,000 rads and one million rads, respectively. A newer dose unit is the gray (G), which is equal to 100 rads (1 G = 100 rads = 11 joule/kg; 1 kGy = 10^5 rads).

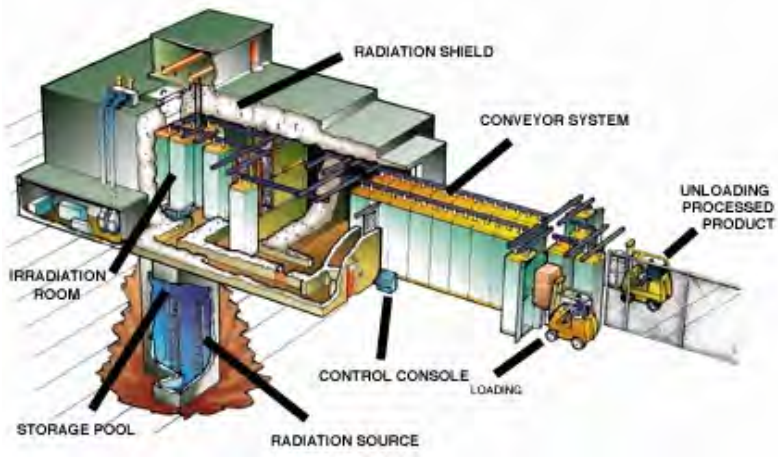


Figure 11.7.2.1 An industrial irradiator used for food products, consisting of a room with concrete walls that contains the radiation source (Cobalt-60), and a conveyor system used to move the products into the room. http://barc.gov.in/bsg/ftd/faq2.html.

Radiation dose is usually split into three application levels: low, medium, and high. Similar to heat processing, small amounts of irradiation will result in pasteurization (i.e., killing some spoilage and pathogenic microorganisms), whereas a high dose will result in sterilization. Radurization is a lower level, pasteurization-type dose (0.75-2.5 kGy) that reduces spoilage microorganisms. It is commonly used to extend shelf life in fresh meat, poultry, seafood, fruits, and vegetables. Radicidation is similar to milk pasteurization and is designed to reduce non-spore forming pathogens, other than viruses. Typical doses are 2.5-10 kGy. Radappertization is a high level pasteurization that can achieve similar results to a heat-treated canned food. Usually, doses are about 30-40 kGy.

Similar to heat inactivation, there are D-values assigned to radiation treatments for different microorganisms. These are important when designing irradiation treatments for different foods (Table 11.7.2.1). Similar to conventional heat treatments, spores are more resistant to radiation than non-spore forming microorganisms. There are also differences in the spore resistance of related microorganisms (*C. botulinum* type E vs type B; Table 11.7.2.1). Once toxin has been formed, a very high dose of radiation is required to inactivate it (36 kGy). The same is true for *S. aureus*, where the D-value for the live bacteria is 0.16 kGy but is 61 kGy for the toxin. This is an important difference from heat processing where, for example, the *C. botulinum* toxin is fairly heat sensitive and can be inactivated

by boiling in water for a few minutes whereas the spores would need to be boiled for a few hours. The reason is that the toxin is a small peptide molecule that can be denatured and inactivated fairly easily by heat, but not by irradiation. Table 11.7.2.1 also shows that viruses are more resistant to irradiation compared to bacteria as can be seen by the D-value of the *Adenovirus* virus.

Table 11.7.2.1 Overview of average radiation D-values for a variety of foods. Adapted from a summary by Jay et al. (2005).

Organisms/Substance	D (kGy)
Bacteria	
C. botulinum, type E Beluga	0.8
C. botulinum, 62A spores	1
C. botulinum, type F spores	2.50
C. botulinum A toxin in meat slurry	36.08
Escherichia coli	0.2
L. monocytogenes	0.42 - 0.43
on meat at 5°C	0.44
on meat at 0°C	0.45
on meat at -20°C	1.21
Pseudomonas putida	0.08
Salmonella typhimurium	0.5
S. enteritidis in poultry meat at 22°C	0.37
Staphylococcus aureus	0.16
toxin A in meat slurry	61.18
Yersinia enterocolitica, in meat	0.19 - 0.38
Viruses	
Adenovirus (4 strains)	4.1 - 4.9

Determining the exact dose of radiation is very important and dosimetry values are used to show that the product was exposed to/achieved the desired level of pasteurization/sterilization. Two main dosimetry systems are used by the industry. The first is based on ceric sulphate where ceric ions, in acidic aqui-solution are reduced by the action of ionizing radiation to cerous ions. The change in ceric ions can be readily measured by spectrophotometry. The second method is based on

colourimetry and is suitable for short irradiation periods. In most cases, another simpler secondary dosimetry system is used after being calibrated against one of the primary dosimetry systems. One such secondary system involves darkening of polymethyl methacrylate exposed to irradiation. The relative darkening is later measured by a spectrophotometer.

Gamma rays and x-rays can penetrate much deeper than visible light. A source with an energy level of 0.15 to 4 million electron volts (MeV) can penetrate about 30 cm of water. Aymerich et al. (2008) provided a summary table in which they indicated that commercial gamma ray sources usually operate at 1.3 MeV, x-rays at 5 MeV, and electron-beams at 5-10 MeV. Penetration depth also depends on the type of ray used. The authors indicated that gamma ray and x-ray systems used for food processing can penetrate 80-100 cm, while E-beam depth is 8-10 cm (note: also related to packaging materials). Fast, charged particles such as electrons, alpha particles, and protons also have enough energy to cleave molecules as they penetrate the material and that is the reason they are used.

As indicated above, there are two major types of commercial food irradiation facilities. The first uses a radioactive isotope and the second employs an electron beam accelerator (Fig. 11.7.2.2). In most countries irradiated food must be labeled with a special symbol to inform the consumer that the food has been exposed to radiation. The international symbol is a round green circle with two green leaves inside. Some industry personnel have argued against mandatory labeling on the grounds that irradiation is a food process similar to heating and freezing, which do not need to be mentioned on the label. However, most governments agree that food irradiation should be considered differently and a label/logo should appear on the package. In order to alleviate consumer fear, the word picowave has been suggested as a replacement for irradiation. Picowave is based on the wavelength used for irradiation (picowave = 1 trillionth of a meter on the electromagnetic spectrum) and is similar to the word microwave (microwave = 1 millionth of a meter on the electromagnetic spectrum). The term picowave was first suggested in the early 1980s but has not yet gained wide acceptance. In any case, food irradiation is becoming more acceptable in different parts of the world (Ahn et al., 2006). Among the reasons are *E. coli* O157:H7 problems in ground beef and requests for *Salmonella*- and *Campylobacter*-free meat.

In terms of food safety, the World Health Organization concluded in 1981 that "no hazard is involved in processing any food with ionizing energy up to an average dose of 10 kGy; hence, toxicological testing of food so treated is no longer required" (WHO, 1981). The WHO conclusion was based on the following factors:

a. Toxicological studies carried out on a large number of individual foods have produced no evidence of adverse effect as a result of radiation,
b. Studies (radiation chemistry) have shown that the radiolytic products of major food components are identical, regardless of the food from which they are derived. Moreover, for major food components, most of these radiolytic products have also been identified in foods subjected to other acceptable types of food processing. Knowledge of the nature and concentration of these radiolytic products indicates that there is no evidence of a toxicological hazard.
c. A body of supporting evidence has indicated the absence of any adverse effects resulting from the feeding of irradiated diets to laboratory animals, the use of irradiated feeds in livestock production, and the practice of maintaining immunologically incompetent patients on irradiated diets (Ahn et al., 2006).

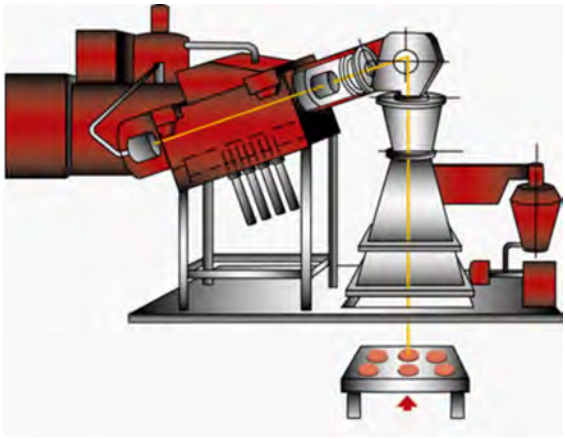


Fig 11.7.2.2 Food irradiation facility using an electron beam accelerator. Courtesy Iowa State University.

The WHO conclusion and recommendation was further elaborated into an international standard under the procedure of the Codex Alimentarius Commission and in 1983 was adopted by 130 governments. Radiation was also promoted by the FAO in the 2003 Codex Alimentarius. Overall, the standard has provided an important incentive for national authorities to introduce favourable regulations for food irradiation. Thayer (1994) and later Ahn et al. (2006) reviewed the wholesomeness of irradiated food, including data cited by the Food and Drug Administration in support of the approval of meat for commercial sale in the US

that had been irradiated with doses of 1.5-3.0 kGy to control food borne pathogens. The reviews showed that neither short nor multi-generation feeding studies had produced evidence of toxicological effects in mammals due to ingestion of irradiated food. This supports the conclusion that properly processed irradiated food is wholesome and that radiolytic changes in the food are minimal and predictable.

Using irradiation to treat meat at the radurization and radication levels can assist in reducing bacteria that cause food borne diseases (e.g., *Salmonella*) and spoilage (e.g., *Pseudomonas* and *Lactobacilli*). The effect of radiation dose on spoilage microorganisms on freshly slaughtered chickens stored at 2°C has been reported by Niemand et al. (1977). The non-irradiated control spoiled within 4-6 d, which is about the normal shelf life of eviscerated poultry. When a 2-5 kGy irradiation was given, however, the reduction in microbial population was in the range of 3 to 4 logs and the shelf life more than doubled. A dose of 5 kGy more than tripled shelf life and these results were in agreement with previous experiments. Others have shown that irradiating eviscerated poultry with 2.5 kGy resulted in an essentially *Salmonella*-free product. In a study involving artificially contaminated broiler skins, Mulder (1982) reported a range of D-values for irradiation at different temperatures (also Table 11.7.2.1). The values were in agreement with D-values obtained for *E. coli* and *Salmonella* reported for other foods, where irradiating at -18°C provided more protection to the microorganisms (than at a higher temperature) and thus required higher doses to achieve the same level of inactivation. Mulder (1982) also indicated that the application of 2.5 kGy to Dutch poultry could not guarantee a *Salmonella*-free product, but would reduce the number of *Salmonella*-positive poultry by a factor of 14. Today, the Dutch situation is quite different as the government implemented measures on farms and in primary processing to eradicate *Salmonella* (farm to plate approach; see Chapter 15).

Employing medium or high irradiation levels can result in the formation of some off flavours and odours due to lipid oxidation that can be induced by irradiation. It is usually suggested that meat irradiated at medium to high levels be vacuum packed and/or frozen in order to minimize off flavour formation. Freezing (at -20 to -40°C) has been recommended (Josephson, 1983). As with heat processed cans, *C. botulinum* spores are the main target and, since they are fairly radiation-resistant organisms (Table 11.7.2.1), a relatively high dose should be used. High level radappertization is used to achieve "commercial sterility" equivalent to thermal processing of canned food. The product can then be stored at room temperature without spoilage. For radappertization, a mild heat pre-treatment, at about 70-77°C, is usually applied in order to inactivate proteolytic and lipolytic enzymes. This

inactivation can minimize flavour, odour and texture deterioration during storage, because not all enzymes will be inactivated by the radiation treatment (Josephson, 1983; Ahn et al., 2006). Although enzyme inactivation, by heat, results in some textural changes and moisture loss, it is necessary to preserve the long-term quality of the product. To ensure complete sterilization, the 12-D concept is used. Anellis et al. (1977) have determined the required 12-D dose for chicken meat with NaCl (0.75%) and tripolyphosphate (0.3%) to be 42.7 kGy when radappertized at -30°C after enzyme inactivation at 74°C. Even though the sensitivity of *C. botulinum* is highest at 0°C, the product (2,000 cans of inoculated chicken meat) was treated at -30°C to minimize flavour deterioration at this relatively high dose.

When irradiating processed foods, interactions with other additives should be investigated. In a study involving frankfurters formulated with either 1.5% or 2.5% salt and then inoculated with five strains of *C. botulinum* (10^3 spores/g), it was shown that a higher salt level provided better protection from toxin production under abused/high temperature conditions (Barbut et al., 1988). The authors reported that a radiation exposure of 5 kGy or greater, at either 1 or -30°C, was sufficient to inhibit botulinum toxin production for 40 d in turkey frankfurters containing $\geq$ 2.5% NaCl. Neither 5 nor 10 kGy inhibited toxin production in products formulated with 1.5% NaCl.

Commercial food irradiation technology was developed after World War II and has been available for over half a century. It is currently used to treat many of our medical supplies (e.g., bandages, plastic tubes that are sensitive to heat), spices, and various other foods. However, consumer acceptance of irradiated food products has been a challenge in several places around the world. This attitude is slowly changing due to better education and also attention given to various food borne disease outbreaks (e.g., *E. coli* O157, *Salmonella*). It is expected that food irradiation will become more widely used in the future and will help increase food safety standards as well as reduce food waste due to premature spoilage.

11.7.3 High Pressure Processing

High pressure processing (HPP) is another non-thermal process that can be applied both to fresh and cooked food products. HPP is commonly used for fruit juices, oysters, guacamole, and processed meat products and the meat industry is currently using HPP to extend the shelf life and reduce/eliminate pathogens (e.g., *Listeria* in cooked sliced meat, *E. coli* in dry fermented products that were not exposed to heat). HPP is also known as isostatic pressure, which is applied at 100 to 900 MPa at room temperature and is generated by a mechanical pump. The pressure chamber (Fig. 11.7.3.1) is filled with water, which transmits the pressure to the sample. A

process applying 500-600 MPa may take about 10 minutes: 2 min to charge, 5 min for pasteurization, and 3 min to discharge. The overall temperature rise can be in the range of 15°C as an increase of 3°C is expected for each 100MPa (Aymerich et al., 2008). HPP accelerates reactions involving a volume change at the molecular level. The hydrophobic and electrostatic interactions are most affected, but not the hydrogen bonds. The process causes microbial cell inactivation, likely through damage to the cell membrane, without changing the organoleptic characteristics of the product. Other components in the cell that are sensitive to pressure include proteins, DNA, and fatty acids. Cell death increases with increasing pressure but does not follow first order kinetics (Garriga et al., 2005). In general, Gram-positive bacteria are more resistant to high pressure than Gram-negative bacteria. The threshold for inactivation also depends on the growth phase of the microorganism, processing time, composition of the surrounding food, pH, etc. Some microbial spores will need treatments > 900 MPa to destroy them, while various forms of mould and fungi need 200-300 MPa to kill their vegetative form and 400 MPa to destroy their spores (Aymerich et al., 2008). Because of sub-lethal injury to some cells, microbiological evaluation is recommended during the storage period.

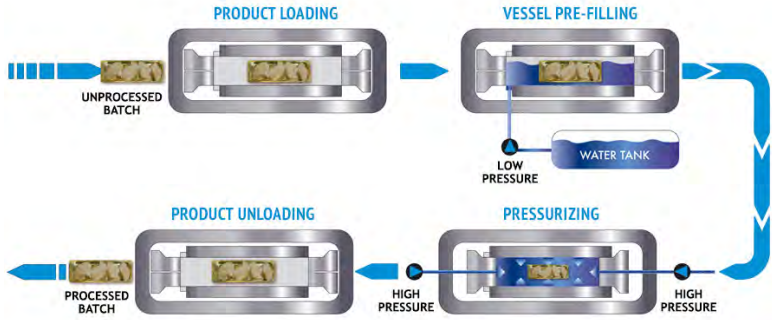


Figure 11.7.3.1 High pressure vessel used to treat packaged meat.
http://www.hiperbaric.com/en/high-pressure

Garriga et al. (2005) followed a 400 MPa treatment of sliced, cooked ham, inoculated with *Listeria*. Survival was detected during 42 days of storage at 6°C, but was not detected up to 80 days later when stored at 1°C. In a previous study they reported that 600 MPa was sufficient to prevent *Listeria* growth in meat products when stored at 4°C. In commercial applications, however, differences in pressure and time profiles might not provide a uniform pattern for microbial inactivation. In fresh meat, HPP can also result in some cooked appearance and

sometimes the development of a rubbery texture as a result of myofibrillar and myoglobin protein denaturation. In any case, recent consumer surveys indicated high acceptability for technologies that use no chemicals and have a minimal effect on the food product's appearance and taste.

11.7.4 Pulsed Electric Field

Short exposure (e.g., milliseconds) of microorganisms to high intensity electrical field, also called electroporation, results in structural changes and electrical disruption in the cell membrane. The technology was introduced in the 1960s and recent developments have opened the possibility for moving to a continuous process. Although the precise mechanism of microbial inactivation is not fully understood (Sun, 2014), the major factor seems to be an enlargement or formation of pores in the cell's membrane, which increases permeability. This can be an irreversible change that results in cell injury/death. Inactivation also depends on the state of the cell (e.g., lag phase vs log phase), food product parameters (e.g., pH, water activity, composition), and process conditions (e.g., number of pulses, electrical field strength). Overall, Gram-negative and positive bacteria are more resistant than yeast to this treatment.

11.7.5 Pulsed Light

In this method, microorganisms on the surface of food (can also be in a transparent package) are inactivated by high-energy light pulses (≤ 0.01 sec) in the wavelength range of 170-2600 nm. Processing units have been developed in which electric energy can be stored in a capacitor over a long period, and then released in short bursts, which damages nucleic acids (especially in the UV range), proteins, membranes, and other cellular components. The antimicrobial effectiveness of the process has been studied on food contact surfaces, packaging materials, and on the surface of various foods, including processed meat, bakery, and fishery products (Ray and Bhunia, 2013).

Paskeviciute et al. (2011) showed that a high-energy pulsed light treatment (1,000 pulses, treatment duration 200 s, total ultraviolet light dose 5.4 J/cm^2) reduced the population of *S. typhimurium* and *L. monocytogenes* inoculated on the surface of chicken by 2.4 $\log_{10}$ CFU/mL. In addition, the total aerobic mesophile population on the surface of meat was diminished by 2 $\log_{10}$ CFU/mL. Data obtained on the investigation of chemical changes in treated chicken breasts indicated that the intensity of lipid peroxidation in the control and treated chicken samples differed by 0.16 mg malondialdehyde per kilogram of chicken meat. Taste

panelists examining the organoleptic properties of treated chicken did not detect any changes in raw chicken, chicken broth, or cooked chicken meat flavour when compared to the control. Other researchers have reported similar positive results in fully cooked products.

11.7.6 Ultrasound

Ultrasound generates high-frequency sound waves and its antimicrobial effect is attributed to intracellular cavitation that disrupts the cellular structures and functional components. Overall, studies revealed that the antimicrobial effect of ultrasound in food is rather low (Ray and Bhunia, 2013). However, it can be enhanced by combining ultrasound with heat treatment above 50°C. Lawson et al. (2009) compared four technologies to reduce *Salmonella* in commercial Danish abattoirs: hot water, steam plus ultrasound, steam plus vacuum, and lactic acid. The results suggested that all technologies reduced the *Salmonella* population from 2.2% to about 0.2-0.9%. Overall, lactic acid was most cost effective followed by steam plus ultrasound decontamination.

11.7.7 Cold Plasma

Cold plasma is a mixture of free electrons, ionized particles, and some neutral atoms and molecules. Some consider plasma the fourth state of matter (the other three are solids, liquids, and gases). Noriega et al. (2011) looked at the efficacy of cold atmospheric gas plasmas for decontaminating chicken skin and lean muscle inoculated with *Listeria innocua*. Operating conditions were optimized for maximum bacterial inactivation by studying membrane filters on which *L. innocua* had been deposited. Higher AC voltage and excitation frequency as well as the presence of oxygen in the carrier gas resulted in the greatest inactivation efficacy. This was later also confirmed in the lean chicken muscle and skin results. Under optimal conditions, a 10 s treatment resulted in a > 3 log reduction of *L. innocua* on membrane filters, an 8 min treatment resulted in a 1 log reduction on skin, and a 4 min treatment resulted in a > 3 log reduction on muscle. These results show that the efficacy of gas plasma treatment is greatly affected by surface topography. Scanning electron microscopy images of chicken muscle and skin revealed surface features that effectively protected bacteria from the reactive chemical species generated within the gas plasma. Further development in gas plasma technology is needed for its commercial application to foods.

11.8 Hurdle Technology

The concept of using a series of preservation methods to enhance food safety has already been introduced in Chapter 6. By using the hurdle concept, one can minimize the negative effects of using a single preservation method at its maximum dose (e.g., pasteurization temperature can cause off flavours and textural and vitamin losses), reduce preservative use (e.g., salt that also affects flavour and nutritional content), and/or reduce processing cost (e.g., energy required to fully dry a product). Many food products on the market are produced using the hurdle concept (Leistner, 2000). An example is a hotdog, which is prepared with salt, phosphate, nitrite, and is sold in a vacuum packaged container after being heat processed. The latter is a major step in reducing microbial count (usually by about 4 to 6 logs) and also serves as a critical control point in most HACCP plans (see Chapter 12). The added salt serves as an antimicrobial agent (e.g., salt is added at about 2 – 3% which is below the 15 – 20% level needed to act as a complete barrier to microbial growth). In addition, the product is refrigerated and consumers are instructed to consume the product within a few days of opening. This is because exposure to oxygen can encourage the growth of spoilage microorganisms. Another example of hurdle technology was provided by Sommers et al. (2010). They demonstrated the combined effect of ultraviolet light (0.5 J/cm^2), potassium lactate, lauric arginate ester, and sodium diacetate (all are UDSA approved) on the shelf life of frankfurters. The combination resulted in a 3.6-4.1 log reduction of *Salmonella*, *L. monocytogenes* and *S. aureus* on the product's surface during a 12 week storage at 10°C. The combined treatments had no significant impact on frankfurter colour or texture. Other studies have investigated this approach and it is expected that more combinations will be introduced in the future. Examples in this chapter have already described the benefits of combining physical methods (e.g., heating, radiation, high pressure), chemical methods (e.g., salt, lactic acid, smoke compounds) and biological methods (e.g., bacteriocins, bacteriophages) to enhance food safety. Use of active packaging to deter microbial growth is another important area, especially when products are shipped long distances, and where longer shelf lives are required. Developments in modified atmosphere and intelligent packaging will continue with the goal of supplying the consumer with high quality products that are safer and more nutritious.

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12

HACCP IN COOKED MEAT OPERATIONS

12.1 Cooked Product – Generic HACCP Model for Cooked Meat

A large portion of the further processed meat products in the marketplace are sold as fully cooked products. Examples include luncheon meats (e.g., bologna, mortadella), whole muscle meats (e.g., oven roasted chicken/turkey, ham) and fermented products (e.g., pepperoni, summer sausage). This chapter describes a generic HACCP model that was developed for cooked ham using either whole muscle turkey/pork leg meat. The model is used to illustrate production steps common to cooked products and it also discusses potential critical control points (CCPs) and limits that could be set to control hazards. The generic model described here was developed by the Canadian Food Inspection Agency (CFIA, 1998). However, it can also be used as an example for various types of other cooked meat products. An introduction to HACCP and its seven principles has been provided in Chapter 6. The model described in this chapter has many similarities to the USDA (1999) model for cured, cooked products, which includes the 'ready-to-eat' (RTE) category of products that do not require heating prior to consumption by the consumer. However, some are heated to enhance product's acceptability (e.g., frankfurter). The products are cured, which means that they contain different salts (e.g., sodium chloride, sodium phosphate, sodium nitrite) that can also play a role in preserving the product (see Chapter 15). After cooking, proper refrigeration or freezing is commonly used to maintain the safety of the RTE product and to prolong the shelf life. A description of the product is available in Table 12.1.1, which is part of the HACCP documentation.

Table 12.1.1 Product description – cooked sliced, ham (e.g., turkey, pork). Modified from CFIA (1998).

Product name	**Cooked, sliced turkey ham**
Important product characteristics (pH, aw)	salt - not less than X%; nitrite - X ppm
Use of product	sliced, ready-to-eat
Packaging	vacuum packaged
Shelf life	X days (e.g., 50 days) after slicing when kept at ≤ 4°C
Distribution	retail, food service
Labeling instructions	best before date, keep refrigerated
Special distribution control	under refrigeration or frozen

12.2 Process Steps

The process flow diagram is presented in Fig. 12.2.1. In addition, see Chapter 10 for a detailed description of the processing steps involved in preparing a cooked product and the equipment used. The process starts with receiving the meat and all the non-meat ingredients. This is also the first control point for biological, chemical, and physical hazards (see Table 12.2.1). The biological hazards mainly include microorganisms in the raw meat (e.g., *Salmonella*) or bacteria that have been transferred from people handling the meat at the plant (e.g., *Staphylococcus*). Of major concern is also the introduction of pathogens to the cooked product prior to packaging (i.e., cross contamination). Table 12.2.1 indicates that CCP-6B and CCP-7B (the cooking and chilling steps, respectively) are two potential control points for this kind of a hazard. Overall, the cooking step is designed to kill most (if not all) of the non-spore forming bacteria (e.g., *Listeria*), and therefore post-cooking contamination can be a major safety issue as is also indicated by CCP-8B, which refers to slicing the fully cooked product (see also discussions on *E. coli* and *Listeria* in Chapter 15).

Chemical hazards in the incoming raw meat may include antibiotics, pesticides and other drug residues that are not permitted by law. Therefore, the receiving point is designated as CCP-1, meaning that the raw materials must be checked. In some cases the processor will require a Letter of Guarantee from the raw meat ingredient supplier to certify that there are no antibiotics or pesticides in the raw ingredients. Besides being illegal, these ingredients can also interfere

with processing procedures such as fermentation (e.g., presence of low levels of antibiotic will prevent the growth of lactic acid bacteria and result in a significant economic loss).

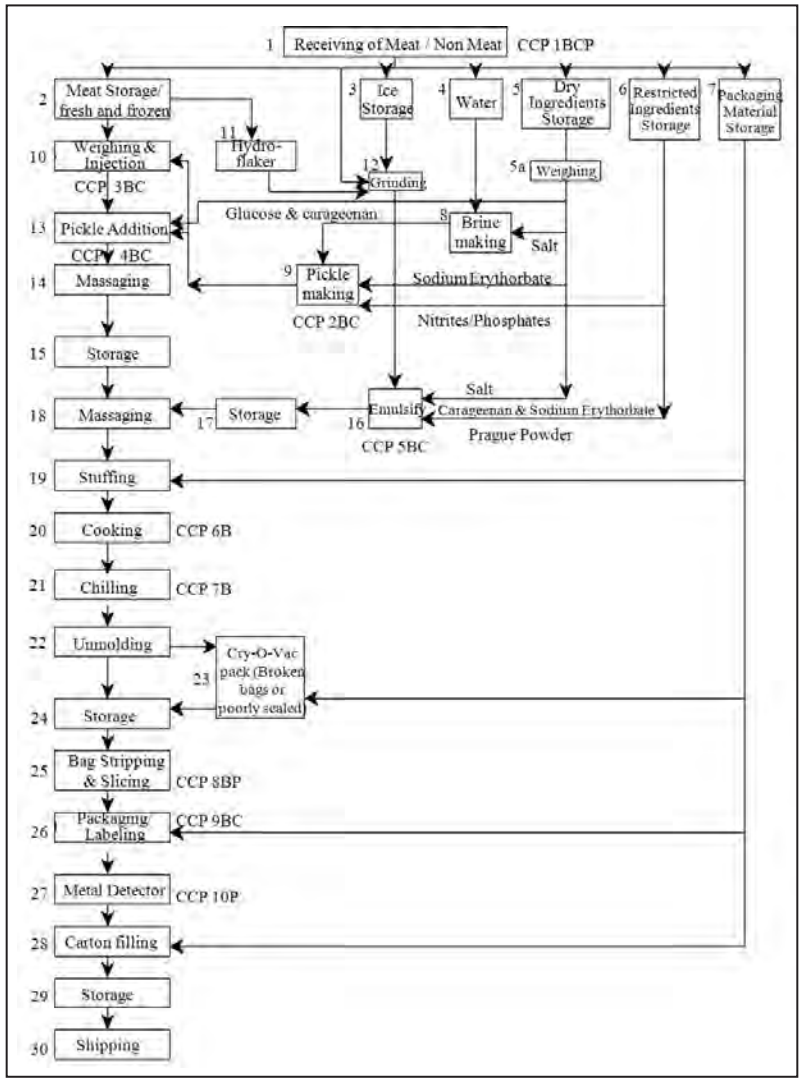


Figure 12.2.1 A flow diagram illustrating the steps involved in the production of sliced cooked ham (e.g., turkey, pork), including suggested critical control points (CCP) for biological (B), chemical (C) and physical (P) hazards. From CFIA (1998).

Table 12.2.1 List of biological (B), chemical (C), and physical (P) hazards and critical control points (CCP) related to incoming materials and processing steps for cooked, sliced ham (e.g., turkey, pork). From CFIA (1998).

Identified Biological Hazards (Bacteria, Parasites, Viruses, etc.)	**Controlled at**
Incoming Materials	
Raw Meat (as received) & Ground Trims – Non-spore forming pathogenic bacteria – *Listeria monocytogenes, Staphylococcus aureus, Yersinia sp., Campylobacter sp., Salmonella sp., E. coli,* etc. – Spore forming pathogenic bacteria – *C. perfringens, C. botulinum,* etc.	CCP-6B CCP-7B
Water (as received) – *Coliforms, faecal coliforms*	Prerequisite programs (Water quality program)
Ice (as received) – *Coliforms, faecal coliforms*	CCP-1BCP
Process Steps:	
#1 Receiving of non-compliant material – Fresh Meat & Non Meat Ingredients: Bacterial (Pathogen) growth due to time/temperature abuse and cross contamination	CCP-1BCP
#2 Meat Storage – Bacterial growth due to time/ temperature abuse	Prerequisite programs (Transport & Storage)
#7 Storage of Packaging material – Bacterial pathogens growth due to environment (rodent, insects, etc.)	Prerequisite programs (Sanitation and pest control)
#9 Pickle Making – Bacterial pathogens growth in finished product due to insufficient amount of Nitrite in pickle formulation	CCP 2BC
#10 Weighing and Injection – Bacterial pathogens growth in finished product due to too little pickle in product	CCP 3BC
#12 Grinding – Contamination due to poor sanitizing of equipment	Prerequisite programs (Sanitation)
#13 Pickle Addition – Bacterial pathogens growth due to insufficient amount of pickle	CCP-4BC
#15 Storage – Bacterial pathogens growth due to time/ temperature abuse	Prerequisite programs (Transport & Storage)
#16 Emulsification – Bacterial pathogens growth in finished product due to insufficient addition of Prague powder	CCP-5BC

#16 Emulsification – Bacterial pathogens growth due to time/temperature abuse	Prerequisite programs (Employee Training)
#17 Storage of emulsion – Bacterial pathogens growth due to time/temperature abuse	Prerequisite programs (Transport & Storage)
#19 Stuffing – Bacterial pathogens growth due to time/temperature abuse	Prerequisite programs (Employee Training)
#20 Cooking – Survival of pathogens due to inadequate temperature or cooking time	CCP-6B
#21 Chilling – Spores of *C. perfringens* sporulation & growth due to inadequate chilling rate	CCP-7B
#22 Unmolding – Bacterial contamination from poor handling of bags	Prerequisite programs (Employee Training)
#23 Vacuum packing (broken poorly sealed bags) – Cross contamination with pathogens (e.g., *Salmonella sp., L. monocytogenes, S. aureus*, etc.) by employee inadequate handling/unclean equipment	Prerequisite programs (Employee Training)
#24 Storage – Bacterial pathogens growth due to time/temperature abuse	Prerequisite programs (Transport & Storage)
#25 Bag stripping & slicing – Cross contamination with pathogens (e.g., *Salmonella sp., L. monocytogenes, S. aureus*, etc.) by employee inadequate handling/unclean equipment	CCP-8B
#26 Packaging/Labeling – Cross contamination with pathogens (e.g., *Salmonella sp., L. monocytogenes, S. aureus*, etc.) by employee inadequate handling/unclean equipment	Prerequisite programs (Employee Training)
#26 Packaging/Labeling – Bacterial pathogens growth due to improper coding (best before)	CCP-9BC
#29 Storage – Bacterial pathogens growth due to time/temperature abuse	Prerequisite programs (Transportation & Storage)
Identified Chemical Hazards	**Controlled at**
Incoming Materials	
Raw meat (as received) & Ground trims – Antibiotics, Pesticides, Drug residues	
Water (as received) – Chemical residues in incoming Water	Prerequisite programs (Water quality program)
Ice (as received) – Chemical residues in incoming Ice	N/A
Packaging material (as received) – Chemical migration of non-food grade packaging material, inaccurate labeling by supplier	CCP-1BCP

Process Steps:	
#1 Receiving – Receiving of non-compliant material (see above)	CCP-1BCP
#9 Pickle Making – Excess nitrite in the pickle	CCP-2BC
#10 Weighing & Injection – Excess nitrite in the pickled product (over pumping)	CCP-3BC
#13 Pickle addition – Toxicity: excess of nitrite (over addition)	CCP-4BC
#16 Emulsify – Excess nitrite added as Prague powder	CCP-5BC
#26 Packaging/Labeling – (Some ingredients not declared on label). Allergic reactions due to wrongly labeled product	CCP-9BC
Identified Physical Hazards	**Controlled at**
Incoming Materials	
Foreign material of non-metallic origin in Meat	CCP-1BCP
Foreign material of non-metallic origin in Ice	CCP-1BCP
Foreign material of non-metallic origin in Salt	N/A
Metallic particles in Meat	CCP-10P
Metallic particles in Ice	CCP-10P
Metallic particles in Salt	N/A
Packaging material contamination with foreign material	CCP-1BCP
Process Steps:	
#1 Receiving of meat and non-meat products – Contamination with foreign material (see above)	CCP-10P
#5 Storage/weighing of Dry Ingredients – Contamination with foreign material	Prerequisite programs (Transport & Storage)
#6 Storage of Restricted Ingredients – Contamination with foreign material	Prerequisite programs (Transport & Storage)
#7 Storage of packaging Material – Contamination with wood, metal, etc.	Prerequisite programs (Transport & Storage)
#8 Brine Making – Foreign material falling into the brine	Prerequisite programs (Premise Control, Equipment Maintenance)
#9 Pickle Making – Foreign material falling into the pickle solution	Prerequisite programs (Premise Control, Equipment Maintenance)
#10 Weighing and Injection – Broken needles	CCP-10P
#11 Hydroflaking – Metal fragments from damaged inadequately maintained equipment	Prerequisite programs CCP-10P

#12 Grinding – Non-metallic foreign material	Prerequisite programs (Premise Control, Equipment Maintenance)
#12 Grinding – Metal fragments from damaged inadequately maintained equipment	Prerequisite programs (Equipment maintenance) CCP-10P
#14 Massage – Metal fragments from damaged inadequately maintained equipment	Prerequisite programs (Equipment maintenance) CCP-10P
#15 Storage – Foreign material falling in product	Prerequisite programs (Premise Control, Equipment Maintenance)
#16 Emulsify – Metal fragments from damaged inadequately maintained equipment	Prerequisite programs (Equipment maintenance) CCP-10P
#18 Massaging – Metal fragments from damaged inadequately maintained equipment	Prerequisite programs (Equipment maintenance) CCP-10P
#19 Stuffing – Metal fragments from damaged inadequately maintained equipment	Prerequisite programs (Equipment maintenance) CCP-10P
#19 Stuffing – Non metal foreign material contamination	Prerequisite programs (Premise Control, Equipment Maintenance)
#27 Metal Detector – Malfunction of the metal detector ferrous metal and aluminum not properly detected	CCP-10P
Identified Hazards	**Indicate the way the Hazard could be Addressed (Cooking Instructions, Public Education, Use Before Date, etc.)**
Incoming Materials	
Chemical – Antibiotics, Drug residues, Pesticides in incoming meat products	Producer education and practices/ proper withdrawal periods observed

Physical hazards in the incoming meat (Table 12.2.1) may include metallic and non-metallic substances (e.g., glass, wood, plastic) that might accidentally fall into the product and/or arrive already in the product (e.g., broken injection needle). This critical step (CCP-1) should be designed to eliminate foreign particles by sampling on raw materials to verify compliance. In addition, some companies are using supplier audit programs where they go visit and inspect facilities. If the number

of complaints (related to foreign objects or other safety/quality issues) increases, more audits will be performed. If no improvement is seen, the supplier might be terminated. At the food processing plant, raw material sampling is performed by equipment such as a metal detector, x-ray (see photo in Chapter 9), or simple visual inspection to identify and then remove any potential problems. Because metal parts (e.g., screws) can fall into the product during processing, a metal detector is also positioned at the end of the processing line to check the final products before shipping (Fig. 12.2.1). However, if there is a known problem of meat arriving with metal particles a metal detector should be placed at the raw material receiving point. Spice suppliers, for example, check all their raw materials (e.g., using metal detectors, sieving) prior to shipping goods to the meat processing plant and are also usually required to provide a Letter of Guarantee.

Table 12.2.2 shows a detailed step-by-step design of a HACCP plan to control the various identified hazards. The table provides information about critical limits, monitoring procedures, deviations, verifications, and record keeping. An introduction to the different steps can be found in Chapter 6.

Table 12.2.3 is an example of a HACCP record keeping sheet for monitoring the showering and chilling of the final cooked product. It is essential that the process be monitored on a continuous basis. That way, problems are flagged as soon as possible and the employee responsible can execute the pre-determined corrective actions and/or reprocessing steps. The rigid process and pre-determined corrective actions take away any employee guesswork, allow the HACCP plans to evolve, and also demonstrate to the inspection agency that consistent corrective actions are taken. Each deviation, its date, and its corrective actions must be available to inspectors. It is usually mandatory to keep records for several years (e.g., 5 years). This tool also helps plant management to focus on sensitive areas and use the concept of an improvement loop to continuously enhance food safety.

There are other documents that can be used to help the processor in designing and/or improving the generic model (i.e., as indicated in Chapter 6, the generic model is intended to be used as a starting point for a specific plant). An example of a useful document is the USDA Compliance Guidelines for Meeting Lethality Performance Standards for Cooked Ready-To-Eat (RTE) Meat and Poultry Products. In it, the USDA is presenting a lethality model for cooked, sliced meat that illustrates how processors can ensure that a specified minimum destructive temperature is achieved and maintained long enough to inactivate certain pathogens.

Table 12.2.2 Examples of details about some suggested critical control points (CCP) provided in the HACCP Generic Model for cooked sliced, ham (e.g., turkey, pork). From CFIA (1998).

Process Steps	CPP/ Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#1 Receiving	CCP-1BPC	Presence of pathogenic bacteria. Bacterial pathogen growth due to time/ temperature abuse and cross contamination.	Normal colour and odour. Contractual specifications for meat products. Maximum temperature of 4° C at the center and surface of meat products. Slaughter/packaging date (max "X" days) for fresh meat. Contractual specifications for hygienic slaughter & boning/handling procedures + transport temperatures for meat product.	Receiver to check lots are covered by contractual specifications for each lot received. Receiver to take temperature of every lot of meat. Check slaughter packaging date. Visually examine for carton damage. Organoleptic examination of product.	Receiver is to place non compliant shipment on hold & inform foreperson and supplier. Product is to be returned or QC test/ decision.	QC to verify log book & procedures once a week. QC check temperature & collect sample for micro verification once a week. QC audit supplier plants.	Receiver's log book. QC records temperature book. Microlab analysis records.
		Bone chips in boneless meat. Extraneous material, metal, wood.	No foreign material 2mm or larger.	Receiver checks that contractual specifications exist for each incoming material. Boneless turkey inspection program at supplier level. Receiver checks product if cartons are damaged.	Hold shipment & inform foreperson & Supplier.	QC to verify log book once per week. QC to perform boneless reinspection every "X" shipment. Product Random sample.	

Process Steps	CPP/ Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#1 Receiving	CCP-1BPC	Packaging material non food grade.	Contractual specifications "Approved" material only.	Receiver to allow unloading only if from approved Supplier/ Material.	Do not allow unloading. Notify QC. QC holds products, requests proof of approval or returns product.		
#9 Pickle making	CCP-2BC	Too little/too much Sodium nitrite ($NaNO_2$) in the pickle mixture.	"Y" ppm for each formulation (volumetric measuring devices within lab. tolerances).	Inventory control sheet by pickle maker. Daily check sheet for each recipe. Test strips used by pickle maker on each batch to indicate presence of nitrite.	Pickle maker to notify foreperson, hold pickle. Foreperson to hold product already pumped & notify QC.	QC to test pickle batches 2×/week with test strips. Review of records 1×/week.	Pickle room check sheet Lab reports.
#10 Weighing & Injection	CCP-3BC	Too little $NaNO_2$ in the product. Excess of $NaNO_2$ in the pickled product (over pump).	Weight after pumping = weight before pumping plus "X"%.	Operator records green & pumped wt. on control sheets and ensures that % of pumping is respected.	Recalibrates injection machine, hold product. Inform QC of over pumped product.	Foreman audits control sheets 2×/ day and verify % of pumping. QC verifies control sheet weekly (green wt. vs pumped wt.) and verify % of pumping.	Injection control records control sheet.

Process Steps	CPP/ Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#13 Pickle Addition	CCP-4BC	Under pump, too little $NaNO_2$ in the product. Excess of $NaNO_2$/over pump.	Pump at "X"%.	Batch weight to equal green weight + "X"%. Finished wt. to = formula wt. for each batch.	Add more pickle, standard operating procedure is to purposely under pump. Pickle injector operator is responsible for topping up each batch to the correct wt. Adjust pickle injector.	Control sheet. Daily scale checks with check weights. Foreperson audits control sheets 2×/ day. QC verifies control sheets weekly (green wt. vs pumped wt.).	Control sheet. Scale check sheet.
#16 Emulsify	CCP-5BC	Too little or excess of $NaNO_2$ in the emulsion.	Add correct wt. of Prague powder as per formula.	Batch control sheets. Formulation signed by the operator.	Hold, contact foreperson and QC. QC to reformulate.	Random lab analysis performed by QC 2× per week. Foreperson to verify 1x/day.	Batch control sheets. QC lab report.
#20 Cooking	CCP-6B	Survival of pathogens due to inadequate cooking time or temperature.	Cooking house temperature/time cycle functioning. Temperature and time limits "X" hrs & "Y"° C.	Check cooking cycle. Manual temp. check by the operator for every batch, thermograph checked and signed by the operator.	Cook to internal temp. of "Y"° C (extend cooking time as necessary).	Thermograph charts reviewed weekly by QC.	Thermograph charts kept on file by QC.

Process Steps	CPP/ Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#21 Chilling	CCP-7B	Growth of *C. perfringens.*	Chill to 4° C in 12 hours or less. Chill water temperature cycle as defined in plant chilling process.	Every batch has a manual temperature check by the operator. Shower product to "Y"°C internal temp., chill to 4° C in 12 hours or less. Check chill water temperature.	Operator monitors room temperature & records deviations. Temperature control person investigates if there is a deviation & if problem cannot be corrected within 1 hour, he/ she contacts fore-person in charge of production. Product moved to coldest section for chilling.	Records reviewed by QC on a daily basis. Audit monitoring procedures at "X" frequency.	Room temperature records and product internal temperature.
#25 Bag Stripping & Slicing	CCP-8B	Cross contamination of product or improper employee handling practices.	Clean and sanitized gloves. Contact with anything other than the loaves requires hand dipping (sanitizing) prior to resuming bag stripping duties. No tolerance of soiled gloves or hands.	Monitoring by foreperson of employee practices by random inspection 2×/day and record results.	Foreperson will instruct the employee on proper procedure and monitor until the employee's performance is satisfactory. Product trimmed sent for rework.	QC to verify employee handling practices through periodic audits 1×/ week. QC swabs gloves and contact surfaces at least once a week.	Departmental QC check sheets. Swab reports on equipment and gloves.

Process Steps	CPP/ Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#26 Packaging	CCP-9BC	Pathogenic bacterial growth due to wrong best before date.	Correct date as determined by shelf life testing.	Designated employee check best before date when checking ingredients listing for each lot.	Foreperson detains defective packages for repackaging. Record each incident.	QC verifies best before date and ingredients listing versus formulation records "X" times/ month.	Departmental QC check sheets.
		Allergies due to incomplete/wrong list of ingredients to the product.	Label to match the product. No tolerance.	Line operator (label installer) will check to ensure correct label is in place at start of each lot and record results.	Designated employee will hold product for repackaging/ relabeling correctly.	Foreperson to randomly check 2×/day and record beginning of each product run. QC reviews departmental check sheet weekly.	Departmental QC check sheets.
#27 Metal Detector	CCP-10P	Metal and aluminum not detected due to detector not functioning or improper calibration.	No metal greater than 2mm in size.	Every package goes through the metal detector. Electrician checks the calibration of the metal detector prior to the start of operations each day and signs the check sheet. Employee checks function of detector by running a test wand through the metal detector 4× per day.	If larger than 2mm in size product is rejected by the metal detector. Notify foreperson & QC. Every "ringer" the lot goes to QC for investigation. Product is held until QC determines cause. Product is retested since last satisfactory test.	QC runs test wand through the metal detector 4x per week. Every "ringer" goes to QC for investigation.	Departmental daily check sheet. Lab contamination report from QC. Contamination file.

Table 12.2.3 HACCP record keeping sheet. An example for monitoring and record keeping of the shower chill for cooked meat products. From CFIA (1988).

Freq.	Foreman	Each Batch	Each Batch	Each Batch	Each Batch	Each Batch	Each Batch	Each Batch	Each Batch		
Freq.	Q.C.	Freq. "X"	Freq. "X"	Freq. "X"	Freq. "X"	Freq. "X"	Freq. "X"	Freq. "X"	Freq. "X"		
Date	Hour	LOT#	State shower time	End shower time	Temperature of product "Y"° C	Chill time in	Chill time out	Final product chill temp. Max 4° C	Total chill time (from start of shower to final chill) Max 12 hrs	Results/Actions	Initials

In 2001, the Food Safety and Inspection Service (FSIS) proposed a rule entitled "Performance Standards for the Production of Processed Meat and Poultry Products'' (66 FR 12590). The proposed regulations included performance standards, *Listeria* testing requirements, and also standards for the destruction of *Trichina* in pork products. The regulations are also applicable to cooked beef, roast beef, chunked and formed roasts, corned beef, and poultry products. The FSIS included compliance guidelines for lethality (Appendix A of the final rule) that describes times and temperatures necessary to achieve a 6.5 log10 or 7.0 log10 reduction of *Salmonella* in meat products (Dawson et al., 2012). These same compliance tables can be used for other RTE meat, such as meat patties. Regulations about cooling times of fully cooked products are also used to eliminate/reduce the risk of microorganisms such as *C. perfringens* growth during the cooling phase.

The proposed regulations also indicated that:

a. Cooked poultry rolls and other cooked poultry products should reach an internal temperature of at least 160 °F prior to being removed from the cooking medium. However, cured and smoked poultry rolls and other cured and smoked poultry should reach an internal temperature of at least 155 °F prior to being removed from the cooking medium. Cooked ready-to-eat product to which heat will be applied incidental to a subsequent processing procedure may be removed from the media for such processing provided that it is immediately fully cooked to 160°F internal temperature.

b. Establishments producing cooked poultry rolls and other cooked poultry products should have sufficient monitoring equipment, including recording devices, to assure that the temperature (accuracy assured within 1 °F) limits of these processes are being met. Note that manual detection should also be performed to verify recorders are working correctly. Data from the recording devices should be made available to FSIS program employees upon request.

The FSIS also included revised time-temperature combinations for cooking RTE poultry (i.e., revised from the previous combinations published for products such as roast beef and pork). The revised material was previously published in a scientific paper (Juneja et al., 2001). The authors developed a formula for predicting time/temperature combinations necessary for achieving a 7 $\log_{10}$ reduction of *Salmonella* in RTE poultry with different fat levels, as well as standard errors for these predictions (see example in Table 12.2.4). The revised times are actually significantly longer than those that were assumed to be effective in the past. A processor can also consult the different alternatives for *Listeria* control issued by FSIS (2014).

Table 12.2.4 Guidelines for time x temperature cooking combinations to achieve a 7 $\log_{10}$ *Salmonella* reduction in poultry products containing 4 or 8% fat. Based on data from Juneja et al. (2001).

fat% = 4					fat% = 8				
Temperature	time for		time for		Temperature	time for		time for	
F	Chicken	unit	Turkey	unit	F	Chicken	unit	Turkey	unit
136	67	min	64.9	min	136	73	min	66.9	min
137	53.2	min	52.8	min	137	58.2	min	54.7	min
138	42.2	min	43	min	138	46.4	min	44.8	min
139	33.6	min	35.1	min	139	37.2	min	36.7	min
140	26.8	min	28.7	min	140	29.8	min	30.2	min
141	21.5	min	23.5	min	141	24	min	24.9	min
142	17.2	min	19.3	min	142	19.4	min	20.5	min
143	13.8	min	15.9	min	143	15.6	min	17	min
144	11.1	min	13	min	144	12.6	min	14	min
145	8.9	min	10.7	min	145	10.2	min	11.5	min
146	7.2	min	8.8	min	146	8.2	min	9.5	min
147	5.7	min	7.2	min	147	6.6	min	7.7	min
148	4.5	min	5.8	min	148	5.2	min	6.3	min
149	3.6	min	4.7	min	149	4.1	min	5	min
150	2.7	min	3.7	min	150	3.1	min	4	min
151	2.1	min	2.9	min	151	2.3	min	3.1	min
152	1.6	min	2.3	min	152	1.7	min	2.3	min
153	1.2	min	1.9	min	153	1.3	min	1.9	min
154	59.1	sec	1.5	min	154	1.1	min	1.5	min
155	46.8	sec	1.2	min	155	50.4	sec	1.3	min
156	37	sec	59.8	sec	156	39.9	sec	1	min
157	29.3	sec	48.5	sec	157	31.6	sec	49.5	sec
158	23.2	sec	39.4	sec	158	25	sec	40.1	sec
159	18.3	sec	32	sec	159	19.8	sec	32.6	sec
160	14.5	sec	26	sec	160	15.6	sec	26.4	sec
161	11.5	sec	21.1	sec	161	12.4	sec	21.5	sec
162	<10.0	sec	17.1	sec	162	9.8	sec	17.4	sec
163	<10.0	sec	13.9	sec	163	<10.0	sec	14.1	sec
164	<10.0	sec	11.3	sec	164	<10.0	sec	11.5	sec
165	<10.0	sec	<10.0	sec	165	<10.0	sec	<10.0	sec

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13

PRINCIPLES OF MEAT PROCESSING

13.1 Introduction

The continuous success of marketing meat depends on the innovation and consistent production of high quality products. Consumers are looking for convenient food products with new/exciting flavours, textures, etc. A simple, inexpensive mix of dry powder containing all essential nutrients can meet our nutritional needs; consumers, however, are looking for diversification and excitement when eating food. As will be discussed in this chapter, the food industry is making and preparing food in different ways and with many ingredients. A simple example of this diversification is the use of white poultry meat in roasts, deep fat fried nuggets, barbequed fillets/wings with honey garlic sauce, or smoked sausages (recipes for all these products are provided at the end of this chapter). Over the past few decades, the meat and poultry industries have been very active in introducing new meat products. Initially, a lot of the products were made from red meat (e.g., salami, pepperoni, ham). However, during the past 30 years the poultry industry has taken the initiative to develop fresh, marinated, as well as fully cooked products, and it has also adopted some red meat recipes. Poultry frankfurters were unheard of 50 years ago; however, after their introduction, they gained widespread popularity and currently represent about a third of the North American market. These new developments have helped to increase consumption and to move away from seasonal meat demands (e.g., in the past, whole turkeys were primarily sold in North America prior to Thanksgiving and Christmas). The industry has also realized that selling large birds, such as whole turkeys, limits its ability to sell meat to all market segments. Therefore, the industry started marketing smaller cuts and further processed products in small packages. Another example that is unique to the poultry industry is the development of the chicken nugget by the fast food industry in the 1970s. This has given the industry a huge boost in sales and has dramatically changed the marketing and processing of chicken meat. This innovation was driven by the industry's need to develop line deboning of poultry as well as find ways to sell the remaining chicken portions (i.e., before nuggets were introduced

the market was mainly set for selling whole birds and some bone-in cut up parts). It also resulted in the introduction of mechanical deboning of the meat left on the frames. All these developments created a market for various innovative further processed meat products (Table 13.1.1; Fig. 13.1.1). Overall, this is an example of the industry successfully responding to consumer demand for more convenient food items including semi and fully prepared items. In this case, the increase in poultry meat consumption (Chapter 2) has been the result of aggressive marketing, the meat's favorable nutrient profile, and its competitive price. As discussed in this book, these developments have been coupled with the introduction of automation, computer assisted programming (e.g., see discussion on Least Cost Formulation below), and increasing line speed.

Table 13.1.1 Categories of the major meat/poultry further processed products on the international market. Note: smoking procedures and cooking recipes for most products are provided at the end of the chapter.

Category	Example	Comment
a. Whole Muscle	Oven roasted turkey breast Smoked chicken/duck/goose fillet	Premium white meat product
b. Restructured	Poultry roll Turkey luncheon roll Cooked duck tenderloins Turkey ham	Large/small meat chunks Pieces of dark thigh meat
c. Ground	Breakfast sausage Pepperoni sticks Salami Chicken hamburger	Sold fresh/frozen to the consumer Fully cooked/frozen ready to eat Semi dried/dried ready to eat
d. Finely Comminuted	Chicken wiener Turkey hot dog Poultry Bologna	Very homogeneous appearance
e. Coated	Nuggets Cordon Bleu Chicken wings BBQ bone in chicken wing/thigh BBQ boneless poultry drum sticks	Battered, breaded and fried Breaded with cheese insert Battered, breaded, par-fried & cooked Marinated and cooked Marinated and cooked

Overall, meat and meat products are mainly composed of protein, water, fat, minerals (salts), and some carbohydrates. Proteins represent the major building blocks of meat products and a major section in this chapter is devoted to protein gelation. Mezzenga and Fischer (2013) indicated that protein aggregation has fundamental relevance not only in the food industry (e.g., providing texture to meat products, gelation of yogurt) but also in the medical field (blood coagulation by

fibrinogen) and others. However, aggregation of food proteins differs substantially from the medical field, where the range of conditions is mostly limited to those found in the human body (e.g., 37ºC, pH – 7.0, ionic strength of about 155mM).



Figure 13.1.1 Examples of different products. Showing chicken roast, turkey roast, turkey pepperoni sticks, poultry wieners, turkey ham and turkey bacon. Photo by Barbut and Jinde.

In the food industry, temperature can range from 0 – 300ºC, pH from 1 – 10, and ionic strength spans as many as seven orders of magnitude. Food systems consist of complex mixtures of various proteins, fats, carbohydrates, and salts. In general, food proteins can be divided into different classes based on the amino acid sequence and thermal history. The protein structure may be referred to as either globular or random coil (folded or unfolded, respectively, Fig. 13.1.2). They will be discussed in more detail later in the chapter.

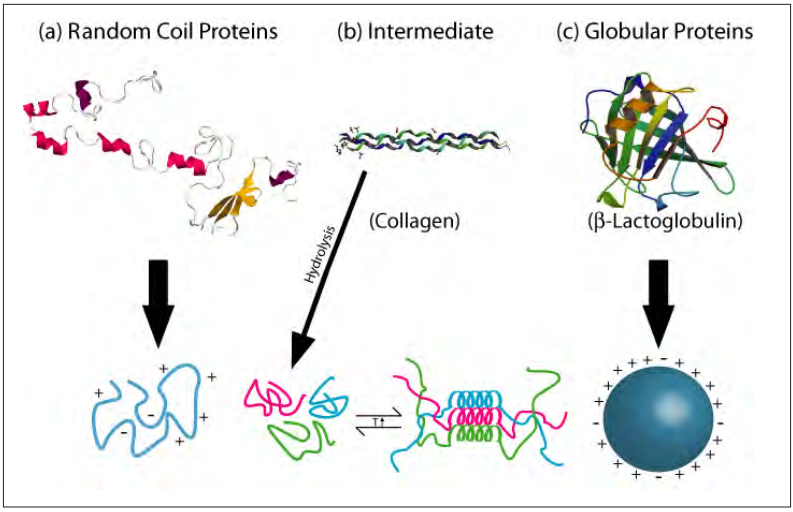


Figure 13.1.2 Schematic representation of the physical description of proteins in soft condensed matter. (a) A hypothetical unfolded protein, interpreted as an ampholytic polyelectrolyte, containing both positive and negative charges. (b) The intermediate case of gelatin, obtained by hydrolysis of the triple-helical collagen: the α-helical structure of gelatin strands can melt by increasing the temperature and reversibly re-constitute upon cooling, with α-helices interacting to induce gelation of the solution. (c) A folded globular protein, such as β-lactoglobulin, viewed as a colloidal sphere with positive and negative charges on its surfaces.
From Mezzenga and Fisher (2013).

13.2 Processing Categories of Meat Products

There is a vast array of meat products available for customers in the supermarket today. Table 13.1.1 shows examples of the main processing categories/groups, but overall there are hundreds of products available on the market, which can be challenging for consumers to understand. To assist them, various systems have been suggested for classifying meat products. For example, one system groups products based on their preparation method (Aberle et al., 2012) and includes six processing categories/groups:

a. Fresh (uncooked) – example: fresh breakfast sausage
b. Uncooked and smoked – example: Italian sausage
c. Smoked and cooked – examples: hot dogs, frankfurters, bologna, mortadella
d. Cooked – examples: liver sausage and pates

e. Dry/semidry or fermented – examples: summer sausage, dry salami
f. Cooked meat specialties – examples: luncheon meats, jellied products and loaves

It should also be mentioned that new technologies have helped to diversify the type of meat products we consume, especially the restructured meat products (e.g., surimi), where small pieces of meat are made into a whole muscle/steak-like product. This can be done by high speed flaking of partially frozen pieces of meat (usually from tougher cuts) that are later recombined under pressure with the addition of hydrocolloid gums (e.g., alginate with a calcium supplement). The surimi technology is based on using minced chicken/fish meat, which is first washed (to remove pigments and enzymes) and later extruded to create a muscle-like fibrous structure and texture.

Section 13.2.1 further discusses the categories of meat products mentioned in Table 13.1.1 and provides an introduction to the unique characteristics of each category. This is followed by an explanation of meat and non-meat ingredients used by the industry (Section 13.3 and 13.4, respectively), protein gel matrix formation (Section 13.5), meat emulsions (Section 13.6), casings (Section 13.7), and recipes for twenty popular, high volume meat products produced by the industry (Section 13.8).

13.2.1 Categories of Meat Products

a. Whole Muscle Products

Some of the largest whole muscle products produced by the industry are a whole ham and a whole oven roasted turkey breast portion (with or without smoke). This is considered a premium product because it is produced from one intact muscle portion. A brine solution (i.e., water, salt, spices, and often gums) is injected into the raw product prior to smoking and cooking. A formula and preparation procedure for this product are provided at the end of the chapter. This specific formulation calls for the addition of 30% brine, but some products on the market are produced with a 50% brine injection, which still results in a high protein level of about 14%. The brine in this case is injected directly into the large diameter product, but in the case of small diameter meat pieces it can be added by tumbling (see Chapter 10). In the case of a whole turkey breast, the meat is massaged or tumbled after brine injection to assist in moisture absorption and help distribute the non-meat ingredients within the muscle. The latter is important in the processing of any meat product as an uneven distribution of ingredients can cause serious flavour, colour and texture problems. Starches and hydrocolloid gums (e.g., carrageenans, see

Section 13.4) are often added to assist in holding the injected brine. Non-meat proteins such as soy concentrate/isolate and whey proteins can also be added for the same purpose (see the recipe at the end of the chapter). The turkey breast muscle can then be placed in a cooking bag or netting (with or without skin) and smoked and cooked in a smokehouse until an internal temperature of at least 71°C is reached.

b. Restructured Products

Poultry rolls can be made from dark meat, white meat, or their combination. The meat portions/trimmings can be obtained from the breast, leg, skin, and mechanically deboned meat (e.g., from poultry, beef, pork). In this product, pieces of muscle tissue ranging in size from 5 – 25 cm are 'glued' together to form a coherent product. This is done with the help of salt, which is used to extract the salt soluble proteins such as actin and myosin (see previous chapters). During mixing, these proteins form a tacky coating on the surfaces of the meat pieces. Later, during cooking they coagulate and the 'glue' is set (similar to the phenomenon seen in a liquid scrambled egg mix turning into an elastic structure during heating). These proteins also contribute to moisture and fat holding within the cooked product, as will be explained later in the chapter. Fat, skin and trimmings are usually finely chopped (the term "emulsified" is often used by the industry, even though no true emulsion is formed) and used to fill the voids between the larger pieces of meat. Moisture is added to compensate for cooking losses and to improve the juiciness of the product. If added moisture exceeds a certain fraction of the raw meat (regulations vary by country), then the product must be labeled accordingly. The meat and non-meat ingredients are then mixed together until the meat batter becomes sticky (an indicator of good protein extraction) and all the added moisture is absorbed. Next, the mix is placed in molds or stuffed into casings and the product is cooked either in water (moisture-proof casings) or an oven (moisture- and smoke-permeable casings), depending on market preference and equipment availability.

Another example of a restructured product is turkey ham, which is manufactured from large pieces of turkey thigh meat. The product is usually lower in fat content than the traditional pork ham and is preferred by some customers. The preparation procedure (see recipe at the end of the chapter) is typical for a product made from medium to large sized meat chunks. In the initial manufacturing step, a brine solution (i.e., water, salt, phosphates, flavourings, and nitrite) is added either by injection and/or by tumbling of the meat chunks. Tumbling is often used when the brine is injected to achieve maximum moisture absorption, distribution of the curing ingredients, and extraction of the salt soluble proteins. The raw meat is then

placed in molds (e.g., 4 × 4" ham molds) or stuffed into large diameter fibrous casings that determine the shape and size of the final product (see Section 13.7). Then the product is smoked and cooked to at least 71°C. If moisture-proof casings or metal molds are used, smoke flavourings can be added to the raw meat batter.

c. Ground Products

Fresh breakfast sausage, pepperoni sticks, cured chicken/turkey/duck sausages, salami and Kolbassa are examples of ground meat products (particle size commonly range from 0.5 to 2.5 cm) that have been stuffed into casings and smoked, cooked, and/or dried. Formulations for five such products are provided at the end of the chapter. These products are usually made from light and dark poultry meat including trimmings, skin, fat, and a small amount of mechanically deboned meat. The meat is first ground and then salt, water, and spices are added. In some products, non-meat proteins (e.g., soy, egg, whey), gums, and/or starches are added to help with water and fat binding. The products can be stuffed into edible casings (e.g., collagen) or non-edible casings (e.g., cellulose or plastic) that must be removed prior to consumption. Fresh sausages need to be cooked by the consumer while products such as pepperoni and salami are fully cooked by the meat processor.

Another unique example of a ground meat product is a poultry/red meat summer sausage, which represents a group of fermented meat products to which a bacterial starter culture has been added. The poultry product is usually made from dark meat, skin, and fat. In the process, lactic acid bacteria are used to lower the pH of the product from about 5.8 to 4.8. This helps to both preserve the product and provide its typical tangy flavour. In the past, microorganisms from previous batches were reintroduced into new batches (this practice is called back-slopping), but today the industry mainly uses starter cultures with a known composition of microorganisms. The industry can select from a variety of cultures that grow at different temperatures and produce distinct flavour notes. During the past 30 years there has been lot of progress in the area of genetic engineering, where desirable characteristics from one bacterial strain are moved to another. Today, the use of a starter culture is highly recommended because it ensures that lactic acid bacteria dominate the fermentation, which both suppresses pathogens (e.g., *E. coli* O157) and produces the desired flavours. The fermentation can be controlled by the quantity of carbohydrate added (i.e., the energy source for the microorganisms) or by continuous pH monitoring and starting a heating cycle when the desired pH is reached. After fermentation, the product is smoked, cooked or dried. If the product is to be sold as a dry product, Canadian government regulations usually require that it be shelf stable with a low pH (around 4.5) and water activity below 0.90.

d. Finely Comminuted Products

Hot dogs, frankfurters, and bologna are examples of emulsified meat products, where the product has been finely chopped and results in a very homogenous appearance. Dark leg meat, trimmings, skin, and/or mechanically deboned meat are commonly used as the starting materials. The meat is then chopped in a bowl chopper or an emulsion mill (see Chapter 10), which efficiently minces the meat particles and emulsifies the fat (i.e., significantly reduces their size and helps coat the small fat globules with proteins; see further explanation below). Salt is used to extract the meat proteins, which are essential in binding the small meat particles and stabilizing the fat globules within the protein matrix (Youssef and Barbut, 2011; Barbut and Findlay, 1989). Nitrite is added to prevent *Clostridium botulinum* growth and provide the typical cured meat colour (Chapters 15 and 16). The meat batter used for small (hot dogs, frankfurters) and large (Bologna) diameter products and is stuffed into cellulose casings, smoked, and cooked in a smokehouse. A newer process is the fully automated co-extrusion casing application, where semi-liquid casing material is extruded onto the meat product as it comes out of the stuffing machine. In this case, an edible casing such as collagen or alginate is applied (see Chapter 10), which does not need to be removed prior to packaging like cellulose casings would. This also helps reduce the potential for cross contamination (e.g., *Listeria*), as product handling by workers is minimized. Since frankfurters are such a popular item, a number of large processors have constructed dedicated lines to continuously make this product (24/7). As with other meat products, low microbial contamination and refrigeration temperatures are essential to the safety and shelf life of these products (some manufacturers guarantee a shelf life of over sixty days).

e. Coated Products

This category includes bone in and boneless products such as poultry drumsticks and wings. The products can be coated with batter and breading (e.g., chicken nuggets) or with a marinade (e.g., honey garlic sauce, BBQ mesquite sauce; see recipes at the end of the chapter) for a few hours prior to cooking to increase juiciness and yield of the fresh meat. The addition of moisture, salt, and spices helps to compensate for evaporation losses during cooking and enhances the flavour and texture of the meat. Coating systems, which include battering and breading, are described in Chapter 14. Chicken nuggets, first introduced in the 1970s, are one of the most successful poultry products. The product was originally prepared from a single piece of slightly marinated breast meat that was battered and breaded. Later, nuggets made from trimmings (including white meat, dark meat, skin, mechanically deboned meat and their combinations) appeared on the

market. These nuggets are usually prepared by marinating and mixing the meat pieces with a brine solution. The meat is then formed into the desired shape, battered, breaded and deep fat fried. Frying preserves the product shape, 'cements' the batter and breading to the product, and provides the typical crunchy texture.

13.3 Meat Ingredients and Least Cost Formulation

A variety of meats can be used for further processing. As has already been mentioned, these meats can come from different cuts (e.g., breast, thigh, belly meat) and states (e.g., fresh, frozen), with or without skin. Formulation of a meat product requires some basic calculations. Most medium and large sized meat companies use a computer program to formulate their products. Two of the main reasons for this are the complexity and time needed to optimize the use of incoming raw materials (i.e., costs are changing on a daily basis) and to formulate products with tight specifications (e.g., protein level, fat content, colour, bind value). In the past, processors commonly used simple formulations with only a few raw meat ingredients. For such recipes the so-called "sausage square" calculation (simple matrix calculation that includes 2-3 meat sources) was sufficient. However, the diversity of raw materials and price fluctuations in the international markets require calculating and optimizing formulations for several products concurrently. In the late 1950s, development of linear programming for sausage manufacturing began. The original term, least cost formulation (LCF), might mislead people who are not familiar with the process into thinking that the goal is to formulate the least expensive product. Instead, the programs are designed to select the lowest cost meat ingredients after all the requirements (protein level, fat content, colour, bind value) have been met. Pearson and Tauber's (1984) description of the advantages of such programs is still true today. The programs:

a. provide the most economical combination of ingredients for a specific product within the limitations placed on each ingredient in the formula
b. permit complicated calculations that would not otherwise be possible
c. save time compared to the more laborious traditional calculation (pencil or a calculator), which can then be devoted to other production problems
d. permit adjustment of formulas on the basis of analysis, using values obtained from pre-blending or other sources
e. maximize the use of available ingredients
f. help reduce inventory
g. supply accurate procurement information
h. allow making real-time management decisions on production, pricing, and labour utilization policies

Today there is a great emphasis on flexibility and traceability, where all data can be kept on file electronically for a program such as HACCP (see Chapters 6 and 12). This is obviously another example of employing automation in the meat industry to help streamline processes, reduce labour costs, and save money. Overall, it should be recognized that computer programming of LCF requires more basic information on ingredient composition (e.g., chemical composition, bind value, water and fat holding capacity values), as well as skilled personnel to operate computers and laboratory equipment. Meat technologists working in the industry need to understand foundational scientific principles such as emulsion stabilization and the functional properties of raw materials. This has become far more important as the number of non-meat ingredients has increased (e.g., dozens of different modified starches are now available on the market). It is important to characterize the ingredients and establish 'constants' that can be used to optimize the quality of the finished product. Two important examples are the bind value and the emulsification capacity value that had to be initially established for running the LCF programs.

Dr. Robert Saffle is generally credited with introducing the concept of meat constants in the early 1960s (LaBudde and Lanier, 1995). The constants were developed based on the meat emulsion stability test and were needed to develop sausage LCF programs. Linear programming requires numerical values that describe each meat's specific properties in order to develop the best combination of raw materials from the few dozen meat cuts/trims available each day to a typical processor. The program's goal is to calculate the best combination of ingredients after satisfying requirements set by the operator. As mentioned previously, the requirements can include protein, fat, and moisture content (Pearson and Tauber, 1984), as well as colour and meat bind values. It is important to note that when Saffle developed his 'constant' emulsification value, at least one major North American company had already developed its own criteria for evaluating meat. Saffle's constant emulsification values were generally based on multiplying the percent salt soluble proteins in a certain cut of meat by the emulsifying capacity results. Today, various medium and large companies continue to use Saffle's values in one form or another, whereas some large meat companies have developed their own proprietary criteria for rating meats and use these values in their in-house developed LCF programs.

13.4 Non-Meat Ingredients

The meat industry also uses various non-meat ingredients in order to:

a. help extract salt soluble proteins
b. provide flavour notes and enhance acceptability
c. help bind moisture through proteins (e.g., soy, dairy) and carbohydrates (e.g., starch, carrageenan)
d. enhance juiciness
e. enhance freeze thaw stability through modified starches
f. improve/modify texture (e.g., gelling of soy proteins, alginate)
g. provide colour (e.g., paprika)
h. lower formulation cost
i. add bulk
j. improve sliceability (e.g., forming a carrageenan gel)
k. extend shelf life (e.g., lactic acid, spice extracts)

To simplify the discussion, non-meat ingredients can be divided into several major groups including water, salts, spices, binders, and fillers.

Limits are imposed on the addition of several non-meat ingredients. The maximum amounts permitted can be found in local regulations/meat inspection guides. An example of a restricted ingredient is nitrite, which is added to prevent the growth of deadly *C. botulinum*. At high levels, however, nitrite can present a health hazard and therefore the level is tightly controlled (e.g., 120-200 ppm in USA and Canada). Other functional ingredients, such as soy protein, are also commonly regulated. For example, up to 3.5% soy can be added, alone or in combination with other binders, to a variety of cooked sausages produced in the USA, However, if this limit is exceeded, the product name must include the words "soy added" or "imitation" to inform the consumer. In most countries, all the ingredients added to a food/meat product must be listed on the label. Below is an example of an ingredient list of a Canadian product showing the additives in a descending order by weight:

> Product name: Chicken Frankfurters. Ingredients: mechanically deboned chicken, chicken, water, wheat flour, salt, modified corn starch, spice, dextrose, sodium erythorbate, sodium nitrite, smoke.

The names and functions of most common non-meat additives used by the meat industry are discussed below:

a. Water – commonly used to compensate for evaporation losses during cooking, increase juiciness, and reduced fat content in products. The latter reflects the trend of combining water with ingredients such as hydrocolloid gums and starch. The amount of added water is regulated in many countries. If the moisture added exceeds a certain level in the finished product (i.e., after cooking and taking into account evaporation loss), it should be mentioned in the product's name (e.g., Chicken Roll with Natural Juices/Added Water). Overall, water is the main component in fresh and processed meats, ranging from 40-80%. Most of the moisture originates from the lean meat portion (e.g., skinless poultry breast meat has 75% moisture, see Chapter 3). Industry and consumers add moisture to products (see recipes at the end of the chapter) because they would have a dry mouth feel if only the original moisture was present. An example is a chicken fillet cooked at home or in an industrial oven. Initially, the raw meat has about 22% protein but it ends up with about 25% protein after cooking and taking into account evaporation loss. This product will be fairly tough and unacceptable to the majority of consumers. Added moisture increases product acceptability by compensating for moisture lost during the heating process. Added moisture also serves as a carrier for spices and other non-meat ingredients and ensures their adequate distribution. In finely comminuted meat products (Table 13.1.1), ice is added during chopping to maintain a sufficiently low temperature so that heat arising from the high friction during cutting will not cause an emulsion breakdown. Additional discussion on this topic is provided below in Section 13.6.

The microbiological and chemical quality of the water is an extremely important issue. From a microbiological standpoint, water should meet the drinking quality standards (e.g., municipal, national standards) at the very least and should be checked on a regular basis (see Chapter 6). From a chemical standpoint, water contaminated with compounds such as nitrate will cause undesirable pinking of products such as oven roasted chicken breast. Nitrite contamination (1-5 ppm) can be common in agricultural areas where the water source is located near fields that are fertilized with nitrates. This is especially of concern after heavy rain (see additional discussion in Chapter 16). Another consideration is the presence of high salt levels. Water with calcium and magnesium salts, also referred to as hard water, can destabilize emulsion-type meat products as well as cause problems within a plant's piping system.

b. Salt – various salts can be added to meat products. The most common salt is table salt (sodium chloride), which is used as a flavouring agent, protein solubilization agent, and anti-microbial agent. Phosphates are another group of salts used to help with meat protein extraction and solubilization (e.g., sodium tri-polyphosphate is used to help extract myosin and actin). Other salts include sodium nitrite (for preservation) and curing accelerators such as sodium erythorbate and sodium ascorbate.

b1. Sodium chloride (NaCl) is the most common ingredient added to meat products because of its three major contributions:

1. Sodium chloride provides a distinct salty flavour, which makes a substantial contribution when added to processed food. The classic salty taste is represented by NaCl and lithium chloride (LiCl), whereas other salts usually have additional flavours associated with them that can include a mixture of sweet, bitter, sour, and salty. Chemically, it appears that cations cause salty tastes, whereas anions inhibit salty tastes (Sebranek and Bacus, 2007).

   Among the anions, Cl^- is the least inhibitory to the salty taste and does not possess a taste of its own. Some anions can not only inhibit the taste of their associated cations, but also contribute tastes of their own. An example is the soapy taste associated with certain phosphates, which results from the specific taste elicited by their anion.

   In general, the most accepted model for describing the mechanism for salty taste perception involves the interaction of hydrated cation-anion complexes with the Shallenberger and Acree AH/B-type receptor site. The individual structures of such complexes vary substantially. In the presence of water, OH groups and salt anions/cations are associated with specific receptor sites. Bitterness in salts involves a different receptor mechanism that seems to be related to the sum of the ionic diameters of the anion and cation components of the salt. Salts with ionic diameters below 6.5 Å are salty in taste (LiCl = 4.98 Å, NaCl = 5.56 Å, KCl = 6.28 Å), although some individuals find KCl somewhat bitter. As the ionic diameter increases (CsCl = 6.96 Å, CsI = 7.74 Å, $MgCl_2$ = 8.50 Å), salts become increasingly bitter.

   In any case, a processor should always try to use the highest quality salt possible. High quality refers to low levels of impurities (e.g., heavy metals such as copper, iron). These trace contaminants are known as pro-oxidants and can trigger fast lipid oxidation during storage, as will be discussed later in the chapter when antioxidants are introduced.

2. Sodium chloride is involved in the protein extraction of the salt soluble fraction (mainly myosin and actin; see also Chapter 3), which is very important in the production of processed meat products as these proteins can bind meat pieces/chunks when heated. Overall, extracting the proteins and bringing them to the surface provides sticky surfaces on the

raw muscle cuts. These proteins also help bind moisture (i.e., increasing the water holding capacity, WHC), assist in emulsifying fat particles in comminuted products (by coating the fat globules), and increasing the raw meat batter viscosity. Later, these extracted proteins coagulate and bind both the meat particles (important for holding the product together) and moisture (important to minimize cooking losses) to form a coherent matrix that is important for texture as well as fat retention during heat processing.

Salt reduction (mainly sodium) in food/meat products was a hot topic in the 1980s and is again today, as more individuals are suffering from hypertension (high blood pressure). Besides the organoleptic effects, an important consideration in replacing NaCl with other chloride salts is the effect on the physical properties of the final product. Sodium chloride reduction by itself will result in lower binding and lower WHC of the proteins. Upon heating, this will result in a softer, drier product with higher cooking losses. If cooking losses are too high the product will be unacceptable to the consumer. The relationship between salt concentration and WHC has been well established and depends on factors such as the amount and type of protein present, pH, and previous storage history. In post-rigor lean poultry meat, an increase in salt results in a concomitant decrease in product shrinkage up to a maximum at around 5% salt (Fig. 13.4.1). Further salt addition will result in a decreased WHC, a phenomenon known as "salting out". This is the result of increasing charges on the protein molecules, which causes them to precipitate.

3. Sodium chloride suppresses microbial growth, as many microorganisms are sensitive to high salt levels. High salt concentration can stop or substantially slow the growth of microorganisms. In the past, high salt levels (10 to 20%) were used as the main means of preservation because these levels can provide shelf-stable meat products. This technique is still used in places where refrigeration is a challenge and/or where the traditional heavily salted products are preferred (i.e., the very high salt content has to be washed out before consumption). However in many markets today, substantially lower salt levels are used (e.g., 1.0 to 2.5%), and it is only in conjunction with other additives (e.g., nitrite, lactic acid) and appropriate refrigerated storage that product safety can be ensured (Barbut and Findlay, 1989; Sebranek and Bacus, 2007).

b2. Sodium Nitrite ($NaNO_2$) and Sodium Nitrate ($NaNO_3$) – also known as curing salts, are added at very low levels (usually 120-200 ppm in the USA) and have four main functions.

1. Prevent *Clostridium botulinum* spore germination. The active compound is nitric oxide (NO) and it inactivates *C. botulinum* spores. Only a very small amount is needed and using the salt form provides an easy and efficient way of introducing the active compound to the meat. It can also be introduced in gas form in a lab setting.

2. Contribute to the development of the typical pink cured meat colour. Again, the active compound is NO. This pink colour is very different from the brown colour of a cooked product such as chicken leg meat, turkey thigh, pork chop, or pork loin. This can be described as the difference between a home-cooked pork chop and a cured pork ham (see additional discussion in Chapter 16). The chemical reaction involved is:

   $$\text{Myoglobin} + \text{NO} \rightarrow \text{Nitrosomyoglobin} \rightarrow \text{Heat} \rightarrow \text{Nitrosohemochrome}$$

   The nitrosohemochrome produces the typical pink pigment found in cured meat products.

3. Protect against lipid oxidation. Nitrite has antioxidant capabilities that can help prolong the shelf life of meat products.

4. Adds some flavour. Nitrite addition results in the development of certain unique flavour notes.

   Overall, the chemical reaction of sodium nitrite (potassium nitrite is also used sometimes by the industry) added to a meat system is shown below. Sodium nitrite is broken down into its components:

   $$NaNO_2 \rightarrow HONO + Na + H_2O$$
   $$3HONO \rightarrow HNO_3 + 2NO + H_2O$$

   The amount of nitrite permitted in meat products is heavily regulated because at high levels it can be toxic. It is very important to note that processed meat products are not necessarily a high source of nitrite in our diet. In comparison, green vegetables such as celery have levels of about 300 ppm nitrate. In addition, bacteria in human saliva and in the gut are capable of producing even higher levels of nitrite. Nitrite added

to meat products is depleted over time, especially during cooking, and a frankfurter with an initial 150 ppm $NaNO_2$ level will end up with about 20-40 ppm or less at the point of purchase. Overall, it is estimated that meat products contribute only 10-20% of the total nitrite in our diet (Sindelar and Milkowski, 2012). There is also a concern in products heated to high temperatures (e.g., bacon) that residual nitrite could react with secondary amines to form nitrosamine compounds, which are potential carcinogens. Therefore, in North America for example, the use of an added curing accelerator (e.g., 500 ppm ascorbate) has been mandated in such products to ensure a fast conversion of nitrite to nitric oxide. This minimizes the chance of nitrosamine formation when the product is exposed to high temperatures (frying at > 100°C). The use of nitrite in processed meat products and its safety has been reviewed by Cassens (1990) and by Sindelar and Milkowski (2012).

b3. Phosphates – salts of phosphoric acid can work together with sodium chloride to enhance muscle protein extraction, which in turn improves the water holding capacity and reduces shrinkage during cooking (Fig. 13.4.1). There are different types of phosphates available on the market. Examples of common polyphosphates and orthophosphates in meat products are shown in Figure 13.4.2. Alkaline polyphosphates such as tripolyphosphate (TPP) are the most popular and by some estimates account for about 80% of the phosphates used by the meat industry. Phosphate use is limited to 0.5% in the finished product in countries such as the USA. This limit is mainly imposed to restrict water addition but greater levels can also result in off flavour problems such as metallic or soapy as reported by consumers. In countries such as Germany, the use of phosphate is not permitted in several products.

The effects of using 0.5% TPP, pyrophosphate, and a commercial blend called KENA (which contains over 50% TPP) are shown in Figure 13.4.1. A synergistic effect is clearly seen when TPP is used with 2-5% salt; i.e, the combined effect of NaCl and TPP is much greater than the simple additive effect of NaCl and TPP. The "salting out" effect, previously discussed, is clearly seen at a salt level above 5%. Pyrophosphate and NaCl show an even greater synergistic effect compared to TPP (Fig. 13.4.1) but pyrophosphates are not commonly used due to their effect on pH and other factors. Hexametaphosphate, for example, results in higher shrinkage during cooking. This raises the point that processors should know exactly what kind of phosphate(s) or blend they are using but this is information that some ingredient companies are not eager to share. However, with the new Material Safety Data Sheet (MSDS) requirements, this information is becoming easier to access by the meat processor.

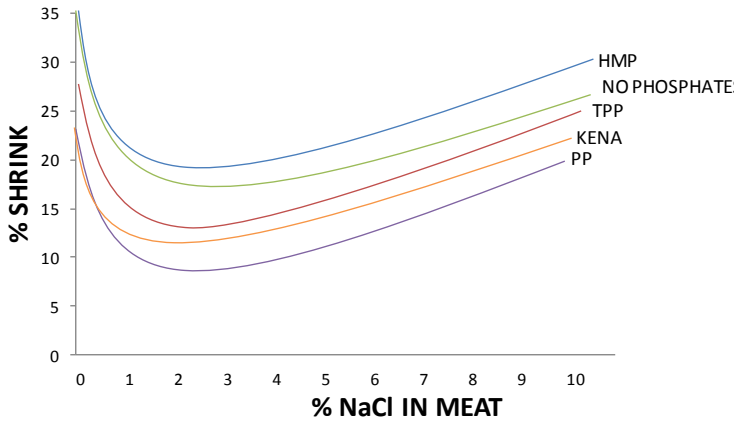


Figure 13.4.1 Effect of NaCl on the shrinking of cooked chicken muscle (70°C) in the presence of salt and different polyphosphates (0.5%). HMP – hexa meta phosphate; TPP – tri poly phosphate; KENA – commercial phosphate blend; PP pyro phosphate (sodium acid). Redrawn from Shults and Wierbicki (1973).

Most phosphates used by the meat industry help enhance the physical and sensory properties of meat products by:

a. Helping extract the salt soluble proteins, hence increasing water holding capacity and meat particle binding.
b. Shifting the pH away from the isoelectric point of the muscle's proteins, hence allowing more charges on the amino acid side chains. This can result in increased repulsion between the proteins, which creates more space for water molecules and more sites for water molecule binding.
c. Assisting in stabilizing meat emulsions due to the hydrophilic/ hydrophobic structure of the molecule
d. Slowing down oxidation due to the chelating effect of phosphate.

Certain phosphates can bind iron and other metals and prevent them from serving as pro-oxidants. This helps extend the shelf life of the meat product in terms of flavour but also protect it from meat pigment oxidation (colour problems).

In general, phosphates act in a food/meat system as polyanions that increase ionic strength, control pH by buffering, and sequester meat ions. Some researchers claim that the increase in water holding is due to an unspecific ionic-strength effect. As indicated above, increasing the net negative charges will result in repulsion of the protein groups, which creates more space for water molecules within the muscle.

However, the effect of a molecule such as pyrophosphate on WHC appears to be greater than would be expected due to its ionic strength alone. Therefore, several researchers have implied a "specific" pyrophosphate effect, where pyrophosphate was reported to dissociate actomyosin into actin and myosin (i.e., pyrophosphate is capable of degrading the actomyosin complex).

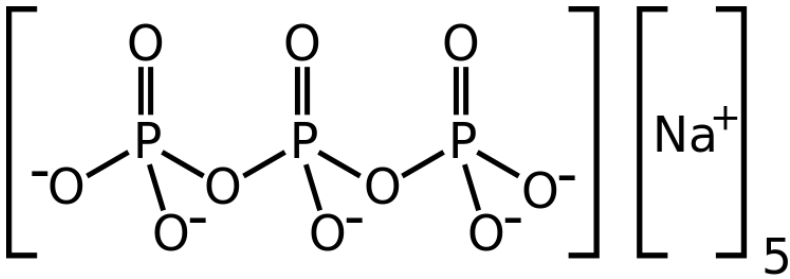


Figure 13.4.2 The chemical structure of sodium tri polyphospate (STPP) commonly used in meat processing (solubility 14.5 g in 100 ml at 25 C; pH of 1% solution is 8.0). From Wikipedia. More detailed information from Material Safety Data Sheet can be found at: http://www.sciencelab.com/msds.php?msdsId=9927608.

b4. Sodium Ascorbate and Sodium Erythorbate – also known as curing accelerators, they are added to increase the rate at which nitrite is reduced to nitric oxide in an aqueous solution. In a meat system, some of the muscle's enzymes help reduce the nitrite. However, in order to speed up the conversion to nitric oxide, curing accelerators that promote reducing conditions are added. Note that they also accelerate the reduction of metmyoglobin to myoglobin. This is especially important in continuous sausage production lines, where the processor's objective is to start cooking the product within an hour of blending and adding the non-meat ingredients. In other cases, such as the manufacture of dry sausages, a slow nitric oxide release is preferred and curing accelerators are not needed. In these cases, processors are actually using sodium nitrate, which takes even longer to breakdown to nitric oxide than sodium nitrite, so they get a prolonged release of nitric oxide.

Sodium ascorbate and sodium erythorbate (or their corresponding acids ascorbic acid and erythorbic acid) are used at low concentrations of about 550 ppm. For products that will be exposed to high temperature cooking (e.g., turkey/pork bacon), a number of countries require that a curing accelerator be added as high temperatures can increase nitrosoamine formation (see previous discussion on nitrite).

c. Spices – used to flavour and colour foods (e.g., paprika) as well as to add some antimicrobial/antioxidant (e.g., rosemary) properties. In several cases they are also used to enhance appearance (e.g., peppercorns on barbequed meat). Various countries restrict the use of artificial food colouring in processed meat products, hence the utility of spices for this purpose.

Examples of spices derived from different plant materials are listed below.

a. seeds – nutmeg (*Myristica fragrans*), mustard (*Brassica nigra*)
b. leaves – sage (*Salvia officinalis*), thyme (*Thymus vulgaris*)
c. bulbs – garlic (*Allium sativum*), onion (*Allium capa*)
d. fruit – pepper (*Piper nigrum*), paprika (*Capsicum annuum*)
e. flowers – clove (*Eugenia caryophyllata*)
f. bark – cinnamon (*Cinnamomum zeylanicum*)
g. roots – ginger (*Zingiber officinale*)

Spices can be added in different forms depending on the product, desired appearance, expected shelf life, etc. In most commercial applications they are added dried or after a heat treatment because they are then easier to handle (e.g., elongated shelf life, inactivated enzymes that can produce off flavours/colours in the meat) and easier to standardize (e.g., strength/heat of pepper). Overall, spices can be added before or after being dried (e.g., onion), whole or ground (e.g., black pepper, mustard seeds), or as extracts (e.g., rosemary oleoresin). The decision as to what form used is based on the meat product type and desired appearance. In coarse ground products such as kielbasa (see recipe at the end of the chapter), whole mustard seeds can be added so the cross section of the product has a nice appearance. However, in a finely comminuted frankfurter whole mustard seeds would not be as attractive.

Spices commonly carry a high number of microorganisms. Therefore, they should be thoroughly cleaned and pasteurized or sterilized. Heat treatment is an option, but is typically not the best approach because it releases many of the volatile flavour/aroma compounds. Therefore, non-heat processes such as ionizing irradiation and chemical pasteurization (e.g., ethylene oxide) are commonly used. Both are considered cold processes that do not volatilize the flavour/aroma compounds. Ionizing radiation is used quite extensively and usually irradiated spices do not have to be identified as irradiated in the meat product ingredient statement, because of the low level of addition. If the whole product is irradiated, however, certain countries require that the international logo for irradiated food appear on the label (see Chapter 11). Chemical sterilization possesses are also commonly used but some consumer groups are concerned with the potential risk of residues.

Large volumes of spice extracts, which contain essential oils and oleoresins extracted from plant material, are sold to the meat industry. The oils can be obtained by pressing, distilling, or solvent extraction, and they are usually concentrated to obtain a more potent solution. The oils will be free of microorganisms if a high distillation temperature or a strong solvent is used. Overall, the advantages of using oil extracts include reduced transportation costs, long shelf life, and they do not change the appearance of the product. In finely comminuted products such as hot dogs and bologna, which have a very homogeneous appearance, this latter point is very important (e.g., adding visible ground black pepper particles would not be acceptable to the consumer). The extracts are usually highly concentrated and are commonly sprayed on to a carrier such as salt or sugar (dextrose) in order to assure an even distribution within the product.

Standardizing the flavour strength is an important consideration when using natural spices or extracts. Spice companies purchase materials from around the world and factors such as growing conditions, climate, and plant variety can result in large variations in taste. To overcome this, spice companies employ trained personnel to standardize flavour profiles and obtain defined strengths (e.g., determine the Scoville Heat Unit for red pepper). This is extremely important to meat processors who want to create a consistent product. When standardizing the flavour of a spice, a technician prepares serial dilutions of the extract and presents them to a trained panel to identify the lowest concentration the panel can detect. This lower threshold can be used to standardize the flavour. Additional sophisticated equipment such as a gas chromatograph can also be used to determine the concentrations of key flavour compounds that contribute to the overall flavour of a spice. In the case of colour standardization of a spice such as paprika, the red colour intensity can be described by the scale developed by the American Spice Trade Association (i.e., measuring absorbance of a sample diluted in acetone at 460nm).

d. Flavour Enhancers – are compounds that act synergistically with meat flavour compounds to enhance the meaty flavour. A few of the most commonly used ones are 5'-ribonucleotides, hydrolyzed yeast proteins, and monosodium glutamate (MSG). When used at levels in excess of their independent detection threshold these compounds contribute to what is called the delicious or umami taste of foods. When used at levels below the independent detection threshold they simply enhance flavours. It is important to recognize that a very small percentage of the population is sensitive to ingredients such as MSG (i.e., they suffer from headaches and nausea when eating MSG). Therefore, MSG should be clearly marked on the package or at a restaurant buffet.

e. Sweeteners and Browning Agents – ingredients commonly used in low amounts to add a sweet flavour, mask saltiness, enhance browning (i.e., the Maillard reaction between proteins and carbohydrates), and provide a substrate for fermentation (e.g., in salami where they are added as an energy source for lactic acid bacteria).

Overall, natural and synthetic sugars vary in their sweetness. The standard for the measurement is sucrose (a disaccharide composed of glucose and fructose that comprises cane sugar), which is assigned a sweetness value of 100. On that scale, dextrose (a monosaccharide of glucose) has a value of 74, fructose has a value of 175, maltose (disaccharide of two glucose monomers) has a value of 40, lactose (or milk sugar) has a value of 16, regular corn syrup solid has a value of 37 (therefore it can also be used as a partial bulking agent; see discussion below), aspartame has a value of 180, and sucralose has a value of 600. There is a wide selection of sugars to choose from and most commonly the meat industry uses natural sugars at about 1 – 3 %. The reason for adding the sugar often determines the type used. Reducing sugars contribute to the Maillard browning reaction when they combine with secondary amines to form a brown pigment during heating. Adding a reducing sugar such as dextrose, fructose, or maltose to a meat product will enhance surface browning. This is important in smoked sausages where a golden/brown colour is desirable (see recipe for smoked flavour turkey sausage at the end of the chapter). Reducing sugars can be also added to fried products where adequate golden/brown colour development during heating prevents overcooking/ burning the sausage.

f. Antioxidants – important compounds used to suppress lipid oxidation. This is a critical issue in meat and meat products as animal fat is prone to lipid oxidation due to its fatty acid profile (including unsaturated fat; see also Chapter 7), there is disruption of cells during processing (e.g., cutting, chopping of meat), and enzymes are released during processing, heat treatments, and prolonged storage. In living tissues there are various natural antioxidants (e.g., tocopherol/vitamin E), however they are not always sufficient to protect the meat/meat products after processing. The process of oxidation is driven by free radical formation and, once started, it accelerates exponentially as one free radical forms two, two then form four, etc. The food industry uses three types of antioxidants:

a. free radical terminators,
b. oxygen scavengers, and
c. chelating agents capable of tying up metal ions.

Because governments have certain restrictions on using synthetic antioxidants and some are not permitted, natural antioxidants such as rosemary oleoresin are an attractive option and are also label-friendly. In this case, they are only listed by the spice name. Products such as a low-flavour rosemary oleoresin are also available, where most of the flavour compounds have been removed so that the amount of the oleoresin added to the product can be increased. Citric acid is another example of a molecule that is an oxygen scavenger (i.e., can tie up free oxygen).

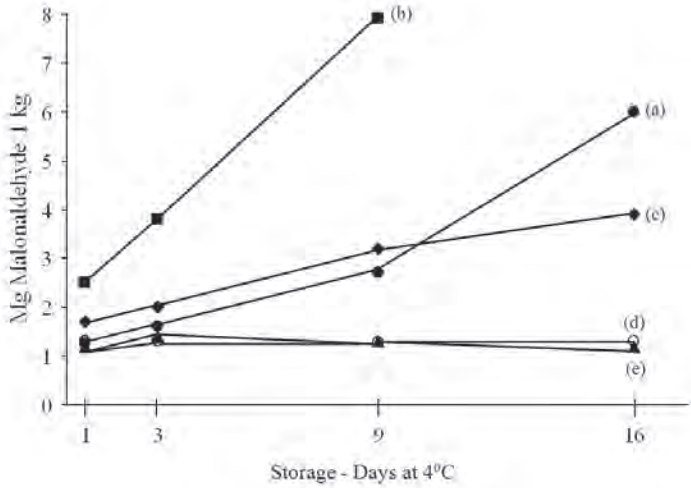


Figure 13.4.3 Oxidation byproduct values of raw turkey sausage. Legends: a) no additives (●); b) 1.7% salt (■); c) spice only (♦); d) spice + rosemary (O); e) spice + BHA/BHT (▲). Adapted from Barbut et al. (1985).

The industry also uses synthetic antioxidants such as butylated hydroxy toluene (BHT), butylated hydroxy anisole (BHA), and propyl gallate (PG). These compounds are free radical terminators, as they have a cyclic carbon ring structure that is capable of accepting a free radical molecule. These three compounds are fat soluble and their usage level (where permitted) is commonly limited to 200 ppm of the fat content. Figure 13.4.3 shows the beneficial effects of using a BHA/BHT mixture (200 ppm) and natural rosemary oleoresin on delaying lipid oxidation in a turkey sausage produced with 25% mechanically deboned meat, which is highly susceptible to oxidation (see Chapter 9). Both the mixture and the rosemary oleoresin were very effective in suppressing oxidation in the stored product. The

spice mix used in isolation also resulted in some antioxidant activity as compared to the meat control treatment. Figure 13.4.3 also illustrates the effect of salt, which can accelerate lipid oxidation due to a small amount of heavy metal (e.g., iron) contamination. The data is reported as the amount of malonaldehyde (i.e. an oxidation byproducts from the breakdown product of oxidized fatty acids), which is commonly used in the literature to follow lipid oxidation. The publication also lists the amounts of other byproducts (e.g., hexanal, heptanal, penanol; measured by gas chromatography) that contribute to off odours that can be detected by a sensory panel.

g. Starter Culture – bacteria capable of producing lactic acid are added to fermented sausages, such as pepperoni and summer sausage. *Lactobacillus plantarum* and *Pediococcus acidilactici* are used to ferment the added sugars and produce lactic acid, which decreases the pH of the product. This helps to make the product shelf-stable and provides unique flavours and textures. Processors should add a simple sugar source (e.g., mono, disaccharide) to prevent bacterial utilizing of fat and proteins which will result in the formation of oxidized compounds and putrefied odours. In the past, processors relied on the naturally occurring lactic acid bacteria or an innoculum from a previous batch of products for the fermentation. Today, however, many use a standardized, controlled starter culture produced by specialized companies. When using starter cultures the inoculation level is 10^7 bacteria per gram meat of the "good lactic acid bacteria" so it dominates the fermentation. Concerns with *E. coli* O157:H7 have also driven the industry to use starter cultures to assure fast and efficient fermentation.

h. Mold inhibitors – are used to inhibit growth on the surface of dry and semi-dry sausages that are not vacuum packed (molds are aerobic). This can be a problem as these products have a water activity that supports mold (but not bacterial) growth. Mold inhibitors are applied by dipping or spraying the outside casings. Common chemical inhibitors include potassium sorbate and sorbic acid. These compounds are permitted for use in some countries (e.g., USA), but not others (e.g, Canada). In countries where these compounds are not permitted processors can use a cold smoke treatment that contains natural antimicrobial compounds (see discussion below) that help prevent mold growth.

i. Binders – are ingredients used to help bind meat particles and increase water holding capacity (see also Section 13.5). These ingredients usually consist of proteins that can form a gel system or participate in meat protein gelation. It is obviously advantageous if they act synergistically with the meat proteins (see Fig 13.5.1, Aguilera and Kessler, 1989). These ingredients can be expensive so when processors consider using them they should look for added values such as:

a. texture enhancement
b. water holding; i.e., reducing shrinkage during processing
c. improved product's formulation
d. emulsification capabilities
e. reduction of formulation cost

The meat industry commonly uses dairy binders (e.g., milk powders and their derivatives), vegetable proteins (soy, pea), and meat proteins (collagen, blood plasma).

Examples of dairy binders:

a. Whey proteins – a by-product of cheese manufacturing, and very effective in meat products. After gentle drying (i.e., to prevent protein denaturation) they are sold as a powder with about 70% protein (marketed as whey protein concentrates) and with about 90% protein (marketed as isolates).
b. Caseinate – sold after drying as a highly functional ingredient that has 80-90% protein content. One of its main uses is in emulsified products.
c. Non-fat dry milk – contains about 35% protein (80% is casein) and about 50% lactose.
d. Calcium reduced non-fat dry milk – used for finely chopped/emulsified products where high levels of calcium can be detrimental to emulsion stability.

Examples of vegetable protein binders:

Soy proteins – commonly used as binders in products such as meat patties, meat loaves, and sausages. In a number of countries their presence is limited to $\leq 2\%$ soy protein isolate or else the product name should include the word "soy". Other vegetable proteins such as pea are also used but to a lesser extent. The vegetable proteins are also marketed under certain categories:

a. Soy/pea protein flour (fine particles with 40-60% protein)
b. Soy/pea grits – coarse particles with 40-60% protein
c. Soy/pea protein concentrates – with 70% protein and bland flavour
d. Soy/pea protein isolate – with 90% protein, bland flavour, and high water/fat binding capacity
e. Textured soy/vegetable protein – cooked and extruded particles sized to order, with or without flavour and/or colour added

It should be noted that vegetable protein flours and grits usually have a distinct flavour (beany) if used at a high concentration. Much work has been done over the past decade to minimize this problem and today the standards for low beany off flavours are much higher.

j. Fillers – are non-meat ingredients, usually made with complex sugars (e.g., starch) and low protein, that help bind water but not meat particles and are usually considered to be good as bulking agents.

Fillers can be divided based on their cereal source (wheat, corn, starch) and are added to the meat product either as flours or extruded/texturized particles. When starch is heated past its gelatinization temperature in the presence of water it opens up to bind water (e.g., can be 1:2 up to 1:10 ratio). At high temperatures the solution becomes more viscous and when temperature is lowered (e.g., cooling food/meat products after heating) the texture will become even more viscous. The meat industry also uses pre-gelatinized starches where the starch manufacturer has heated the product (in a solution) and then dried it. This creates a product that is capable of binding water at lower temperatures, which is advantageous for the meat industry because as meat proteins are heated (and denatured) they bind less water. Please note that another popular application of flour and starches is in coated products (see Chapter 14).

k. Hydrocolloid gums – are unique compounds that are capable of forming a high water gel matrix at low concentrations (e.g., at 1% carrageenan forms a very firm gel after heating, which nicely binds the rest of the 99% water). Such gums are added to meat products at relatively low concentrations to bind added brine/water (see Turkey Pastrami recipe at the end of the chapter). In this case the firm gel (upon cooling) also helps enhance the texture. Many gums are obtained from seaweed, some are extracted from seeds, and others are the result of microbial fermentation. Below are a few examples of common hydrocolloid gums:

a. Alginate – is extracted from brown algae (*Phaeophyta*) that is usually harvested off the coasts of Ireland (Davis et al., 2003). Alginate is composed of manmuronic and guluronic acid monomers; the ratio between them determines the brittleness of the gel, water holding, etc. Since the algae are harvested at different places and during different seasons, there are variations in the gelling performance. Therefore, it is important that the meat processor uses a supplier who is reputable and can control and standardize the gel performance. One of the unique characteristics of alginate is its ability to gel at room/refrigerated temperature instantly when a small amount of calcium ions is added.

The meat industry uses it for binding raw meat particles in products such as restructured cutlets (Fig. 13.4.4) in order to provide binding of the smaller meat trimmings and hold the product together prior to cooking. It is also used today to make casings (Harper et al., 2013) that are co-extruded directly onto the product (see discussion in Chapter 10).



Figure 13.4.4 Meat trimmings bound with an alginate gum to form a restructured product. The binding is done at low temperature with the help of $CaCl_2$ which causes cold gelation of the alginate. Showing raw chicken and beef products, as well as the resulting cooked beef product. Photo by S. Barbut.

b. Carrageenan – gum that is extracted from Irish moss (*Chondrus crispus Stackh*.) found along the Atlantic coast of the British Isles, Europe and North America. It is composed of monomers of sulfated galactose and anhydro-D-galactose. The gum is a complex mixture of about ten different polymers. The main ones used by the meat industry are kappa and iota (note: some lambda is also used to increase viscosity but it is a non-gelling component). The type of gel formed depends on refining the raw material (Fig. 13.4.5), the dominant polymer in the mixture and the cation used to induce gelation during heating. Carrageenan forms a reversible gel (i.e., can be remelted and reformed), is very effective at binding water, and is added to products where water is used to replace fat such as oven roasted turkey/chicken breast products and low fat sausages.

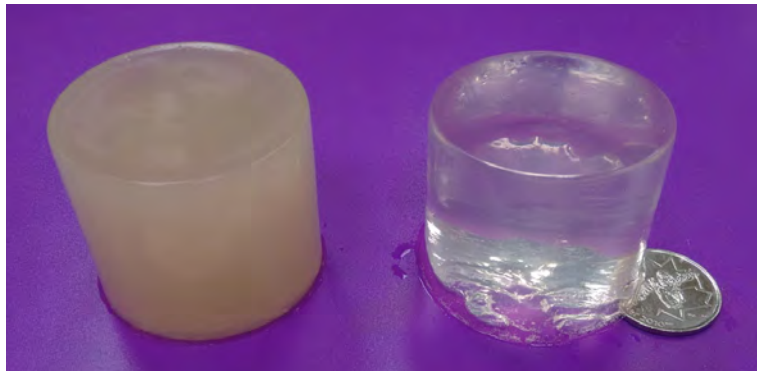


Figure 13.4.5 Carrageenan gels (1%) made by the addition of hot water (85 °C) followed by cooling (see text for explanation). The gel on the left was made from non-refined carrageenan and the one on the right from refined carrageenan. The latter produced a clearer, harder, and more elastic gel, but with more syneresis. Photo by S. Barbut.

c. Xanthan gum – is produced by microbial biosynthesis and is an extracellular polysaccharide. It is composed of cellulose chains with attached oligosaccharide groups. Low xanthan concentrations produce a highly viscous solution. Together with locust bean gum, xanthan can produce a thermo-reversible gel.

l. Acids/Acidulants – used to reduce pH, add flavour, extend the self-life and/or produce a fermented-like meat product. A common example of an acid is vinegar and an example of an acidulant is glucono delta lactone (GDL; introduced in the 1960s), which can yield a more rapid and improved colour development to cooked comminuted meat products. An important advantage of using GDL is its slow acid release that does not cause a problem with later protein binding (note: adding a large amount of liquid acid to a meat product at the beginning of the process will result in early protein denaturation, poor binding, and decreased WHC). Although GDL was introduced to accelerate raw meat processing operations, it has been later used in the production of fermented-like meat products (e.g., pepperoni for a pizza topping and other industrial acidified products).

Encapsulated acids (e.g., lactic, citric) are another way to add acids to produce a fermented-like products. The encapsulation material (wall component) is usually made of hydrogenated vegetable oil with a melting point that has been adjusted to be slightly higher than denaturation temperature for major meat proteins (e.g.,

60-65ºC). Other sensitive compounds can also be encapsulated (e.g., flavours) to protect them until needed (e.g., coating material can be designed to be broken by saliva, enzymes or mechanical shear). Overall, the market for encapsulated flavour, sensitive oils, and vitamins has been growing at a tremendous rate over the past three decades.

In the food ingredient business, the area of nanotechnology including encapsulation, is becoming an important topic. Currently there is quite a lot of use of encapsulation technology, but not so much at the nano scale. As mentioned above, encapsulation is used to protect food additives such as flavour compounds, vitamins, sensitive omega-3-fatty acids, and microorganisms (e.g., to protect some probiotics from the stomach's low acidity and only release them later on in the gut). This topic is beyond the scope of this book, but further information can be found in Prakash et al. (2013) and Graffagnini (2010).

m. Natural and Liquid Smoke – are mainly used to provide flavour, colour (Maillard reaction), antimicrobial protection, and antioxidant compounds to the surface of the product. Historically, smoking meat cuts over an open fire was used to preserve different products. The exposure to mild/high temperature for an extended period of time (e.g., several days; not currently used in the industry) also resulted in significant drying. Today, smoking is commonly employed for a short period of time (e.g., 10 - 90 min) and is mainly done to add flavour and colour and to help increase the shelf life to the product.

There are several hundred different compounds in natural smoke. Maga (1989) and Toledo (2007) reported over 300 in some of the commonly used hard woods (maple, cherry). The compounds can be divided into four groups:

a. carbonyls – contribute to flavour and colour development
b. organic acids – help in preservation and coagulate surface proteins (i.e., assist in casings peeling)
c. phenols – contribute to colour and flavour development, preservation, and retard oxidation
d. polycyclic hydrocarbons – are created when high burning temperatures are employed; some of the compounds, such as benzopyrene, are potentially carcinogenic.

Smoke can be applied by burning the sawdust or pieces of hard woods (e.g. maple, cherry) or as a liquid smoke solution. The former is achieved with the help of a special generator outside the smokehouse. As the moist sawdust is slowly burned, the smoke is circulated into the smokehouse by a fan system usually for

10 – 30 min. During this process, the exhaust duct must be closed so smoke can accumulate and is not wasted. The product's surface must be dry (it could be wet due to condensate) or else the smoke will drip off. Liquid smoke is a newer product that is prepared in dedicated facilities where smoke compounds from burning wood are captured by letting the smoke rise inside a tall chimney equipped with a counter flow water shower. The smoke compounds can later be concentrated and the preparation is applied to meat products as a dip, spray, or atomized mist. An advantage of this process is the ability to separate some/most of the polycyclic hydrocarbons by allowing then to settle out. In addition, some liquid smoke products can be added directly to the raw product after the pH has been adjusted.

n. Enzymes – several groups of enzymes can be added to meat products for a variety of reasons. The two main groups are used for binding meat particles/surfaces and for tenderizing tough meat cuts. Transglutaminase is an example of commercially available enzyme used to bind meat pieces at low temperature (i.e., prior to cooking) in products such as those that have been restructured. This specific enzyme has been used for hundreds of years in the production of fish surimi, although the chemistry was not understood until recently. Transglutaminase is able to catalyze acyl transfer reactions and introduce covalent cross links between proteins. It is now commercially harvested from microbial fermentations.

The other major group of enzymes used is the one that can break down connective tissue. Papain and ficin extracted from pineapples and figs respectively are able to break down collagen and are sometimes used to tenderize meat. However, their activity should be stopped at a certain point as extensive proteolysis can turn the meat into mush.

13.5 Meat Protein Gelation and Binding

Note that sections 13.5 and 13.6 contain more detailed reviews of the protein gelation, binding, and emulsification topics to help the reader understand the relationships between the science and practical application of meat processing principles.

Proteins are the main building blocks of meat products. Thus protein type (e.g., myofibrullar, sarcoplasmic, stromal proteins; see Chapter 3), configuration (Fig. 13.1.2), quantity, and quality (e.g., fresh vs. frozen) have major impact on the final meat product characteristics. The product is also affected by processing parameters such as the size of the meat pieces (small vs. large), addition of ingredients (e.g., salts, acidulants, gums), and cooking method (e.g., hot air vs frying). Overall, the

proteins interact with other components in the meat batter/product to form a gel matrix. In any case, it should be recognized that proteins are the main functional ingredient in meat products while the other two main components, water (30-75%) and fat (5-30%), are important but do not directly contribute to structure building. When discussing protein's contribution to structure it is useful to look at its interactions with the other components in the meat product:

a. Protein-protein interactions: this is one of the main mechanisms that contribute to the formation of an elastic gel upon heating of meat products. As discussed in Chapter 3, there are over 50 different muscle proteins. The amount and type of extracted salt soluble proteins (myofibrillar) and their later associations during heat processing has a strong effect on the meat product's characteristics. As will be highlighted in the following comment, not all meat proteins can form a gel and some proteins such as collagen actually melt when cooked (e.g., 65-72ºC) and will only form a gel upon cooling (e.g., the basis of Jell-O ® manufacturing). This example is mentioned here so the reader can understand that the production of an acceptable meat product is complex. As much as possible, the meat processor should understand the mechanisms involved and be aware of potential positive and negative effects (e.g., using meat with too much connective tissue is less expensive, but can destabilize the gel matrix). Processors should also be aware of the compatibility (e.g. similar gelation temperature) of added non-meat proteins (e.g., soy, whey) and how they will interact with meat proteins.

b. Protein-water interactions: water retention within a lean cut of meat or a ground/finely comminuted meat product is extremely important in creating a product that is acceptable to the consumer (e.g., juicy, not too tough) and profitable to the producer (e.g., reasonable yield). A lean meat chicken fillet portion contains 75% water. In some products added water (e.g., 10-50%; see recipes at the end of the chapter) should also be held within the product.

c. Protein-fat interactions: meat proteins' associations with oils/fats present in fat cells, membranes, or that have been added to the product are very important in providing a mechanism to keep the fat within the product. This is extremely important for sensory and economic reasons.

The binding of meat proteins during cooking involves extensive protein-protein interactions as a result of heat denaturation. Overall, a meat gel matrix can be described in terms of a composite structure. Figure 13.5.1.a shows various possibilities for the production of simple, mixed, filled, and filled-mixed gels with different results in terms of compatibility or incompatibility (i.e., possible enhancement or disruption when two proteins are used). For a mixed gel system a

synergistic effect can result from the cooperation of two proteins/components. As will be discussed in the following comments, another component in the gel matrix can be fat particles/globules in a meat emulsion (e.g., frankfurter). When present as small particles fat can significantly increase the gel's hardness.

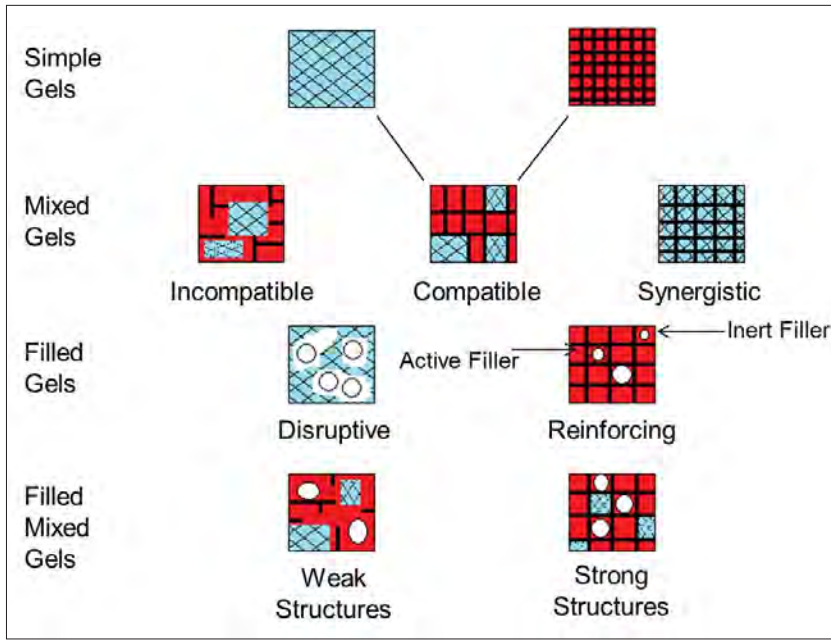


Figure 13.5.1.a Possibilities for engineered structures of simple, mixed, filled and filled – mixed gels. Redrawn from Aguilera and Kessler (1989).

In general, a meat product is composed of various soluble and non-soluble proteins, fat, water, and carbohydrates. Together they can form composite materials that strengthen the polymetric matrix due to volumetric and/or surface phenomena. A non-food example is rubber, a polymer that can be described as a filled gel system. When the so called carbon-black particles are added, there is a great increase in the mechanical moduli. In such a case both the size of the carbon black particles and their strong surface adsorption properties contribute to the gel strength. Aguilera and Kessler (1989) have also shown this strengthening phenomenon in a mixed dairy gel containing small fat globules with modified membranes.

Gravelle et al. (2015) have reported on the physical and mechanical properties of particle-filled composite gels prepared from chicken breast meat proteins. They

examined the effects of solid filler with varying size (1.0-1.4, 0.50-0.60, 0.15-0.21, 0.045-0.090, and < 0.50 mm) and surface properties (hydrophobic rice bran wax particles and hydrophilic glass beads). All composites were found to be stable up to 0.5 volume fraction (φ) filler, based on post-gelation liquid loss, light microscopy and cryo-SEM analyses. Both filler type and size were found to influence the Young's modulus and stress at 50% strain (Fig. 13.5.1.b). The recoverable energy and post-compression height recovery were found to be predominantly influenced by the filler volume fraction, and were less influenced by particle/gel interactions. Interestingly, filler type and size range were observed to have no effect on the cohesiveness of the composites, as this parameter was found to be solely dependent on the volume fraction of the elastic filler present. The behavior of the Young's modulus was compared to that predicted by particle-reinforcement theories proposed by van der Poel and Kerner, each with subsequent extensions (Fig. 13.5.1 b).

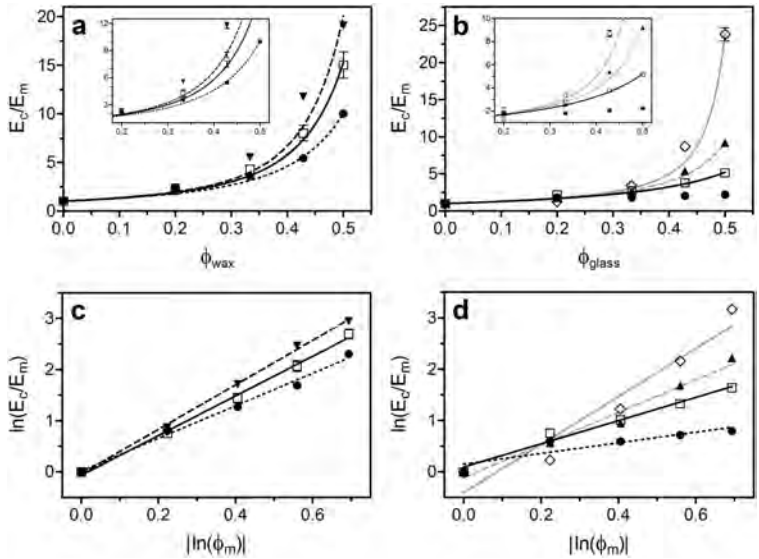


Figure 13.5.1.b Effect of filler type, size, and volume fraction filler (φ) on the Young's modulus (Ec) of particle-filled comminuted meat protein gels. (a,c) Rice bran wax; strongly bound filler (insets show greater separation in the y-axis). (b,d) Glass beads; weakly bound filler. Experimental data in (a) and (b) were fit to the exact solution of the van der Poel model and the Kerner model, respectively. Fitted parameters are presented in the actual paper. The data presented in (c) and (d) is a ln-ln transformation of that shown in (a) and (b), respectively. Note: φm in panels c and d denote the volume fraction of the gel matrix. Particle size ranges ●: 1.0-1.4 mm, □: 0.50-0.60 mm, ▲: 0.15-0.21 mm, ◊: 0.045-0.090 mm, ▼: < 0.50 mm. From Gravelle et al. (2015).

Protein gelation can be defined as an aggregation of denatured protein molecules with a certain degree of order, which results in the formation of a continuous network. This can be described as a two-step process: denaturation and aggregation (see review by Totosaus et al., 2002). Gelation can be induced by physical means (e.g., heat, high pressure) as well as chemical means (e.g., salt ions, acid, urea, and enzymes such as transglutaminase). Phillips et al. (1994) and later Totosaus et al. (2002) classified the factors that affect gelation as extrinsic or intrinsic factors.

Extrinsic factors are the environmental conditions surrounding the proteins and include:

a. pH – affects the net charge of a protein. At its isoelectric point the protein's charge is equal to zero but the further the environment is from the isoelectric point, the more charged the protein becomes.
b. Protein concentration – in general, the cross-linking of macromolecules of an arbitrary initial size distribution is required for gelation and is proportional to the protein concentration. There must also be a minimal concentration of the protein itself, below which a continuous three-dimensional structure cannot be formed. Gel strength and deformability is highly dependent upon protein concentration.
c. Ionic strength– affects water absorption, swelling, and solubility of proteins as competitive linkages are created. Ionic strength has an effect on the microstructure of the gel matrix; at low ionic strengths (<0.1 M) of monovalent cations a fine-stranded matrix is formed, whereas at high ionic strengths (>0.1 M) the matrix becomes mixed (Foegeding et al., 1995).
d. Type of salt – chloride monovalent ions (e.g., Li^{+}, K^{+}) form a fine stranded matrix at ionic strengths less than 0.1 M. The salt concentration required to affect gel microstructure depends on the salt's position in the Hofmeister series. Matrix formation also occurs when low concentrations (10–20 mM) of divalent cations (e.g., Ca^{2+}, Mg^{2+}) of chloride salts are present (Foegeding et al., 1995).
e. Temperature– one of the most important factors because it is a driving force behind protein unfolding. When the gelling temperature coefficient is high, the first gelation step (denaturation) is completed faster than the second (aggregation).
f. Pressure – can affect the sol–gel transition of protein solutions. High pressures (e.g., 200-500 MPa) modify the native volume of proteins, which is composed of the volume of constituent atoms (compositional volume), the volume of internal cavities, and a contribution due to solvation (e.g., presence of water). The native structure governs the

biological activity of proteins and is a delicate balance between the stabilizing and destabilizing interactions within the polypeptide chain and the solvent.

Intrinsic factors are related to the protein itself and include:

a. Amino acid composition – proteins that contain less than 31.5% mol of hydrophobic residues (i.e., proline, leucine and tryptophan) form a coagulum-type gel, whereas proteins with more than 31.5% hydrophobic residues form a translucent gel. Some suggest that a more appropriate parameter might be the ratio of the net charge to hydrophobicity rather than hydrophobicity alone (Totosaus et al., 2002).
b. Electrostatic interactions – are related to the net charge of the protein molecule as influenced by attractive and repulsive forces. They affect protein–protein and protein–solvent interactions (Phillips et al., 1994). These electrostatic interactions are promoted by changes in ionic strength and/or pH (extrinsic factors).
c. Hydrophobicity – when non-polar amino acids are grouped together, they form a hydrophobic nucleus surrounded by a polar residue layer that remains in contact with the solvent (e.g., water). This plays an important role in protein organization and should be taken into account in any protein-folding consideration. Effective hydrophobicity refers to the value representing the interactions between the proteins and surrounding medium.
d. Molecular weight – differences in the average molecular weight and the hydrodynamic size of polypeptide species could be related to variations in the formation of self-supporting gel network and gel strength. The polypeptide critical molecular weight for gel formation is about 23 000 Da.
e. Disulphide bonds and thiol-disulphide interchanges – increase the apparent chain length of the polypeptide rather than acting as an initial network stabilizer among polypeptide chains involved in protein gelation. Disulphide bonds are not essential for gelation of proteins, but their role in gelation is related to their ability to increase the average molecular weight and hence the chain length.

Meat proteins denature at different temperatures (Fig. 13.5.2) and can then form a gel structure. The figure shows that myosin and its subunits denature first (54-58ºC), followed by sarcoplasmic proteins and collagen (65-67ºC), and then actin as actomyosin and as fragments of F and G monomers denature last (71-83ºC; Wright et al., 1977).

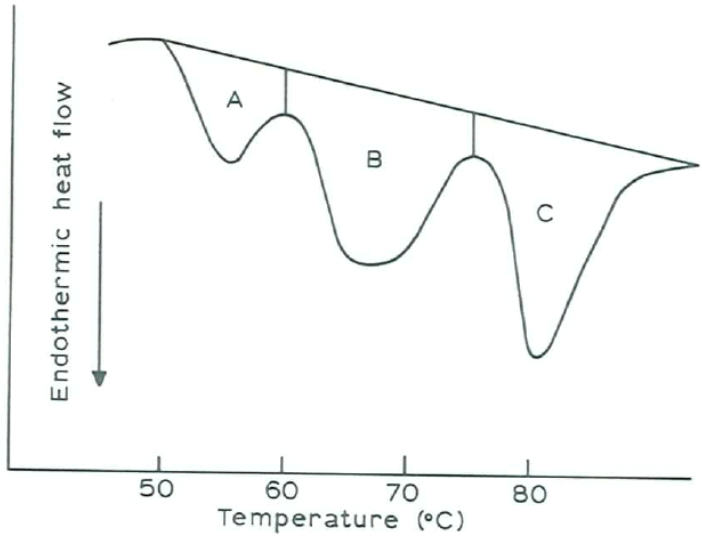


Figure 13.5.2 Typical thermal curve of muscle with three major transition zones. Figure shows a summary of denaturation peaks: (A) myosin subunits; (B) sarcoplasmic proteins and collagen (C) actin. As muscle type and environment change the shape of the curve changes accordingly. Based on data from Barbut and Findlay (1989) and Wright et al. (1977).

Studying the textural changes in a raw meat system during the cooking process and correlating that data with molecular changes is useful in understanding protein gelation. As well, following the rheological changes (i.e., small deformation testing) that take place during gel formation has been useful to studying the sequence of molecular interactions within a food/meat system. The latter studies have become more feasible within the last few years as the market has seen the development of high precision programmable rheometers. Prior to the development of scanning rigidity monitors, samples had to be changed for each temperature point, which resulted in time being a continuous independent variable. An example of information from an early thermal scanning rigidity monitor is shown in Figure 13.5.3. Yasui et al. (1980) studied the effect of using pure myosin, pure actin and their combinations at different ratios on forming a gel matrix. The researchers chose these two proteins because they are the main proteins responsible for meat binding (i.e., myofibrillar salt-soluble proteins). Overall, binding characteristics of meat products prepared from isolated myofibrillar proteins provide a basic understanding of the gelation process. Figure 13.5.3 shows that myosin by itself will start forming a gel at 45ºC. The authors indicated that this gel structure determines the binding quality in meat products and that binding strength bears a

close relationship to the amount of myosin liberated from the myofibrils. The data also show that actin by itself does not form a gel under these conditions.

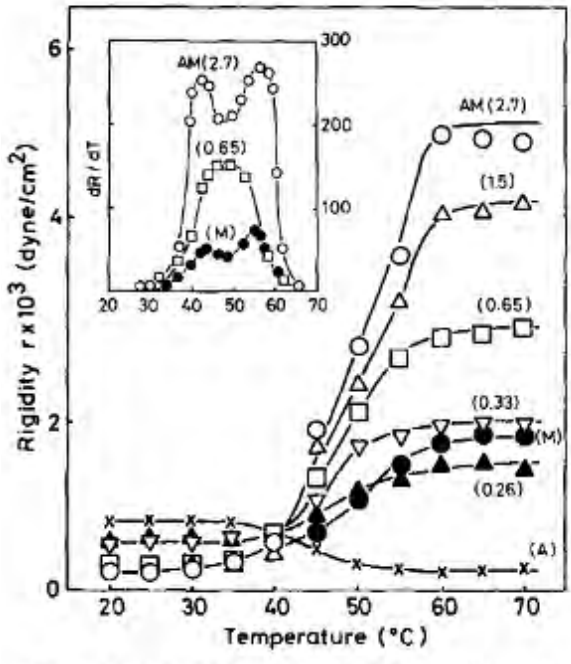


Figure 13.5.3 Heat-induced gel strength of actomyosins reconstitution of different myosin-to-actin ratios. The protein samples (5 mg/ml) were dissolved in a 0.6 M KCl solution containing 20 mM phosphate buffer, pH 6, and incubated for 20 min at temperatures varying from 20 to 70°C. Gel strength was measured at each temperature. M - myosin alone; A - actin alone; AM - actomyosin. The figures in parenthesis indicate the mole ration (corrected) for myosin-to-actin ratio in respective systems. From Yasui et al. (1980).

However, in the presence of myosin, a synergistic effect between actin and myosin is observed. This is because actin, in the presence of other cross-linking proteins, can enhance gel structure. The effect of the relationship between myosin and actin concentration on rigidity is demonstrated in Figure 13.5.3. This can be used to also illustrate the effect of a two protein system that produces a synergistic mixed gel (see also Figure 13.5.1; second row on the right side). Maximum gel rigidity was obtained when the myosin to actin mole ratio was 2.7, (a weight ratio of myosin to actin of about 15:1). Increasing the portion of myosin beyond this point caused

a decrease in gel strength. Yasui et al. (1980) suggested that the synergistic effect is either ionic strength dependent or is determined by the state of myosin per se at different ionic conditions. At <40°C it can also be observed that actin exhibits some resistance to gel, probably due to its thixotropic nature. However, upon heating, the gel collapsed into a compact string or bead-like structure (scanning electron microscopy pictures are not provided here). Isolated myosin fragments were shown to affect gel characteristics differently. Intact myosin monomers produced the strongest gels, followed by myosin rods and the S-1 fragment (see Chapter 3 for myosin structure). The S-1 fragments produced gels with low water-retaining ability. As mentioned above, the differences were also evaluated by electron microscopy. Myosin rods produced an extended three-dimensional network system, while the S-1 fragment formed a bead-like aggregate structure upon heating. Combining the myosin rods and S-1 fragments did not produce high gel strength as was observed for the intact myosin molecules. This indicates that, once cleaved, the fragmented myosin did not have the same capabilities to form a gel matrix.

Table 13.5.1 Effect of sodium chloride (NaCl), tripolyphosphate (TPP) and heating temperature on gel strength and amount of extractable protein. Adapted from Barbut et al. (1996).

	Penetration Force (N)		Extractable Proteins (mg/mL)	
Treatment Temp.	2.5% NaCl	1.5% NaCl[a] + 0.4 TPP	2.5% NaCl	1.5% NaCl[a] + 0.4 TPP
20 ºC	30.8^{f}	25.3^{f}	1.62^{ab}	1.72^{a}
40 ºC	43.3^{ef}	40.1^{ef}	1.58^{b}	1.60^{b}
50 ºC	60.0^{e}	60.5^{e}	1.38^{c}	1.50^{b}
55 ºC	189.0^{d}	194.1^{d}	1.18^{de}	1.21^{d}
60 ºC	356.6^{b}	287.5^{c}	1.07^{e}	1.08^{e}
70 ºC	475.8^{a}	373.3^{b}	0.37^{f}	0.40^{f}

[a]Both the 2.5% NaCl and 1.5% Nacl + TPP were formulated with the same ionic strength (IS=0.42).
Means followed by the same letter, within each test category, are not significantly different at 95% level.

Structure development during heating of a commercial type meat batter can show the direct relationship between the meat protein system (i.e., containing many different proteins) and structure formation. Table 13.5.1 shows gel strength values (measured via penetration force) for a chicken meat batter heated from 20-70ºC and the available protein extracted at each temperature. As temperature increased, more protein-protein interactions occurred and penetration force values increased

from 30 to 475N. At the same time the amount of available proteins decreased because progressively more were bound together to form the gel structure. The microstructure of the gels at the different heating temperatures is shown in Figure 13.5.4. As other researchers have shown, the basic gel structure is formed when the meat batter is prepared (at low temperature) and is solidified during heating through the creation of covalent and disulfide bonds.

In the study, Barbut et al. (1996) followed the gelation of finely comminuted turkey meat (mechanically deboned) prepared with 13% fat and 2.5% NaCl and in reduced sodium (1.5% NaCl plus 0.41% tripolyphosphate) products. From 20-70°C, the process was studied by evaluating gel strength, extracting available proteins, and microscopy. Gel strength, as measured by the penetration test, tripled as temperature increased from 50 to 55°C and then doubled again when temperature was raised to 60°C (Table 13.5.1). The amount of extractable proteins continuously decreased as heating temperature was raised. The decrease in the amount of soluble protein indicates that they were taken up into the gel structure (Asghar et al., 1985). Cryo-scanning electron micrographs (Fig. 13.5.4) revealed that adding phosphate to the low sodium meat batter resulted in a protein matrix with larger pores than the 2.5% NaCl treatment (both treatments were formulated with equal ionic strength). The overall differences in microstructure of the two treatments remained the same during cooking (micrographs taken every 10°C). Development of a rigid gel structure during cooking was characterized by some contraction of protein strands within the matrix. Closer examination of the data revealed that the first major increase in rigidity was observed when the temperature was increased from 20 to 40°C. This corresponded to an initial small reduction in the amount of soluble protein (Table 13.5.1). A further increase was observed from 40 to 50°C and then a major increase was observed when temperature was increased from 50 to 55°C. The latter actually resulted in tripling gel strength values, which could be related to myosin denaturation and its transformation into a rigid structure. A major decrease in the amount of soluble protein at this range has been previously reported by Yasui et al. (1980). They showed that, at this temperature, interactions between actin and myosin were responsible for the rigid structure development (i.e., actin by itself will not gel, but with myosin a synergistic effect can be observed; Fig. 13.5.3). The values for gel strength were further increased when the temperature was increased from 55 to 60°C. Temperature increases in this range have been shown to be critical in the thermal gelation of meat systems. The amount of extractable protein significantly decreased above 50°C in both the 2.5% salt and reduced salt treatments. This corresponded to the large increase in gel strength. Contrast analysis showed that the overall means for extractable protein were significantly different between the 2.5% NaCl and 1.5% NaCl + TPP treatments across all temperatures.

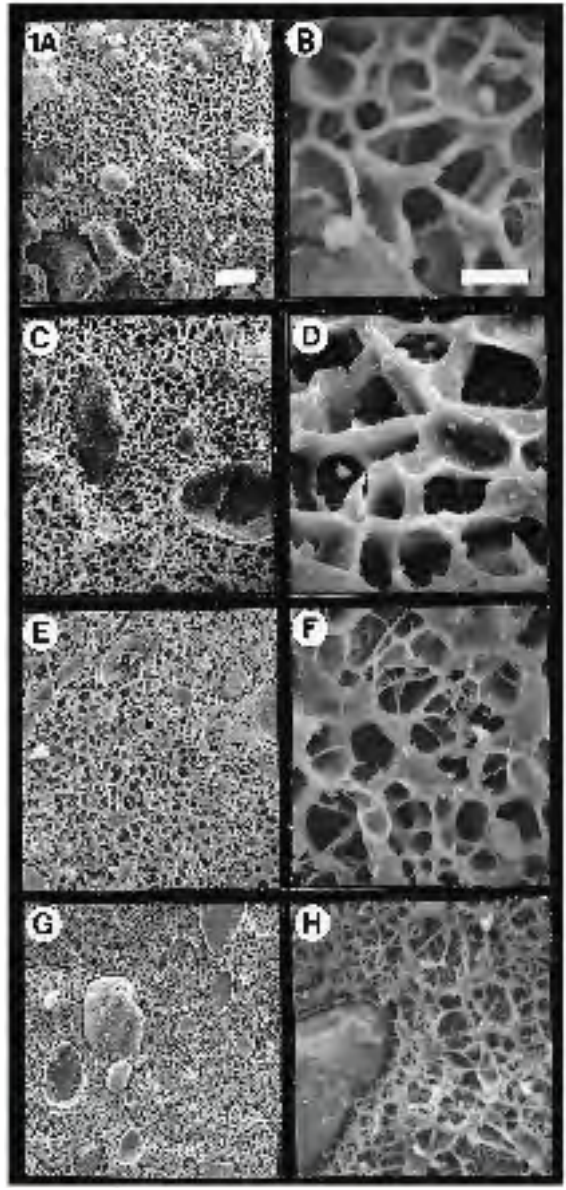


Figure 13.5.4 Cryo scanning electron micrographs of meat batters containing 2.5% NaCl (ionic strength = 0.42), heated to (A,B) 20ºC; (C,D) 40ºC; (E,F) 55ºC; and (G,H) 70ºC. Micrographs on the left are at low magnification (bar = 15 μm), on the right at higher magnification (bar = 3 μm). Part G shows a fat globule entrapped within the protein matrix. From Barbut et al. (1996). With permission.

Micrographs taken during different stages of cooking (Figure 13.5.4) showed a progressive change in the batters' microstructures. The first micrograph shows an organized gel structure prior to heating. This kind of structure has been previously observed by other groups. On heating to 40°C, the protein strands became thicker while the pore size stayed the same. A further increase to 55°C resulted in an increased number of connections among protein strands. The junction zones between strands also became thicker. In addition, thin protein strands were visible among the thick strands. This also increased the density of the protein matrix. These changes corresponded to the large increases in gel strength at this temperature (Table 13.5.1). Further heating to 70°C resulted in a denser protein matrix, which resulted from the formation of additional protein strands concurrent with a reduction in pore sizes. With the help of a scanning electron microscope, Wang and Smith (1992) reported that a salt-soluble protein solution (30 mg/mL, at pH 6.5) heated to 55ºC produced aggregates composed of globular structures connected by strands. When the temperature was increased to 65ºC the strands became thicker (125 vs. 300 nm). Additional heating to 80ºC caused a reduction in strand size, but the structure remained ordered. Since they only started monitoring the structure at 55ºC, comparison with a structure at a pre-denaturation temperature (20ºC) is not possible.

A meat product's gel formation is strongly affected by use of additives such as salts and pH modifiers. As already shown, salt concentration plays an important role in the amount of proteins extracted and later in binding. This is observed in the reduction of salt from 2.5 to 1.5% in commercial-type poultry meat batters (14% protein and 18% fat), which resulted in a substantially lower final rigidity value (12.2 vs. 4.9 kPa, respectively; Figure 13.5.5) as observed by small deformation testing (using a programmable rheometer). Differences were also observed in the development of the modulus of rigidity (G') after the initial protein coagulation started at around 55°C. In both batters, a small but linear increase was observed up to 55°C, indicating that the protein matrix was continuously developing. When the temperature reached the myosin denaturation zone at around 55°C, a rapid increase in G' was observed. However, when the temperature reached the collagen and sarcoplasmic protein coagulation zone at around 63°C, there was a sharp decline in the 1.5% NaCl treatment's curve, whereas there was a steady G' value in the 2.5% NaCl treatment. The sharp rigidity decline might indicate a structural breakdown in the reduced salt meat batter. The general gelation pattern for the 2.5% NaCl, seen in the figure, is similar to the one reported by Montejano et al. (1984) for hand deboned turkey meat containing 2.5% NaCl. Overall, the rapid steady increase in G' from 56 to 70°C (Fig. 13.5.5) indicates the formation of a stable, elastic, and self-supporting matrix structure typical of heat-induced protein gels. With further increase in temperature, there was no increase in G' value, up to 80°C. When

polyphosphates were added to the reduced salt (1.5% NaCl) meat batters, structure weakening around 63°C was eliminated; however, gelation patterns were different depending on the phosphate. Adding 0.5% sodium acid pyrophosphate (SAPP) resulted in the closest match to the rigidity modulus development pattern seen in the 2.5% NaCl treatment. It is interesting to note that, in another study, a taste panel also rated reduced-salt poultry frankfurters containing SAPP as having the most closely matched texture to frankfurters containing 2.5% NaCl. The curve of the TPP treatment shows that structure formation followed the pattern of the 1.5% NaCl treatment up to 64°C, but unlike the 1.5% NaCl, it did not weaken and stayed at a constant value (G'=8.9) up to 80°C. Addition of SAPP resulted in further increases of the G' values as temperature was raised above 64°C. Evidently, the change from a viscous to an elastic structure in a meat batter happens almost instantaneously; additional heating further increases the rigidity modulus, but only up to a certain point. It is important to note that salt and phosphate addition already affect raw meat batter viscosity during preparation. This can be seen in Figure 13.5.5 as the differences in G' at 20ºC. The authors also investigated the effects of applying higher shear rates to the raw meat batters (Figure 13.5.6) in order to determine viscosity and yield stress values. Both are important when selecting pumps to move large volumes of meat in a processing plant.

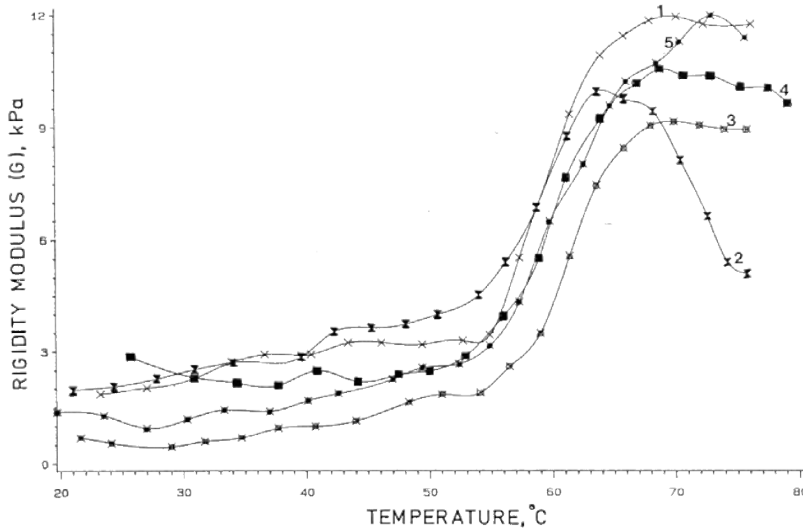


Figure 13.5.5 Shear-rigidity modulus profile of regular and reduced salt meat batters containing various phosphates during heating. (1 = 2.5% NaCl; 2 = 1.5% NaCl; 3 = 1.5% NaCl + 0.5% TPP; 4=1.5% NaCl + HMP; 5 = 1.5% NaCl + 0.5% SAPP). From Barbut and Mittal (1989). With permission.

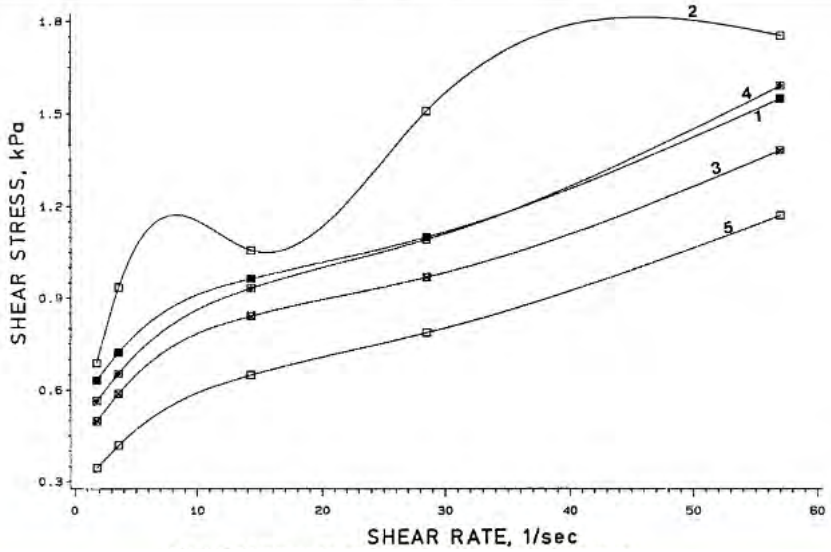


Figure 13.5.6 Relationships between shear stress and shear rate for regular and reduced salt raw meat batters with three phosphates (1 = 2.5% NaCl; 2 = 1.5% NaCl; 3 = 1.5% NaCl + 0.5% TPP; 4=1.5% NaCl + HMP; 5 = 1.5% NaCl + 0.5% SAPP). From Barbut and Mittal (1989). With permission.

The following short discussion is not directly related to meat protein gelation, but is included here to explain flow behavior of raw meat batters and to help the reader understand the forces involved. Figure 13.5.6 shows the relationship between shear rate and shear stress for the same treatments shown in the previous figure. The relationship is nonlinear and displays Bingham pseudo plastic behavior. The shearing rate tends to increase faster than the shearing stress; i.e., also showing a certain yield value. It was suggested that particles (e.g., muscle/connective tissue fibers) in a meat batter are initially randomly oriented and become increasingly more aligned as shear is applied. The contribution of particle interactions to the apparent batter viscosity was reported to decrease when shearing stress increased. All meat batters required the application of a certain shearing force before any noticeable flow took place. On a molecular level, Bingham materials are envisioned as a three-dimensional network at rest. Forces applied to this network can be resisted up to a certain point, but then the network breaks down and the flow becomes essentially pseudo plastic. Both NaCl treatments had the same pH (6.35), TPP slightly increased the pH to 6.45, and SAPP addition decreased the pH to 6.25. These relatively small pH differences are not believed to play a major role in the viscosity differences observed. Rather, the type and concentration of the salt ions involved seem to be most influential. The general power law model

(Herschel-Bulkley) with yield stress was used to fit the data. The 95% confidence interval for yield stress (T_o) was 291 to 580 Pa, for the consistency coefficient (b) was -11 to 191.0 Pa.sn, and for the flow behavior index (n) was 0.50 to 0.82. The T_o for the emulsion containing 1.5 % NaCl + SAPP was significantly lower than those of the other treatments. Thus, SAPP decreased the Bingham behavior of the meat batter. Similarly, the T_o value for the control (2.5% NaC1) was significantly higher than those of the other treatments. Thus, low NaCl (1.5%) reduced the T_o value. The b value of the meat batters with 1.5% NaCl was significantly higher than those of the 2.5% NaCl or 1.5% NaCl + phosphate batters. The n value was between 0 and 1, indicating pseudoplasticity. Similarly, the n value of meat batters containing 1.5% NaCl was significantly lower than those of other treatments. According to previous work, more stable formulations tended to have higher b values, lower n values, and larger values for yield stress. As indicated above, these values and the relationships between them are important for equipment selection in a meat processing plant.

Returning to the effect of pH on meat protein gelation, it is important to note that pH can affect gel characteristics (hard, soft) and certain pH values can actually prevent gel formation. Xiong and Brekke (1991) reported that the optimum pH for gelation of chicken muscle in 0.6 M NaCl (or KCL) was about 6.0 for breast myofibrils and 5.5 for leg meat myofibrils. Wang et al. (1990) studied the effect of pH on the gelation (30 to 80ºC) of 3% salt soluble proteins (SSPs) extracted from chicken breast. Table 13.5.2 shows the storage modulus (G', the elastic element) and the loss modulus (G", the viscous element). Salt soluble proteins at all conditions exhibited higher G' than G" throughout the heating process which indicated the elastic nature of SSPs during the sol-to-gel transformation. The pH 5.5 and 6.5 treatments show the highest final G' values, indicating the strong effect of pH on gel formation. At the end point, the G' of SSPs at pH 4.5 was not significantly different from that at pH 7.5. Salt soluble proteins at pH 5.5 and 6.5 tended to have a higher G' at the end point, which indicated the formation of a more elastic gel matrix and more cross-linking between the protein molecules. Protein gels at pH 5.5 exhibited the highest G" at the end point, which indicated the formation of a more viscous matrix.

The increase in G" was thought to be due to the partial unfolding of protein structure, which caused an initial increase in the viscous characteristics of the SSPs. The subsequent increase in G', which indicated an increase in the elastic or solid nature of the material, indicated that the SSPs were cross-linking to form an elastic gel. An examination of the tangent delta (G"/G') showed the relative viscous:elastic properties of the material (i.e., in an elastic solid the tangent delta is zero and for a viscous fluid it is infinite). For all pH levels, there were no significant differences in

the tangent delta values for the SSP preparations at the initial point prior to heating. No second peak was observed in SSPs at pH 4.5, which corresponded to the lack of transitions in both G' and G". Similarly, no significant differences in tangent delta were observed at the first and second peaks in SSPs at 5.5, 6.5, and 7.5. At the end point, protein gels at pH 4.5 showed higher viscous properties than at pH 6.5 and 7.5. This indicated that gels at pH 6.5 and 7.5 formed a more elastic network.

Table 13.5.2 Effect of pH on the storage modulus (G'), loss moduli (G"), and loss tangent (tangent delta) of 3% chicken breast salt-soluble proteins heated from 30 to 80ºC at 1ºC/min and with 0.6 M NaCl. Adapted from Wang et al. (1990).

Parameters	pH			
	4.5	5.5	6.5	7.5
Storage modulus (Pa)				
Initial point	34.2^{b}	141.6^{ab}	196.0^{a}	187.0^{a}
Peak maximum	…	1,000.3^{a}	1,190.7^{a}	614.7^{a}
End point	216.3^{b}	1,725.7^{a}	1,286.0^{a}	575.9^{b}
Loss modulus (Pa)				
Initial point	6.8^{b}	32.8^{ab}	38.8^{a}	31.4^{ab}
Peak maximum	…	116.6^{a}	128.6^{a}	82.8^{a}
End point	24.4^{b}	123.1^{a}	30.6^{b}	24.9^{b}
Loss tangent (temp;C)				
Initial point				
Temperature, C	30	30	30	30
Tangent delta	0.22^{a}	0.23^{a}	0.20^{a}	0.17^{a}
First peak				
Temperature, C	37^{b}	34^{c}	47^{a}	49^{a}
Tangent delta	0.24^{a}	0.20^{a}	0.19^{a}	0.17^{a}
Second Peak				
Temperature, C	…	53^{b}	57a	58^{a}
Tangent delta	…	0.15^{a}	0.12^{a}	0.15^{a}
End point				
Temperature, C	80	80	80	80
Tangent delta	0.12^{a}	0.07^{ab}	0.02^{b}	0.04^{b}

^{a,b}Means within the same row with no common superscripts are significantly different ($P < 0.05$), n=3.

The authors also reported the complex modulus (G*, the amount of force required to deform a sample). There were no major transitions at pH 4.5 when SSP solutions were heated. This was because the proteins coagulated at this low pH and did not from a gel network. This is typical of protein systems at pH levels close to their isoelectric point (i.e., where the net charge on the proteins is close to zero). The isoelectric point of actomyosin is around 5.0 and at this point an electrostatic attraction between the molecules can be seen. Electrostatic attraction minimizes protein unfolding during heating and prevents gel formation. At pH 5.5, 6.5 and 7.5, G* increased after the first transition at 35-47°C. Afterwards, it peaked, then decreased on further heating to the third transition around 54-60°C, and then increased again until 80°C. The first transition, which led to the development of gel elasticity, was attributed to unfolding in the tail portion of the myosin molecule. The G* values at the end of cooking were significantly higher at pH 5.5 and 6.5 than at pH 4.5 and 7.5 ($P < 0.05$). The authors mentioned that the thermal transitions, graphed as differential plots of the complex modulus against temperature (dG*/dT versus T; not shown here), were pH-dependent throughout the heating process. The differential plot illustrated the rate of G* change during heating and provided additional information on how pH affects protein conformational changes during sol-to-gel transition. No rate changes were observed for the SSPs kept at pH 4.5 during the heating process. The first transition of the pH 6.5 and 7.5 treatments occurred at temperatures above 45°C. At pH 5.5 even the third transition had occurred before any changes were observed in the higher pH treatments. However, further transitions at pH 5.5 were similar to those of the higher pH treatments; temperature differences between the first and sixth transition were 18°C, 14°C, and 12°C for pH 5.5, 6.5, and 7.5, respectively. The pH 6.5 and 7.5 treatments showed almost identical transition temperatures and rheological transitions, which suggested similar changes in protein conformation during the gelation process. These results also demonstrate that pH influences the unfolding and aggregation of native protein molecules during heating and results in different gel properties.

Overall, the data presented above indicate that pH should be monitored and adjusted (if needed) to obtain consistent meat product quality. The texture and water binding capacity of meat products can be manipulated by adjusting the pH and by adding various salts and binders to optimize meat formulations.

13.6 Fat Binding and Emulsification

Meat products that are finely comminuted, sometimes referred to as meat emulsions (e.g., bologna and frankfurters), are basically composed of protein, fat, water, and salt. Products in this category are produced from different meat and non-meat ingredients (e.g., salt, soy proteins, starch) all around the world. In North America their estimated market share is over 35%. Producing high quality comminuted products is an ongoing challenge to processors who deal with a large selection of raw materials whose prices fluctuate daily (see Section 13.3 on Least Cost Formulation). The basic structure of a comminuted product is shown in Figure 13.5.4 where fat globules are dispersed in a protein gel matrix. The matrix has a structure that can be described as a sponge where there are lots of small spaces that confine water. The products shown in the figure have about 60% water, 20% fat, and 14% protein. The protein matrix represents the main structure that forms the product/holds the water and fat components. It consists of the salt soluble proteins and small pieces of intact muscle and collagen fibers. All ingredients are comminuted either in a bowl chopper or an emulsion-mill (see Chapter 10) in order to reduce the lean meat particles, open their structure, and extract the salt soluble proteins. This process also reduces fat particle sizes to increase their stability (see later discussion) and obtain a homogeneous mass. However, as the fat particle/globule size can be above 20μm, these products cannot be classified as true emulsions and the forces that govern a true emulsion cannot explain their entire stability. In any case, the challenge to the meat processor is to produce a stable meat product that can withstand the cooking process without fat and water separation (Acton et al., 1983; Barbut et al., 1996).

A good understanding of the mechanism(s) responsible for stabilizing/binding the fat within the product is essential to the meat processor because most comminuted products contain 15-40% fat that is held by a smaller amount of protein. As the proteins are also needed to retain water, they should be of high quality. Studying the mechanisms affecting meat batter stability is important because an "emulsion breakdown" can be very costly especially in high volume processing plants. In addition, understanding the relationship between meat batter stability and processing equipment can help the processor select the right equipment (i.e., different machines are available) and utilize the best ingredients for a specific product. It should be noted that this is not an easy task as there are many binders available on the market. Understanding meat batter stability also helps the processor effectively use least-cost-formulation programs and respond to consumer demands (e.g., reduced fat/salt meat products which cannot actually be prepared by a straight fat/salt reduction).

From a practical standpoint, one of the major reasons for studying meat batter stabilization is that during chopping the processor cannot see/detect any warning signs indicative of a later "emulsion breakdown" (a term referring to fat separation during cooking). This point is illustrated in Figure 13.6.1, which shows the effect of chopping time on meat batter stability. As chopping time increases, more proteins are extracted, fat particle size is reduced, and less liquid and fat is separated from the product. This is known to most meat processors; however, just looking at the raw meat batter usually does not provide any hint to the amount of liquid/fat losses that can be expected during cooking. This is a constant challenge because meat block formulations can change daily depending on the availability of raw materials, cost, etc. Therefore, meat processors usually use pretty high safety margins (e.g., more proteins and longer chopping time; both of which increase processing costs) to protect themselves against emulsion breakdown incidents. The data in Figure 13.6.1 are used to illustrate the point that understanding the process should benefit the processor. This material was also used in the development of an automated fiber-optic system to monitor the emulsification process.

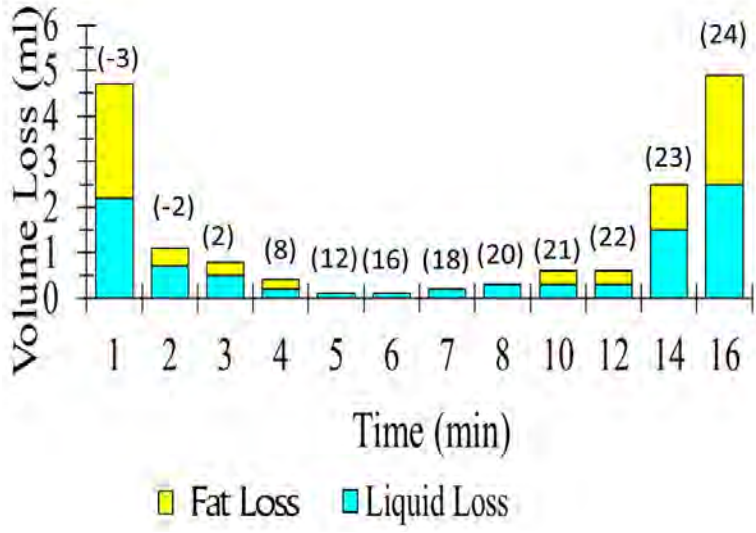


Figure 13.6.1 Effect of chopping time on cooking loss (ml) from comminuted beef meat batter. Temperature values (ºC) at each time are listed above bars. From Barbut (1998).

There is still debate in the scientific community as to the correct definition of finely comminuted meat products: meat emulsion or meat batter? The controversy arises from the interpretation of the mechanisms responsible for holding the fat within the

product. Figure 13.5.4 shows the microstructure of finely comminuted products where the small fat globules are dispersed within a water soluble protein matrix. Borchert et al. (1967) were among the first to show the presence of an interfacial protein film (IPF) surrounding the fat globules (Fig. 13.6.2) and suggested that the film is responsible for stabilizing the fat.

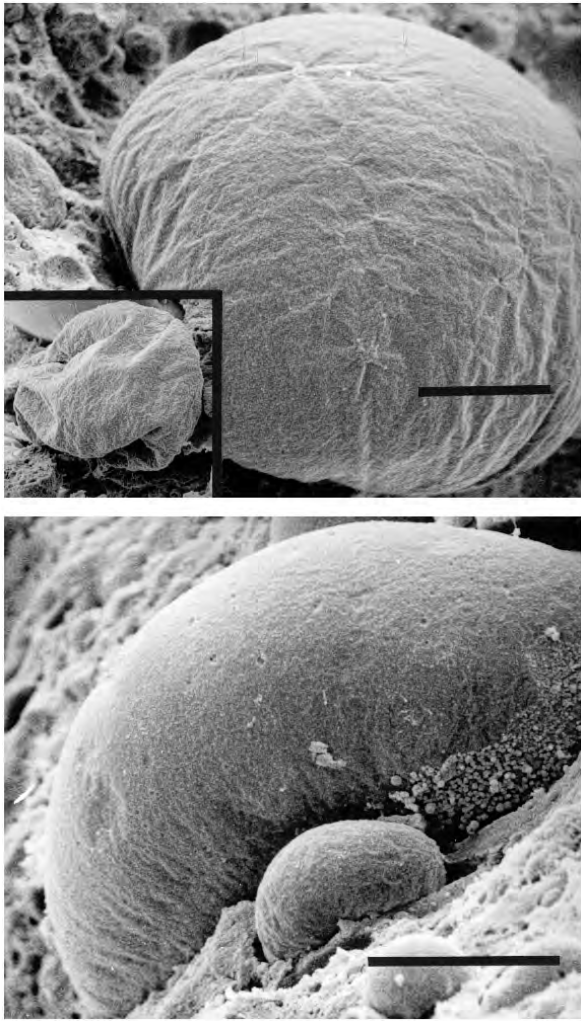


Figure 13.6.2 Scanning electron micrographs of fat globules with surrounding interfacial protein film in a cooked, low salt poultry meat batter formulated with 1.5% NaCl (top), and with an adequate salt level of 2.5% NaCl (bottom). Bars = 10 μm. From Barbut (1988). With permission.

The myofibrillar proteins, which have hydrophilic and hydrophobic sites, arrange themselves in such a way that they reduce surface tension and forces responsible for fat globule coalescence and prevent separation. The same phenomenon is observed in homogenizing milk, where small fat globules are covered with the milk protein caseinate (to help reduce fat separation/creaming). If finely comminuted meat products hold fat using this mechanism, they would be considered true emulsions. However, other researchers have suggested that the protein matrix is the main factor responsible for physically entrapping the fat globules (Lee, 1985). According to the physical entrapment theory, the viscous protein matrix restricts fat globule movement, hence coalescence. This mechanism would suggest that finely comminuted products are behaving as meat batters. In any case, the whole issue of which mechanism is more important is not so simple, since numerous changes take place during the production of products such as frankfurters/bologna. During the initial stage of chopping, a flowable product, with a toothpaste-like texture, is formed and the meat batter can be easily pumped (note: care should be taken to limit shear forces, which can cause fat globules to coalesce and destabilize the meat batter). The structure formed in the raw stage is shown in Figure 13.5.4.A. Later, during the initial heating process (20-40ºC), the fat starts to melt and is present in a liquid form. Myofibrillar protein denaturation and gelation starts at a higher temperature (around 50ºC; see Fig. 13.5.4.E). At that point, the melted fat starts to expand, collagen starts to be transformed into gelatin (i.e., liquid form), and the salt soluble proteins form a gel. The texture of the product at the end of the cooking process (70°C) is semi-rigid and does not flow anymore because the salt soluble proteins have been denatured. As indicated above, there is continuing debate about which mechanism is more important but today there is support for the notion that fat stabilization is a combination of the ability of proteins to form an interfacial film, as well as the formation of a gel matrix which physically restricts the movement of fat globules prior to cooking (Youssef and Barbut, 2011).

The thickness of the interfacial protein film, its elasticity, complete or partial coverage of the fat globules, and weak spots along the film have been discussed by various researchers (Borchert et al., 1967; Jones and Mandigo, 1982; Barbut, 1999; Ramirez-Suarez and Xiong, 2003). The authors discussed the formation of a relatively thin, flexible protein film around fat globules, and emphasized the importance of pore formation as a "pressure release mechanism" during the cooking stage (i.e., when fat is heated and expands). Some have experimentally modified the thickness of the protein film by varying chopping procedures. Overall, it appears that the formation of a relatively thin and flexible protein film provides the best stability, whereas a thick inflexible film results in large ruptured holes during cooking. Figure 13.6.3 illustrates the microstructure of stable and unstable finely comminuted meat products. In the stable product, fat globules are confined within a distinct globular structure. In the unstable product (in this figure caused

by Tween 80 addition) they are distorted in shape and start to form fat channels. Destabilization can also be caused by decreasing the salt level (e.g., 2.5 to 1.5%), which is associated with lower protein extractability and subsequently higher fat and moisture losses during cooking (Acton et al., 1983). The combined loss of fat and moisture from finely comminuted meat products has been mentioned by Schmidt (1984), who observed that fat exudation usually follows moisture loss. Schmidt postulated that the formation of channels through the meat batter was important to allow some moisture and fat losses. Figure 13.6.2 shows a fat globule that has lost some of its fat, during cooking, due to salt reduction in the raw meat formulation (2.5 to 1.5%). The scanning electron micrograph reveals a protein envelope around the fat globule. When too much fat is exuded from the globule, the protein envelope shrinks and indentations plus small exudative holes are seen on the surface. When salt is increased, little or no fat is lost and round globules can be seen. Whiting (1987) has also reported that 1.5% salt is a threshold in frankfurters, as determined by the amount of fat and water released during cooking. It should be mentioned that the amount of salt required to produce a stable batter also depends on factors such as the amount of fat and protein and their quality.

The connection between the texture of the meat protein matrix and the size of the fat globules can be seen in Table 13.6.1. Youssef et al. (2011) indicated that increasing the meat protein level (9–15%) increased the hardness of finely comminuted meat batters prepared with beef and animal fat or canola oil (CO). Overall, a higher protein level formed a denser protein network (microstructure not shown here), which had increased resistance to compression. The meat emulsions prepared with animal fat showed lower fracturability and hardness values compared to the CO emulsions. This is most probably due to the higher number of small CO globules present in a given volume (similar results were also shown for milk protein gels). In a previous experiment the authors showed that fat globule size was reduced from 6627 to 121 μm^2 when beef fat was substituted with CO at 8% protein. The same idea can also be seen here in Figure 13.6.3. Overall, the presence of smaller fat globules and higher protein increase resistance to compression. This is in line with the composite gels discussed at the beginning of the section.

The treatments with Tween 80 + animal fat resulted in higher fat and moisture losses than the CO-Tween 80 or animal fat treatments (Table 13.6.1). This resulted in an increased protein concentration and higher hardness values in the cooked products; i.e. they formed denser protein matrixes.

Table 13.6.1 Effects of meat protein level and fat type on texture profile analysis parameters of cooked finely comminuted meat batters Meat batters were produced with 9, 12 or 15% protein, with either beef fat (BF), or canola oil (CO; all treatments contain 25% fat or oil). An emulsifier (Tween 80 indicated as T-80) was added to one set of products, and sodium caseinate (SC) was used to replace 2% of the meat proteins in another set. M=meat protein; P*=indicates total protein when 2% SC was used. Data adapted from Youssef et al. (2011).

Treatment	Treatment Identification	Fracturability (N)	Hardness (N)	Springiness (cm)	Cohesiveness (ratio)	Chewiness (n cm)	Gumminess (N)
1	9M + BF	16.57 ± 0.24^{h}	17.13^{j}	0.68	0.22	2.56 ± 0.10^{hi}	3.76 ± 0.14^{j}
2	12M + BF	26.98 ± 0.38^{e}	33.99^{g}	0.77	0.26	6.80 ± 0.19^{f}	8.83 ± 0.17^{g}
3	15M + BF	29.99 ± 0.39^{abc}	61.50^{e}	0.79	0.28	13.60 ± 0.36^{c}	17.22 ± 0.28^{d}
4	9M + CO	29.53 ± 0.28^{bcd}	31.33^{g}	0.81	0.34	8.62 ± 0.25^{e}	10.65 ± 0.28^{f}
5	12M + CO	31.54 ± 0.48^{a}	66.35^{d}	0.81	0.46	24.72 ± 0.55^{a}	30.52 ± 0.60^{a}
6	15M + CO	29.27 ± 0.35^{bcd}	69.78^{c}	0.85	0.43	25.50 ± 0.67^{a}	30.00 ± 0.75^{a}
7	9M + BF-T80	19.38 ± 0.68^{g}	20.42^{i}	0.71	0.25	3.62 ± 0.20^{h}	5.10 ± 0.26^{i}
8	12M + BF-T80	29.01 ± 0.82^{cd}	46.27^{f}	0.76	0.31	10.90 ± 0.70^{d}	14.34 ± 0.90^{e}
9	15M + BF-T80	31.30 ± 0.44^{a}	73.69^{b}	0.78	0.37	21.26 ± 0.69^{b}	27.26 ± 0.45^{b}
10	9M + CO-T80	10.31 ± 0.44^{i}	13.78^{k}	0.57	0.23	1.80 ± 0.11^{i}	3.31 ± 0.12^{j}
11	12M + CO-T80	25.29 ± 0.66^{f}	27.71^{h}	0.71	0.26	5.11 ± 0.21^{g}	7.20 ± 0.21^{h}
12	15M + CO-T80	29.06 ± 0.50^{cd}	63.59^{e}	0.84	0.40	21.36 ± 0.33^{b}	26.45 ± 0.41^{c}
13	9P* + BF-SC	10.54 ± 0.33^{i}	12.48^{k}	0.60	0.21	1.57 ± 0.06^{i}	3.04 ± 0.07j
14	12P* + BF-SC	30.75 ± 0.68^{abc}	32.60^{g}	0.74	0.24	5.78 ± 0.21^{fg}	10.48 ± 0.21^{gh}
15	15P* + BF-SC	30.84 ± 0.55^{ab}	80.16^{a}	0.78	0.33	20.63 ± 0.85^{b}	29.48 ± 0.79^{c}
16	9P* + CO-SC	7.87 ± 0.47^{j}	11.73^{k}	0.59	0.26	1.79 ± 0.18^{i}	3.15 ± 0.19^{j}
17	12P* + CO-SC	27.98 ± 1.02^{de}	33.81^{g}	0.80	0.31	8.38 ± 0.53^{e}	10.73 ± 0.62^{f}
18	15P* + CO-SC	31.64 ± 0.61^{a}	71.91^{bc}	0.83	0.41	24.47 ± 0.66^{a}	31.23 ± 0.59^{a}

[a-p]Means within a column no common superscript are significantly different ($P < 0.05$).

The CO-T80 batters had lower hardness values than batters prepared with CO, possibly related to the formation of an incoherent protein matrix (Fig. 13.6.3). When Tween 80 surrounds fat globules it can interfere with the interaction of the interfacial protein film with the actual protein matrix. Theno and Schmidt (1978) observed that fat particles coated with proteinaceous material could cross link with the protein matrix and therefore stabilize frankfurters. It was suggested that the physical binding of fat might be the result of protein–protein interactions between the interfacial protein film and the matrix proteins.

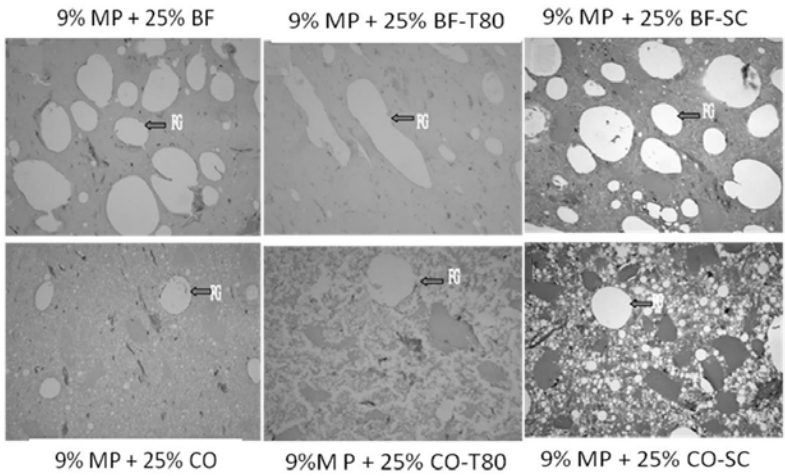


Figure 13.6.3 Light micrographs of meat batters with pre-emulsified fat/oil with T-80. Fat globule (FG); meat protein (MP); made with canola oil (CO), or beef fat (BF); pre-emulsified with Tween 80 (T80) or with the addition of sodium caseinate (SC). Bar = 200μm.
From Youssef et al. (2011). With permission.

The use of sodium caseinate (SC), which is used by the meat industry to stabilize fat, lowered fracture and hardness values at the 9% protein level (hardness of 12.48 vs. 17.13 N with and without SC, respectively) when 2% of meat proteins were replaced with SC. This was because SC cannot form a heat induced gel (at 72°C) and the amount of meat protein (7%) was insufficient to produce a hard texture. However, when 12% protein and 2% SC was used, the texture was comparable to the 12% meat protein. At 15% protein (13% meat protein and 2% SC), hardness surpassed the control (15% meat proteins). CO-SC batters showed reduction in hardness values at the 9% and 12% protein levels compared to the comparable CO treatments. This change in hardness indicates that incorporation of pre-emulsified fat/oil with SC can significantly modify the textural properties of meat batters.

Replacing beef fat with CO also increased springiness and cohesiveness; this is possibly related to the size and distribution of the fat globules (Table 13.6.1), which agrees with previously published data.

Overall, the control beef fat treatment revealed a typical meat batter in which fat globules are embedded within a homogenous protein matrix (Fig. 13.6.3). Microstructure was affected by the type of fat/oil and protein content. In all treatments, increasing protein resulted in the formation of a denser protein matrix structure, caused by the higher amount of extracted salt soluble proteins forming more protein–protein interactions. Replacing beef fat with CO showed a larger number of small, closely packed, fat globules compared to the beef fat treatment. This is because of the liquid nature of CO relative to the more solid nature of beef fat, which plays an important role during chopping. As meat protein level was raised in the CO emulsions, irregularly shape fat globules began to appear as fat globules coalesced into larger globules that later led to the formation of fat channels. The discontinuity of the protein matrix allowed fat and liquid to leach out of the matrix.

The beef fat -Tween 80 (BF - T80) showed more protein matrix aggregation than the beef fat treatment, suggesting that fat mobility overcame the ability of the protein matrix to contain the fat. This resulted in large irregularly shaped and elongated fat pools; this also caused meat batter instability (Fig. 13.6.3). The CO-Tween 80 treatment, at 9% protein, showed an incoherent matrix with very few fat globules with visible IPF. In the past, non-protein emulsifiers, particularly Tween 80, were shown to be preferentially absorbed by fat globules than meat proteins because of their higher hydrophilic–lipophilic balance values. This can reduce protein–lipid interactions by interfering with the adsorption of protein molecules to the fat globule surfaces and can result in decreased binding of fat globules to the protein matrix.

Pre-emulsification of fat/oil with sodium caseinate produced a finer dispersion of fat globules compared with the control (Fig. 13.6.3); this was probably because caseinate has a higher emulsifying capacity than lean beef meat. The protein matrixes were also less dense than in the all other meat matrixes. This is believed to be due to the dilution effect of replacing 2% meat protein with SC (which does not gel at 72°C).

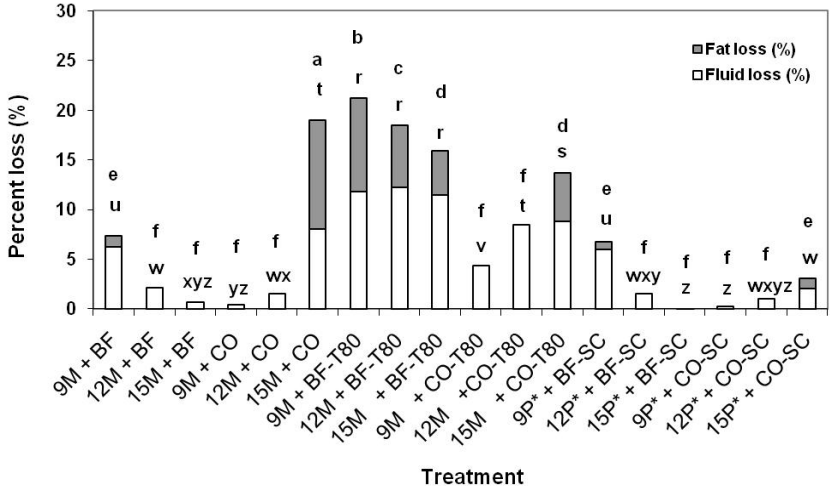


Figure 13.6.4 Means of fat and fluid losses of meat batters prepared with 25% beef fat (BF) or canola oil (CO) and pre-emulsified fat/oil with T-80 or sodium caseinate (SC) at different protein levels. All treatments contain 25% fat or oil; 2% of the meat protein was substituted with SC; M, meat protein; BF-T80, beef fat pre-emulsified with T-80; CO-T80, CO pre-emulsified with T-80; P, protein; BF-SC, beef fat pre-emulsified with SC; CO-SC, CO pre-emulsified with SC. Means related to fluid loss (r-z), and fat loss (a-f), with no common superscript are significantly different ($P < 0.05$). Last six treatments; 2% of the meat proteins (M) were substituted with SC and then denoted as P* to show total protein in the whole treatment.
From Youssef et al. (2011). With permission.

13.7 Casings

Meat and sausages have been stuffed into natural casings for thousands of years. Today this continues in the industry but with increased automation, a larger variety of pre-formed casings (Fig. 13.7.1), and the option for co-extrusion. The latter has been one of the most significant developments in sausage casings over the past century. This process allows continuous, direct deposit of an initially semi-liquid material (e.g., collagen paste) onto the product as it is extruded from the stuffer. This has allowed the industry to move from a batch type operation to a continuous operation (see also Chapter 1 discussing automation). The continuous operation is a key concept in reducing labour cost, increasing efficiency, and introducing more mechanization into the process. However, it should be pointed out that the process does not fit all products (e.g., large diameter sausages) and the initial capital cost can be high.



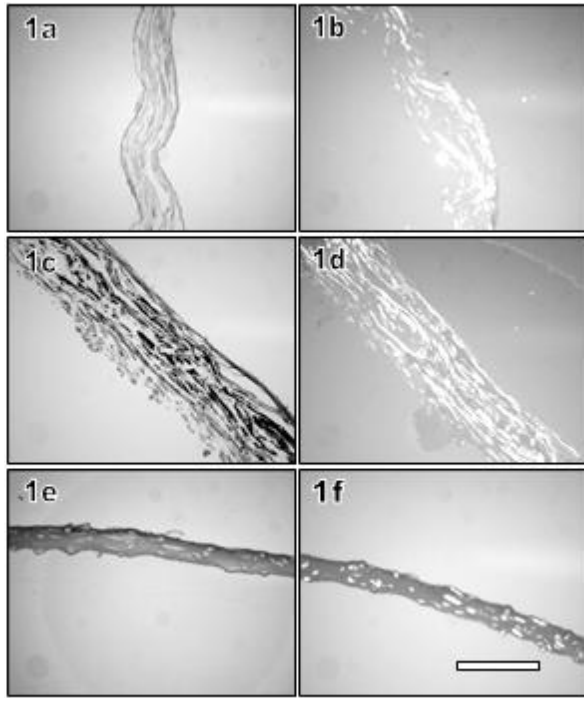
Figure 13.7.1 Different types of casings used for various meat products. Products made at the University of Guelph. Photo by S. Barbut.

When producing a sausage, the raw meat batter consists of ground/chopped meat which is a fairly viscous material that can be pumped and stuffed into different sized casings. During cooking, the meat proteins are denatured and form a heat stable gel (see Section 13.5). At that point, the cooked firm product can be removed from the casings (e.g., cellulose casings stripped off hot dogs at the meat plant), or by the consumer prior to slicing/consumption (e.g., salami casings removed at home by the consumer). In the case of edible casings (natural or manufactured collagen) the casing is left on the product (see recipe for European Style Chicken Weiners at the end of the chapter).

As mentioned above, humans have been using natural casings, such as those derived from the gastrointestinal tracts of sheep, cattle, etc., for thousands of years. These casings are still popular in certain products and to some represent the golden standard. Over the past century, there has been a rapid development of new packaging materials, including casings (Savić and Savić, 2002), and currently there are hundreds of different casings on the market. Overall, they can be divided into a few groups based on their origin.

a. Natural collagen casings are derived from the digestive tracts of sheep and hogs. Because of the bovine spongiform encephalopathy (BSE) problem, cattle

casings are not so popular today. Preparation of casings involves thorough cleaning, removal of the mucosa layer, and washing the casings several times. This is done in dedicated plants and requires a lot of manual labour. The cleaned and inspected casings are then stored in a saturated salt solution and have a shelf life of a few months. The microstructure of such casings can be seen in Figure 13.7.2, which shows the collagen fibers in the casing. These fibers provide elasticity during stuffing of the raw product and a bite/snap in the cooked product. The casings are permeable to water and smoke, and can shrink with the product since they adhere to the surface. This is a desired feature, especially in sausages that shrink during the smoke house operation and/or later on. An example for the latter is dry sausage manufacturing, where the product loses a substantial amount of water during the drying process (can be 30 – 50%), and loose casings will make the product unsalable. Most natural casings are edible and digestible, and do not need to be peeled off prior to consumption. However, if a very thick casing is used consumers will peel it off. Overall, natural casings are relatively expensive because of the labour involved in their cleaning and application. Today they are used for selected products to provide an "old fashioned" look and a certain "snap".



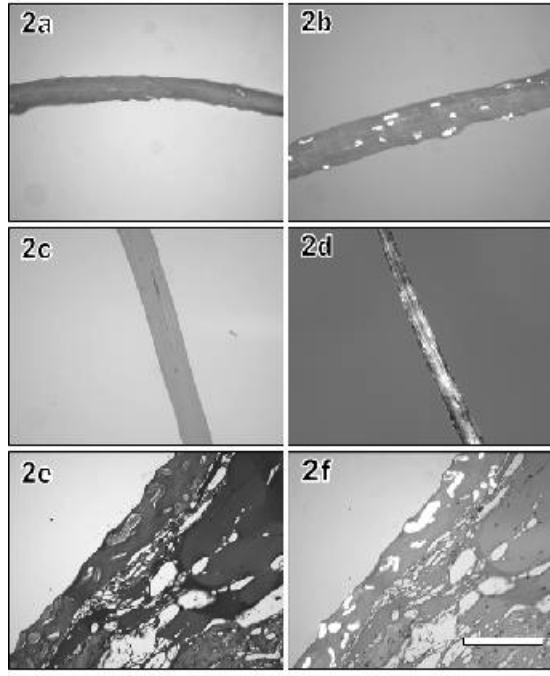


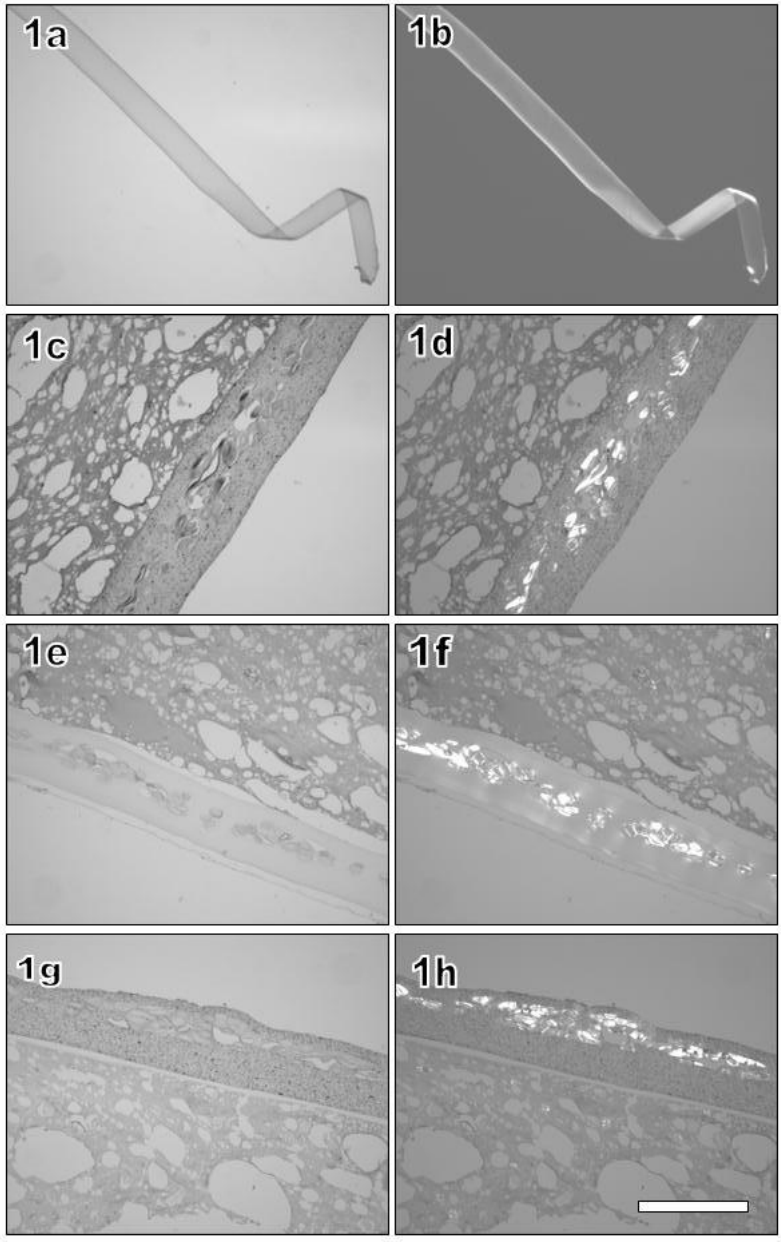
Figure 13.7.2 Light micrographs of raw collagen casings. First frame showing: (1a) and (1b) natural sheep; (1c) and (1d) natural hog; (1e) and (1f) manufactured collagen for fresh sausage. Polarized light was used in (1b), (1d) and (1f) to reveal connective tissue fibers. Second frame showing: (2a) and (2b) manufactured for smoked sausage; (2c) and (2d) manufactured for large diameter ring sausage; 2(e) and (2f) co-extruded; the lower right part shows the meat batter. Polarized light was used in (2b), (2d) and (2f) to reveal connective tissue fibers. Bar = 200 μm. From Barbut (2010). With permission.

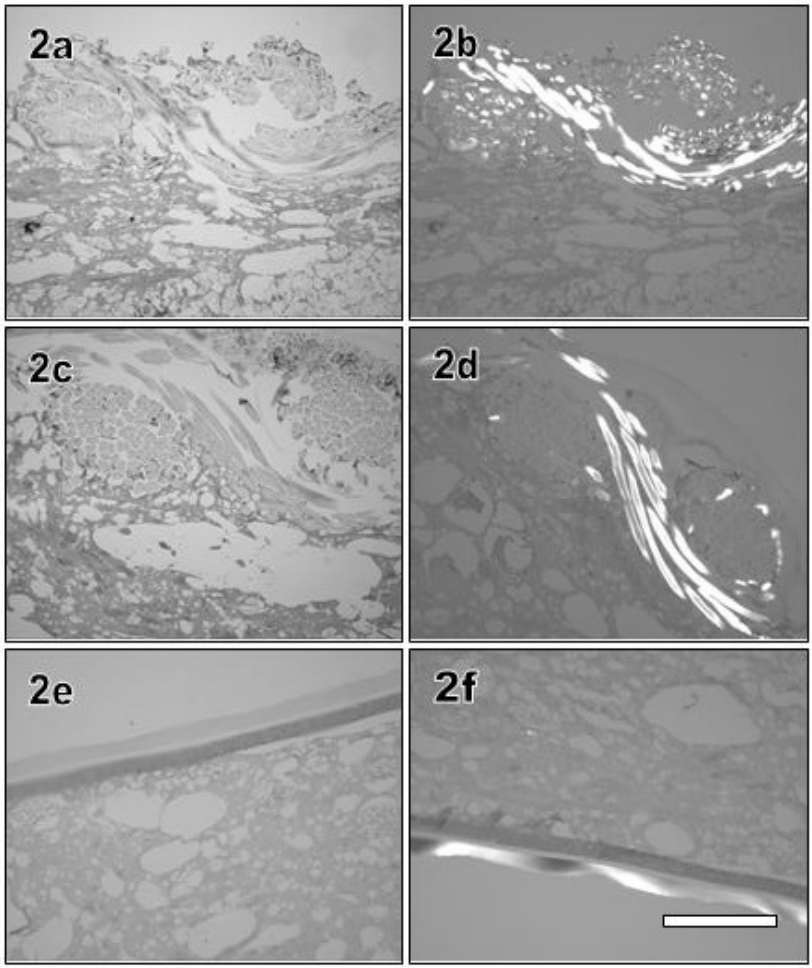
b. Manufactured collagen casings are made from regenerated collagen extracted from the skins and hides of various red meat animals (Savić and Savić, 2002). The microstructure of such casings can be seen in Figure 13.7.2. The casings are usually edible (depending on the thickness) and therefore do not have to be removed prior to consumption. They are very uniform and do not have size variations or weak spots like the natural casings. Because of this, manufactured casings are easier to work with than natural casings. They are also very uniform, which is important for portion control, and they are less expensive to buy and require less labour (i.e., they arrive at the plant as a roll that can be put directly onto the stuffing horn). Since they can be made by extruding the regenerated collagen, they can be made with

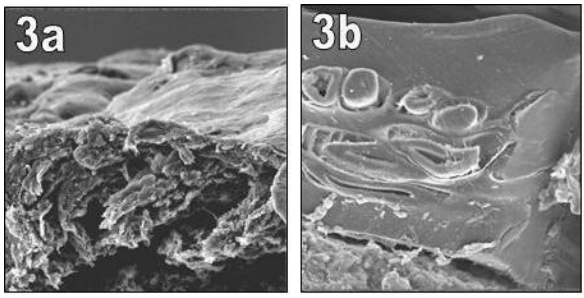
different thicknesses and degrees of cross linking. They are made at special plants and cross linking agents such as ammonia or gluteraldehyde can be used as well as special colouring agents. Their microbial counts are much lower than natural casings since they are manufactured from collagen that was extracted at high pH. Like natural casings they are permeable to water and smoke and can also adhere to the product and shrink with it.

c. Co-extruded casings are made from pretty much the same material as the manufactured casings described above and are often made by the same companies. The collagen gel is usually sold to the industry as a 3.5 – 5.5% protein dough. It is used by the meat processor with a special counter rotating head (see Chapter 10 for description of the equipment) that dispenses the gel on top of the product while it is coming out of the stuffer. Later on, the casing is dewatered to some extent in a salt bath, dried in an oven, and the collagen molecules are cross-linked with liquid smoke (i.e., using the aldehyde components; see discussion on liquid smoke in this chapter). This is usually followed by a full cook cycle inside or outside a cook-in-bag. Note that there is also a process where alginate is used for co-extrusion but the sensory characteristics are different compared to collagen casings. New hybrid gels of collagen and alginate have also started to appear on the market (Harper et al., 2013).

d. Manufactured cellulose casings are very popular for the manufacturing of high volume products such as hot dogs, bologna, and salami. They are made from cotton liners and can be produced at various sizes (e.g., 1.5 to 15 cm in diameter). The microstructure of such casings can be seen in Figure 13.7.3. The casings are very strong and lend themselves to highly automated equipment. Because they are so uniform and manufacturers control the degree of stretching, portion control is easy. They are non-edible and have to be peeled off prior to consumption. In the case of many small diameter products such as hot dogs they are peeled at the plant by an automated high speed peeler. In the case of products such as large diameter salami, they are sometimes left on the product and peeled off by the consumer. Where some shrinkage of the product is expected, the inside of the casing is coated with protein to improve adherence to the product. Cellulose casings are water and smoke permeable unless they are coated with plastic (see below – combination casings). The casing can be dyed with different colours and information can be printed on them. They also have low microbial counts due to the way they are made. In order to keep them that way, they should be kept in a dry environment; otherwise mold can grow on them.


1a
1b
1c
1d
1e
1f
1g
1h


2a
2b
2c
2d
2e
2f


3a
3b

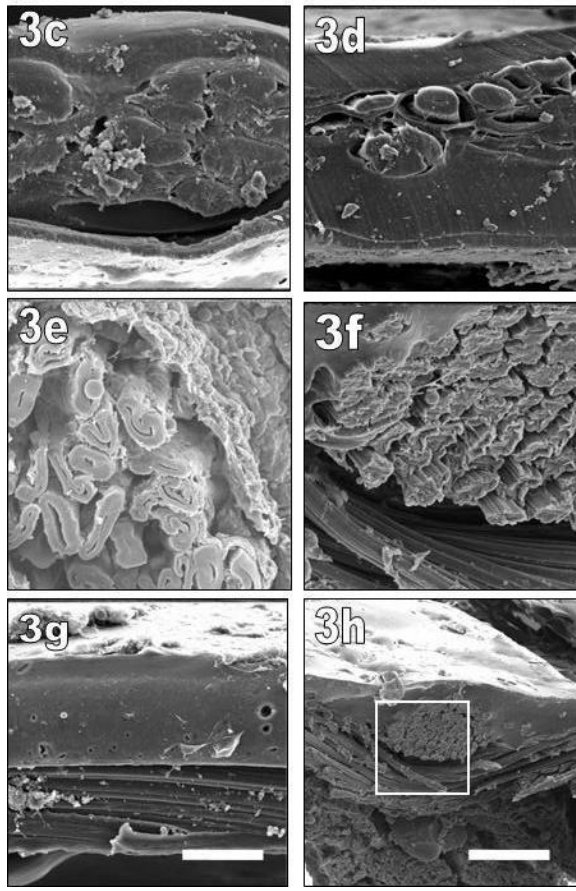


Figure 13.7.3 Light micrographs of cellulose and plastic casings. First frame shows: (1a) and (1b) thin cellulose type "Fast-peel"; (1c) and (1d) large diameter regular casings covering the actual meat batter; (1e) and (1f) outside polyvinylidene dichloride (PVDC) coated cellulose casings; (1g) and (1h) inside PVDC coated cellulose. Polarized light was used in (1b), (1d), (1f), and (1h) to reveal cellulose fibers. Bar = 200 μm. Second frame shows: (2a) and (2b) fibrous/cotton casing covering a meat batter; (2c) and (2d) outside coated fibrous/cotton; (2e) and (2f) extruded plastic casing. Polarized light was used in (2b), (2d) and (2f) to reveal cellulose fibers/special plastic. Bar = 200 μm. Third frame shows scanning electron micrographs of casings: (3a) thin cellulose type "Fast-peel"; (3b) large diameter cellulose sausage; (3c) outside PVDC coated cellulose; (3d) inside PVDCcoated cellulose; (3e) regular fibrous/cotton; (3f) outside coated fibrous/cotton; 3(g) extruded plastic; and (3h) lower magnification of micrograph "f" - see box. Bars = 25 μm for all, except (3h) which is 120 μm. From Barbut (2011). With permission.

e. Plastic polymer casings are very popular for water/steam cooked sausages because they are impermeable to water (this is advantageous as water is a more efficient medium to transfer heat than dry, hot air). A simple way to demonstrate this is by imagining putting your hand into an oven set at 100ºC compared to a boiling pot of water. Where smoking and drying of the sausage surface is not required, plastic casings represent a viable option. The microstructure of a plastic casing can be seen in Figure 13.7.3 and a product in this casing is shown in Figure 13.7.4. The micrograph shows the lamination of the layers and is basically a dense barrier. Extruded plastic casings are strong and uniform, and can therefore be used for very large diameter products. They also offer protection against oxidation since they are usually impermeable to oxygen. This also means that they are impermeable to smoke. Thus, if smoke flavourings are desired they should be added to the meat mix. There are also some new developments where liquid smoke can be applied to the inside of the casings prior to stuffing. Materials such as polyethylene, nylon and polypropylene are used as a single layer or as a combination of different layers in the manufacture of plastic polymer casings (Savić and Savić, 2002). These casings are extruded so usually there is no seam/weak point in the casing. The casings can be coloured and material printed on them can be used to describe the product (e.g., nutritional label). Casings can also be extruded with a UV-barrier so colour fading is not a problem (see Chapter 16).



Figure 13.7.4 Plastic casings used for a jelly meat loaf. Product made at the University of Guelph. Photo by Barbut.

f. Metal casings/molds are commonly used for canned meats (e.g., meat loaf processed at high temperature, 121ºC, in hermetically sealed cans) or for producing large sausages/hams/loaves at lower temperature (70 - 80ºC). The mold provides the product with a certain defined shape. This is important for large meat masses and it also helps in precise portion control when using high speed automated systems. In some cases, a cellulose or plastic casing is used to stuff the product before it is placed in a metal press to facilitate removal of the cooked product (no sticking and/or peeling surfaces) and cleaning of the molds. When plastic casings are used, prior to placing the meat in the mold, they are often left on the product after cooking and act as the packaging material that also provides a barrier against cross/re-contamination of the product. This technology can be seen in the preparation of oven roasted turkey breast, 4 × 4 hams, etc.

g. Retortable pouches are flexible pouches usually made from several layers of synthetic polymers, of which aluminum foil is one. They provide good moisture and oxygen barrier properties. It is interesting to note that although the pouch thickness appears small, it can contain a dozen different layers. The pouches can be used for meat products that are sterilized at high temperatures. Slices of meat loaf-type products and chicken soup/stew are commonly packaged in such a way and then retorted at a temperature of about 121ºC. The advantage of these thin pouches is that they can reach the desired cooking temperature much faster than a traditional round can. As with cans, the product is shelf stable after the heat treatment and no refrigeration is needed.

h. Combination casings are manufactured casings made from two or more materials such as collagen reinforced with a cotton mesh, or cotton fibers coated with plastic. Figure 13.7.3 shows an example of this where two components (cellulose and plastic) are included. By combining two or more layers, the processor can take advantage of both materials (e.g., strength of the plastic mesh with the smoke permeability of cellulose, or peeling ease of cellulose casings with the strength of large cotton fibers).

13.8 Formulations

In this section you will find various recipes of further processed meat products popular around the world. The recipes are courtesy of Hermann Laue Spice Company, Canada. These formulations are used by the industry but here they only serve as general guidelines and should be used as such. Also, local government regulations vary among countries (e.g., use of additives such as nitrite, phosphate) and therefore careful examination of local legislation is required. The section

contains formulations related to whole muscle products, restructured products, boneless, bone in, ground and emulsified products.

13.8.1 Smoked Chicken Roast – Naturally Cured

Ingredients

Meat:

- 72.0 kg boneless skinless chicken breast
- 8.0 kg white chicken trim

Brine:

- 20.0 kg

The brine is made by mixing:

- 12.0 kg cold water
- 3.4 kg ice flakes
- 1.7 kg sea salt
- 1.2 kg vinegar (serves as a bacteriostat)
- 1.0 kg evaporated cane sugar
- 0.6 kg fermented celery extract
- 0.058 kg onion powder
- 0.040 kg ground white pepper
- 0.002 kg rosemary extract

Processing

- Grind the chicken breast through a 25 mm plate.
- Grind the white chicken trim through a 5 mm plate.
- Mix the brine and add to the ground chicken meat inside a vacuum tumbler.
- Vacuum tumble for 1.5-2.0 hr at 10-12 rpm.
- Rest overnight.
- Firmly stuff the product into a 105 mm caliber, cellulose casings.
- Process in a preheated smokehouse.
- Heat at 55ºC and 30% RH for 30 min.
- Dry at 65ºC for 20 min.

- Hot smoke at 65ºC for 45 min or to the desired colour
- Steam cook at 85ºC to an internal temperature of 74ºC (Fig. 13.8.1.1).
- Chill down rapidly and store under refrigeration prior to shipping.



Figure 13.8.1.1 Oven roasted chicken. Photo by Barbut and Jinde.

13.8.2 Traditional Chicken/Turkey Roast (30% pump; optional 50% pump)

Ingredients

Meat:

- 100.0 kg boneless skinless chicken/turkey breast

Brine:

- 30.0 kg

The brine is made by mixing:

- 22.0 kg cold water
- 3.6 kg ice flakes
- 4.0 kg brine and cure unit (salt, sugar, phosphate, erythorbate, nitrite)

- 0.4 kg roast seasonings (natural roast flavour, spices)
- Spice rub: 6 g roast flavoured rub mixed with 18 ml of water, per 1 kg of tumbled roast.

Processing

- Inject the turkey breast meat with 30% brine.
- Vacuum tumble for 4 hr at 12-15 rpm; start immediately after injecting. Rest overnight and tumble for 1½ hr at 12-15 rpm.
- Combine 2 turkey breasts together (thick end over thin end) and wrap with a collagen film before stuffing it into a net #22-3 (i.e., a net with 22 squares around the circumference made up of 3 stitches between squares). Clip both ends of the net.
- Mix 5 parts of roast flavoured rub together with 3 parts of water until a thick paste has been formed and rub the roasts evenly.
- Place roasts on smoke screens, place in an oven and cook.
- Dry at 90°C for 1 hr or until the surface is completely dry.
- Steam cook at 78°C to an internal temperature of 71°C (Fig. 13.8.2.1).
- Shower with cold water to cool down quickly.
- Note: a 50% pump roast can also be made by adding 50 kg brine to 100 kg of boneless skinless turkey/chicken breast meat. The brine consists of 35 kg cold water, 9 kg of ice flakes, 5 kg of turkey/chicken roast brine unit (salt, sugar, phosphate) and 1.3 kg spice unit (soy protein isolate, sugar, spice extracts).



Figure 13.8.2.1 Oven roasted chicken prepared in netting.
Photo by Barbut and Jinde.

13.8.3 Smoked Turkey Roast

Ingredients

Similar to previously described Traditional Chicken/Turkey Roast.

Processing

Similar to injection and stuffing of Traditional Chicken/Turkey Roast.

- Dry at 65°C for 45-60 min.
- Hot smoke at 65°C for 1.5 hr or to the desired colour.
- Steam-cook at 78°C to an internal temperature of 71°C (Fig. 13.8.3.1).
- Shower with cold water to cool down quickly.



Figure 13.8.3.1 Oven roasted turkey. Photo by Barbut and Jinde.

13.8.4 Turkey Roast Slicing Log – Salt Free

Ingredients

Meat:

- 100.0 kg skinless turkey breast

Brine:

- 15.0 kg

The brine is made by mixing:

- 7.2 kg cold water
- 2.8 kg potassium lactate/diacetate
- 4.28 kg salt free turkey roast pumping unit
- 0.72 kg transglutaminase powder

Processing

- Grind the turkey breast meat through a kidney plate.
- Mix the transglutaminase with cold water.
- Mix the ground turkey meat with the dry ingredients for 8 min.
- Add the transglutaminase slurry and mix for 8 min.
- Add the potassium lactate/diacetate and mix for 4 min.
- Firmly stuff into moisture proof casings of desired caliber.
- Store under refrigeration for at least 2-3 hr prior to cooking (time for enzyme to work).
- Steam cook at 80ºC to an internal temperature of 72ºC.
- Cool down quickly with a cold water shower.

13.8.5 Smoked Chicken Ham – Naturally Cured

Ingredients

Meat:

- 72.0 kg chicken thigh meat (defatted)
- 8.0 kg chicken drum meat

Brine:

- 20.0 kg

The brine is made by mixing:

- 12.0 kg cold water
- 3.3 kg ice flakes
- 1.8 kg sea salt

- 1.25 kg vinegar (serves as a bacteriostat)
- 0.90 kg evaporated cane sugar
- 0.600 kg fermented celery extract
- 0.058 kg onion powder
- 0.050 kg sweet cherry powder
- 0.040 kg garlic powder
- 0.002 kg rosemary extract

Processing

- Grind the chicken thigh meat through a 25 mm plate.
- Grind the drum meat chicken trim through a 3 mm plate.
- Mix the brine and add to the ground chicken meat in a vacuum tumbler.
- Vacuum tumble for 2.5 hr at 10-12 rpm.
- Rest overnight and vacuum tumble for 20 min.
- Firmly stuff the product into a 105 mm caliber, cellulose casings.
- Process in a preheated smokehouse.
- Heat at 55ºC and 30% RH for 30 min.
- Dry at 65ºC for 20 min.
- Hot smoke at 65ºC for 45 min or to the desired colour
- Steam cook at 85ºC to an internal temperature of 74ºC.
- Chill down rapidly and store under refrigeration prior to shipping.

13.8.6 Turkey Ham (4 × 6)

Ingredients

Meat:

- 100 kg boneless lean turkey thigh meat

Brine:

- 40 kg

The brine is made by mixing:

- 28 kg cold water
- 6.5 kg ice
- 5.5 kg brine and cure unit
- (salt, soy/whey proteins, phosphate, spices, erythorbate, nitrite)

Processing

- Lacerate the turkey thigh meat (especially from the skin side) to increase the surface area.
- Tumble the meat with the brine in a well-chilled vacuum tumbler for 6 hr at 12-15 rpm.
- Rest overnight and tumble for 1.5 hr the next day.
- Stuff the meat into cook-in-bags (also referred to as "cook & ship bags").
- Place hams into 4 × 6 inches ham molds and press firmly.
- Cook in a smoke house by using steam at a temperature of 78°C, until reaching an internal temperature of 71°C (Fig. 13.8.6.1).
- Shower with cold water to chill quickly prior to transferring to a refrigerator.



Figure 13.8.6.1 Turkey ham. Photo by Barbut and Jinde.

13.8.7 Turkey Pastrami

Ingredients

Meat:

- 100 kg skinless turkey breast

Brine:

- 50 kg

The brine is made by mixing:

- 14.0 kg cold water
- 12.3 kg ice flakes
- 8.7 kg sodium lactate/diacetate
- 1.85 kg brown sugar
- 0.35 kg pastrami liquid seasoning
- 13.5 kg brine and cure unit
- (salt, soy/whey proteins, phosphate, spices, erythorbate, nitrite)
- Rub per 1.0 kg of tumbled turkey breast: 10g fine/coarse pastrami rub.

Processing

- Completely dissolve all of the dry ingredients in the cold water.
- Add ice and the sodium lactate/diacetate and mix until all of the ice has melted.
- Pump the turkey breast 50% and immediately start the tumbling process.
- Vacuum tumble for 3-4 hrs at 10-12 rpm.
- Rest under refrigeration overnight and tumble again for 30 min under vacuum.
- Add the spices and rub ingredients into the tumbler and tumble at slow speed until an even coating is created.
- Place the turkey breast onto smoke screens and process in the smokehouse:
- Dry at 75°C for 1 hr or until the surface feels dry.
- Hot smoke at 65°C for 30 min.
- Steam cook at 78°C to an internal temperature of 71°C.
- Shower for 5 min, then quick chill with air.
- Store under refrigeration overnight prior to shipping.

13.8.8 Regular Smoked Turkey Sausage

Ingredients

Emulsion part (60 kg):

- 42.0 kg turkey thigh meat (first ground 3 mm)
- 8.0 kg turkey skin (frozen, first ground 3 mm)
- 10.0 kg ice

Coarse insert (40 kg):

- 34.0 kg turkey thighs (ground 5 mm)
- 6.0 kg cold water

Spice and ingredients:

- 3.0 kg seasoned binder (salt, potato starch, dextrose, spices, erythorbate)
- 1.0 kg brown sugar
- 0.3 kg curing salt
- 0.3 kg phosphate
- 0.2 kg garlic powder
- 0.1 kg black pepper (fine grind)

Processing

- Mix the coarse ground meat, one day prior to processing, together with water and 40% of the spice and ingredient mix, until a good bind develops. Store the meat under refrigeration overnight.
- Chop the ground meat and skin, intended for the emulsion part, while adding the rest of the spice and ingredient mix. Chop for a few revolutions at the slow speed before adding about half of the ice. Continue cutting at high speed to a temperature of 12°C, add the rest of the ice and proceed cutting to a final temperature of 8°C.
- Add the pre-seasoned coarse insert and mix well before cutting at slow speed to the desired size.
- Stuff the meat into collagen casings (caliber 29/32) or any other smoked sausage casing.
- Dry in a smoke house at 55°C for 15 min.
- Hot smoke at 60°C, 25-30% relative humidity for 30 min or desired colour is reached.

- Steam cook at 78°C to an internal temperature of 71°C.
- Shower with cold water for fast cooling.

13.8.9 Smoked Maple Flavour Turkey Sausage

Ingredients

Emulsion part (60 kg):

- 50.0 kg skin on turkey thigh meat (first ground 3 mm)
- 10.0 kg ice

Coarse insert (40 kg):

- 25.0 kg turkey drum meat (ground 5 mm)
- 5.0 kg turkey skin and fat
- 10.0 kg cold water

Spice and ingredients:

- 3.0 kg seasoned binder
- 1.0 kg maple flavour
- 1.5 kg brown sugar
- 1.0 kg specialty starch
- 0.3 kg curing salts (erythorbate, nitrite)
- 0.3 kg phosphate
- 0.1 kg black pepper (32 mesh)

Processing

- Follow procedure of previous product (Turkey Sausage) up to the stuffing stage.
- Stuff into collagen casings, caliber 32/35 and link to 110g.
- Warm up in a smokehouse set at 55ºC and 40% RH for 20 min.
- Dry at 65ºC for 20 min.
- Hot smoke at 65ºC for 40 min or to the desired colour.
- Steam cook at 80ºC to a core temperature of 71ºC.
- Cool down with shower and store under refrigeration overnight prior to packaging.

13.8.10 Tikka Masala Fresh Chicken Sausage

Ingredients

Meat:

- 30.0 kg chicken breast (ground 8 mm)
- 55.0 kg chicken thigh (ground 8 mm)
- 15.0 kg cold water

Spices and ingredients:

- 16.0 kg salt
- 5.0 kg Tikka Masala seasoning unit
- 1.0 kg potato starch
- 0.2 kg phosphate

Processing

- Mix the ground chicken meat with all the ingredients until a good bind has developed.
- Add the water in 2-3 steps while mixing.
- Stuff the meat batter into collagen casings of desired caliber, link to the desired weight and pack. Product to be kept refrigerated or frozen prior to shipping.

13.8.11 Turkey Kielbasa

Ingredients

Coarse meat insert (70 kg):

- 59.0 kg lean turkey thighs (ground 25 mm)
- 11.0 kg cold water

Fine meat part (30 kg):

- 25.0 kg turkey thighs (ground 3 mm)
- 5.0 kg cold water

Spice ingredients:

- 1.9 kg salt
- 0.9 kg kielbasa seasoning
- 0.8 kg brown sugar
- 0.6 kg curing salt (includes erythorbate and nitrite)
- 0.3 kg phosphate

Processing

- One day prior to processing, put the coarse meat in a vacuum-tumbler for 1.5 hr together with water and 70% of the dry ingredients.
- Cover and store the tumbled coarse insert under refrigeration overnight.
- Immediately before processing, tumble/mix again for 10 min.
- Mix the fine ground turkey thigh meat together with the rest of the dry ingredients and water, until a good bind has developed.
- Add the tumbled coarse material to the fine ground meat and mix together to an even distribution and a good bind.
- Stuff the batter into collagen ring casings cal. 52 mm.
- Process the product in a smokehouse:
- Warm at 50ºC and 40% humidity for 30 min.
- Dry at 60ºC for 15 min.
- Hot smoke at 60ºC for 45 min or to the desired colour.
- Steam-cook at 78ºC to a core temperature of 71ºC (Fig. 13.8.11.1).
- Product to be cooled down with shower.
- Store under refrigeration overnight prior to shipping.



Figure 13.8.11.1 Turkey kielbasa. Photo by Barbut and Jinde.

13.8.12 European Style Chicken Wieners

Ingredients

Meat:

- 40.0 kg chicken thigh meat
- 26.0 kg chicken drum meat
- 7.0 kg fine textured chicken meat (frozen)
- 5.0 kg chicken skin and fat

Ice:

- 28.0 kg

Spices and additives:

- 1.7 kg salt
- 1.4 kg dextrose
- 1.0 kg modified starch
- 0.8 kg Wiener seasoning
- 0.6 kg curing salt (with erythorbate and nitrite)
- 0.2 kg phosphate
- 0.1 kg paprika
- 0.1 kg onion powder

Processing

- Grind all meats and skin through a 3 mm plate.
- Use a bowl cutter to cut the meat for a few revolutions at slow speed before adding all of the spices and ingredients plus 1/3 of the ice.
- Cut at high speed to 8 - 10ºC.
- Add the remaining ice in 2 steps while cutting at high speed to 6ºC.
- Cut at slow speed to 8ºC.
- Stuff into sheep casings and link to the desired size.
- Smoke and cook:
- Pre heat in a smokehouse at 55ºC and 40% RH for 20 min.
- Dry at 65ºC for 15 min.
- Hot smoke at 65ºC for 30 min.
- Steam-cook at 78ºC to a core temperature of 71ºC (Fig. 13.8.12.1).
- Cool down with a cold water shower.
- Store under refrigeration overnight prior to packaging.



Figure 13.8.12.1 Chicken wieners. Photo by Barbut and Jinde.

13.8.13 Chicken/Turkey Hot Dogs/Bologna

Ingredients

Meat:

- 86.0 kg mechanically deboned chicken/turkey meat

Ice:

- 14.0 kg

Spices and additives:

- Binder unit – 8.70 kg (salt, soy/whey proteins, spices, erythorbate)
- Curing salt – 0.3 kg (includes nitrite)
- Phosphate – 0.3 kg

Processing

- Slowly cut the slightly frozen meat with about 5 kg of flaked ice in a bowl chopper for a few revolutions.
- Add the binder unit, salt and phosphate and chop at the high speed setting while adding the rest of the ice until temperature reaches 8-10°C.

- Remove the emulsion from the chopper.
- Stuff into easy-peel hot dog casings and link to desired size.
- Place the product on a smoke house tree.

Smoke and cook:

- Dry the surfaces in a smoke house at 55ºC for 5 min or as required.
- Hot smoke at 55°C and 25% RH for 20-30 min.
- Steam cook at 75°C to an internal temperature of 71°C (Fig. 13.8.13.1).
- Shower with cold water for 10 min.
- Refrigerate overnight prior to peeling the casings.
- Note: for bologna – use the same formulation and procedure, and then stuff into large diameter cellulose or fibrous casings. Heat process should be lengthened to achieve a 71°C internal temperature.



Figure 13.8.13.1 Chicken bologna. Photo by Barbut and Jinde.

13.8.14 Turkey Pepperoni Sticks

Ingredients

Meat:

- 60.0 kg turkey thigh meat
- 22.0 kg turkey drum meat

Water:

- 18.0 kg cold water

Spices and additives:

- 1.7 kg salt
- 1.5 kg mild pepperoni seasoning
- 1.5 kg potato starch
- 1.2 kg liquid vinegar
- 1.0 kg corn syrup solids
- 0.6 kg curing salt (including erythorbate and nitrite)
- 0.3 kg phosphate

Processing

- Grind the turkey thigh meat through the 5 mm plate.
- Grind the turkey drum meat through the 3 mm plate.
- Mix for 2 – 3 min all the meat and dry ingredients before adding 6 kg of the cold water.
- Add the remaining water in 2 steps while mixing to a good bind.
- Stuff into collagen casings (19 – 21 mm caliber) and link to 60 – 65 g.
- Smoke and cook:
- Use a smoke house to dry the surfaces at 65ºC for 20 min.
- Hot smoke at 65ºC for 20 min or to the desired colour.
- Cook at 70ºC and 60% RH for 20 min.
- Cook at 78ºC and 60% RH to a core temperature of 71ºC (Fig. 13.8.14.1).
- Cool down with shower and store under refrigeration overnight prior to packaging.



Figure 13.8.14.1 Turkey pepperoni sticks. Photo by Barbut and Jinde.

13.8.15 Hot Habanero Turkey Sticks

Ingredients

Meat:

- 40.0 kg turkey drum meat, ground 3 mm
- 10.0 kg turkey fat, frozen, ground 5 mm
- 50.0 kg turkey thigh, ground 5 mm

Spices and cure:

- 5.55 kg seasoning and cure mix (salt, dextrose, paprika, spices, erythorbate, nitrite)

Processing

- Mix all of the ground meat and fat together with the spices and cure until a good bind has developed.
- Stuff the batter into natural casings or collagen casings (calibre 15-20 mm).
- Process the product in a smokehouse:
- Dry heat at 55°C for 2 hr.
- Dry heat at 60°C for 1 hr.
- Dry heat at 65°C for 1 hr.
- Dry heat at 72°C for 1 hr or until the desired dryness is reached.
- If desired, hot smoke can be applied during the second drying cycle.
- Product to be air cooled only.

13.8.16 Honey Garlic Marinated Chicken Wings

Ingredients

Meat:

- 90.0 kg chicken wings

Water:

- 10.0 kg (cold)

Spice:

- 5.5 kg honey garlic marinade (sugar, salt, garlic, natural honey flavour, vinegar, spices)

Processing

- Dissolve the spice unit in the cold water.
- Vacuum tumble the well-chilled chicken wings together with the liquid marinade; use slow speed for 30-45 min.
- Remove the marinated chicken wings from the tumbler and pack in vacuum bags or immediately freeze (IQF).
- Keep product refrigerated or frozen prior to shipping.
- Cook at home/restaurant to 72 C internal (Fig. 13.8.16.1).



Figure 13.8.16.1 Chicken wings. Photo by Barbut and Jinde.

13.8.17 Mesquite Chicken Wings

Ingredients

Meat:

- 95.0 kg chicken split wings

Water:

- 5.0 kg (cold)

Spice:

- 5.0 kg Mesquite marinade

Processing

- Put the fresh chicken wings into a vacuum tumbler.
- Mix the BBQ marinade together with the cold water and add to tumbler.
- Vacuum tumble for 15-20 min.
- Remove the seasoned chicken wings from the tumbler, tray pack and overwrap.

13.8.18 Ginger Lemon Chicken Drum Sticks

Ingredients

Meat:

- 85.0 kg chicken drum sticks

Water:

- 15.0 kg (cold)

Spice:

- 6.5 kg ginger lemon marinade
- (salt, sugar, lemon juice, spices)

Processing

- Mix the spices together with the cold water.
- Vacuum tumble the well-chilled chicken drum sticks together with the liquid marinade; use slow speed for 30-45 min.
- Remove the marinated chicken drum sticks from the tumbler and pack in plastic bags or immediately freeze.

- Note: other variations, such as Hot Buffalo Chicken Wings can also be made the same way, but with a different spice mix.
- Keep product refrigerated or frozen prior to shipping.

13.8.19 Caribbean Jerk Chicken Drum Sticks

Ingredients

Meat:

- 95.0 kg chicken drum sticks

Water:

- 5.0 kg (cold)

Spice:

- 1.2 kg salt, fine
- 1.5 kg Caribbean Jerk seasoning
- 0.2 kg phosphate

Processing

- Place the well chilled fresh chicken drum sticks into a vacuum tumbler.
- Dissolve the dry ingredients in the cold water and vacuum tumble for 15 – 20 min.
- Remove the seasoned chicken drum sticks from the tumbler, tray pack and overwrap.

13.8.20 Fajita – Chicken/turkey/duck/goose

Ingredients

Meat:

- 82.0 kg chicken/turkey/duck/goose breast filets or breast strips
- 14.8 kg cold water

Spice:

- 3.2 kg chicken Fajita seasoning (salt, dextrose, soy sauce powder, phosphate, garlic powder, spices)

Processing

- Completely dissolve the Fajita seasoning in the cold water.
- Vacuum tumble the chicken meat and seasoning solution for 40-50 min at 8-10 rpm.
- The marinated chicken strips can then be individually quick frozen (IQF) and packed or put onto a skewer and frozen.
- Prior to serving, pan fry together with red, yellow and green bell pepper strips and fresh or frozen diced onions.
- Serve on pita bread or in taco shells; a sauce can be added if desired.

13.8.21 Jellied Chicken/Turkey/Duck Roll

Ingredients

Meat:

- 45 kg white turkey/chicken roast (see second recipe)

Vegetables:

- 15 kg canned mushrooms and/or broccoli heads

Gelatin:

- 40 kg gelatin solution (7 kg seasoned gelatin powder plus water)

Processing

- Dice the chicken/turkey roast into approximately 1 × 1 × 1 cm cubes.
- Rinse the mushrooms (and/or broccoli) with hot water and mix with the diced meat.
- Completely dissolve the dry gelatin powder in hot water (> 80°C). You can add a little bit of oil to the hot water to avoid foaming.
- Fill clear plastic casings (e.g., 12 cm diameter) with the diced meat and vegetable mix.

- Add the proper amount of gelatin solution into the casings and remove all air bubbles prior to clipping.
- Cool down in a cold water bath (see Fig 13.7.4).

13.8.22 Chicken/Turkey/Duck Chili Con Carne

Ingredients

Meat:

- 31.25 kg chicken/turkey/duck thigh meat

Vegetables:

- 25.00 kg red kidney beans (canned)
- 28.15 kg ground tomatoes (canned)
- 7.80 kg diced onions (frozen)
- 7.80 kg hot water

Spice:

- 2.62 kg chili seasoning mix
- (sugar, salt, paprika, garlic powder, spice)

Processing

- Grind chicken/turkey thigh meat through a 3 mm plate.
- Mix ground meat together with the chili seasoning mix and hot water. Cook in a steam kettle over medium/high heat until meat is well done.
- Add all of the canned and frozen vegetables, bring to a boil and simmer over medium heat for 10-15 min.
- Cool down completely prior to packing.

13.8.23 Chicken Nuggets

See Chapter 14

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14

BATTERING AND BREADING – PRODUCTION UNDER HACCP

14.1 Introduction

Battered and breaded products have become very popular on the market and include quite a large variety of boneless and bone-in products (Fig. 14.1.1, Table 14.1.1). The development of commercial breading lines dates back to 1937 when a breading mixture was applied to fish fillets in St. Louis, Missouri. The history of breading machines followed this marketing development when Dr. S. Hart of Syracuse University designed the first successful machine for this purpose. At first, labour-intensive breading lines depended on many people battering and breading the product. Besides cost, manual production presented quite a few challenges in terms of consistency and sanitation. The initial equipment developed basically duplicated the hand operation, and for each coating step, a separate machine was used (Suderman and Cunningham, 1983). Today, modern fully automated lines can produce thousands of identical nuggets per hour without any human contact (Fig. 14.1.2). An illustration of a basic coating line with repeated batter and flouring/breading application is shown in Figure 14.1.3.



Figure 14.1.1 Examples of battered and breaded products on the market. Photo by S. Barbut.

Overall, the consumption of battered and breaded meat products sold at retail and food service operations has increased tremendously during the past 40 years. In 1996, it was estimated that 1.2 billion pounds of food products were breaded in the US, most of which was poultry, followed by seafood and vegetables (e.g., onion rings). Over the next decade, consumption has further increased in the USA and other parts of the world. One of the greatest success stories is that of the chicken nugget which was introduced to the North American market by the fast food chains in the 1970's. Originally, the product was made from a whole breast muscle strip which was pre-dusted battered, breaded, and then fried. Today, nuggets are made from different meats (poultry, pork, fish), and cuts such as whole muscle, ground meat, chunks of white and dark meat, as well as ground meat with and without the inclusion of mechanically deboned meat and skin (Barbut, 2012). The traditional oval shape of the nugget has also been modified in some markets (e.g., animal-shaped nuggets are currently used to attract young children). The breading and spices used can also greatly vary, depending on the market (e.g., today more whole grain breading is seen on the market).

Table 14.1.1 Examples of battered and breaded meat products.

Whole muscle –	chicken* breast fillet – skin off chicken breast fillet – skin on chicken nuggets chicken drumsticks
Bone in product –	chicken wings chicken drums
Ground/chucked meat –	chicken nuggets (white/dark meat) chicken patties
Filled products –	Cordon Blue Chicken Kiev
* the term chicken can be replaced by other poultry meat such as turkey and duck and/or meat from other species such as fish, beef, pork	

Battered and breaded products are coated products in which the meat protein component (e.g., chicken breast fillet, whole chicken leg, ground meat) is the core, surrounded by a cereal base coating (e.g., wheat flour). The coating process can

range from a simple homemade operation to a complex production line requiring equipment worth millions of dollars. A simple homemade process that seems to have originated in Europe consists of dipping slices of meat in dry flour (pre-dust), followed by a quick dip in an egg batter, and then using homemade dry bread crumbs to cover both sides while pressing the crumbs into the meat. This is followed by frying in a pan filled with hot oil. This popular 'old time' example is the European "schnitzel" which has been commonly made out of pork meat, but today poultry and to a lesser extent beef are also used. The product can be served immediately after production, and has a very enticing fried smell and a crispy texture. Today, commercial chicken nuggets, pork schnitzel products, and breaded fish sticks go through essentially the same process. However, in a high speed batter and breading line, extreme care to details, cost, sanitation and quality control are taken at every step (see also Trouble Shooting at the end of the chapter). Paying attention to details is imperative, because a high volume commercial product must be made efficiently and consistently, as well as be able to maintain a full breading coverage during the various transfers between machines, within the plant. The product should also be able to withstand transportation stresses such as vibration which can result in breaking off poorly adhered coating. Other challenges that will be discussed below include coating uneven products (e.g., chicken wings) using an automated process.



Figure 14.1.2 Illustration of battered and breaded products processed on a high volume automated line. Courtesy of Townsend.

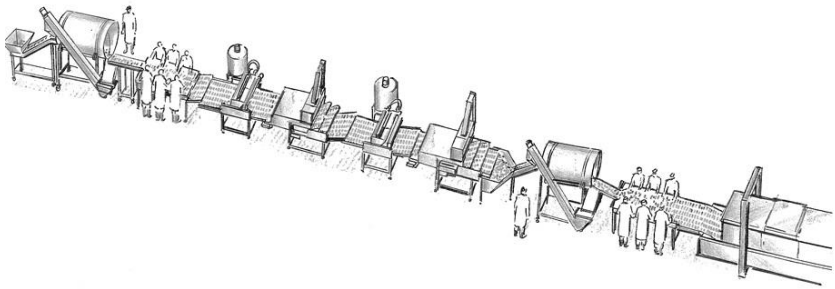


Figure 14.1.3 A view of a coating line used for a whole muscle or a bone in product (i.e. irregular shape product such as a drumstick). The line starts with a pre-dusting drum on the left followed by a group of people ensuring that the products are positioned correctly on the belt, and later a batter applicator with an overflow pattern. This is followed by a second breading/flour applicator that uses a triple flip, a second batter applicator, and a dry breading/flour applicator. Next is another rotating drum to achieve complete coating of the dry ingredients on an irregular-shaped product. A second group of people is then ensuring that the products are positioned correctly after leaving the drum. The last structure on the right is a deep fryer.

14.2 Processing Steps – Overview

A flow chart showing the different steps used in a commercial operation is shown in Figure 14.2.1. The Figure is part of a HACCP generic model which is going to be discussed later in the chapter. The steps illustrated are the ones most commonly used; however, some may be omitted (e.g., pre-dusting) while others may be repeated a few times (e.g., a double or triple pass through the batter/breading operation) to increase pick-up. Frying is used to achieve a full-fried product at the end of the line, or may be done for a very short time, called par-frying (e.g., 30 sec at 190°C), to "cement" the breading to the surface, and develop an attractive golden colour and crispy bite. In most cases, the product is then quickly frozen prior to shipping to the store.

The battering and breading process is used to coat various meat and non-meat products. Examples of some popular poultry products are listed in Table 14.1.1.

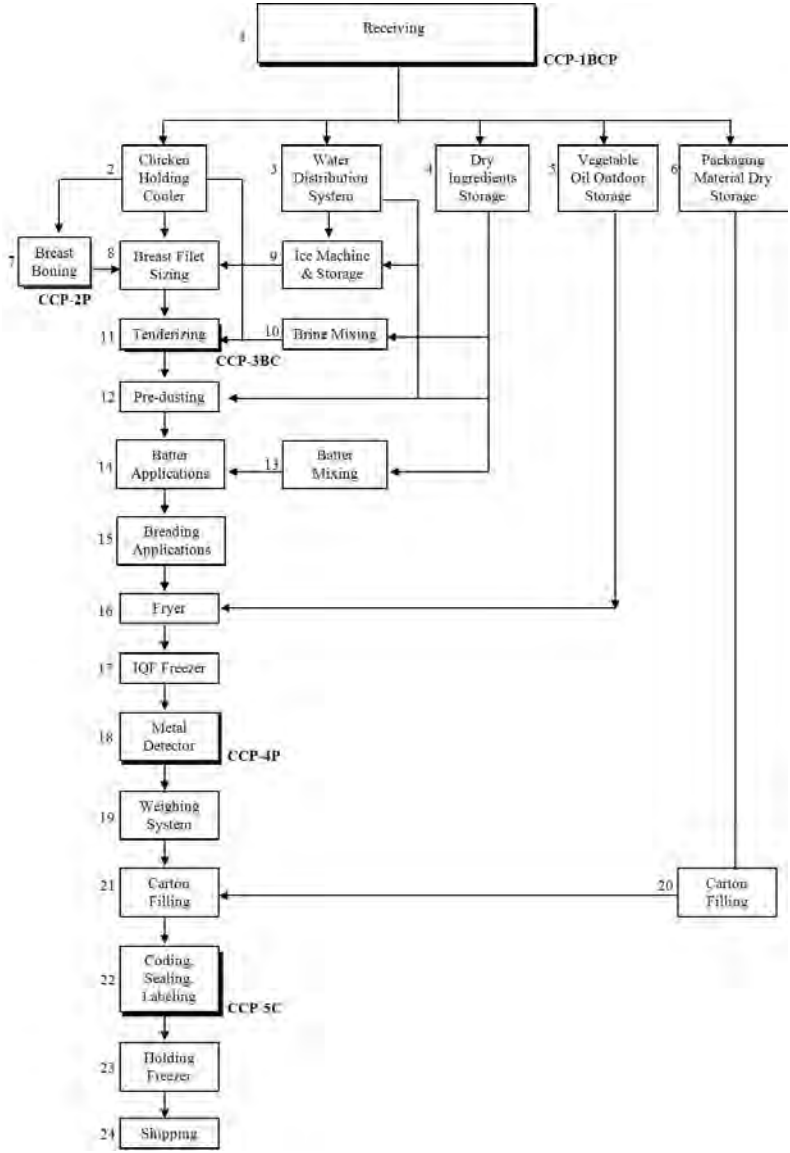


Figure 14.2.1 Process flow diagram from a HACCP generic model, for the production of a whole muscle product with suggested critical control points (CCP); to be discussed later in the chapter. Originally drawn for chicken breast fillet but similar steps can be used for other meats as well as for formed nuggets. From CFIA (2008).

During the process, dry and/or wet ingredients are applied to the moist surface of a regular or marinated (moisture enhanced) meat product. Proper adhesion is a challenge for the processor, as it depends on the roughness (skin on, skin off), temperature (partially frozen, thawed), amount of moisture on the surface (semi-dry or wet after forming), fat/grease on the surface, etc. Typical steps involved in chicken nugget production would be:

a. forming whole muscle/chunked meat ~ 25g. See illustration below
b. coating with pre-dust – ≈ 5% pick up. See equipment below
c. coating with batter – 5-10% pick up. See equipment below
d. coating with breading – 20-30% pick up. See equipment below
e. frying at 185 - 195 °C oil for about 30 - 60 sec (par-fry) or, continue to fully cook in oil/hot air oven.
f. freezing to maintain structure and freshness.

Overall, there are many factors that can affect the coating operation, ranging from meat surface properties (e.g., skin on, skin off, partially frozen surface) to batter viscosity and its temperature, breading size, and frying temperature.

An example of an operation to coat an irregular shape chicken thigh can include a repeated coating process and include the following steps:

a. whole chicken thigh portion (130-170g)
b. drum coating with pre-dust*
c. batter application – triple flip**
d. breading or flour application
e. drum tumbling to coat all areas and further open the structure**
f. second batter application
g. second breading/flour application

* for irregular shape, needs a drum applicator because of the uneven surface.
** each flip/turn helps to slightly open the surface structure and allows more pickup.

An illustration of a product with the different coating layers is shown in Figure 14.2.2.

The terms ‘pick-up’ and ‘yield’ are commonly used when producing battered and breaded products. “Pick-up,” under US regulations, refers to the amount of coating material adhering to (or ‘picked up’ by) the product and is based on the final weight.

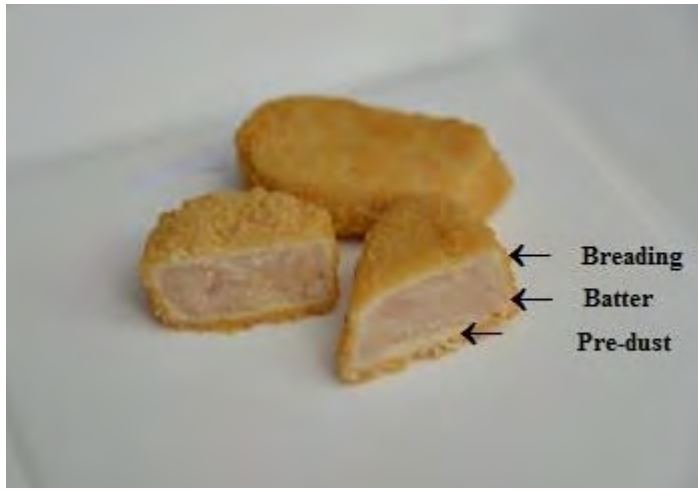


Figure 14.2.2 Illustration of the different layers of a coated meat product, and an actual view of a cross section of a par fried chicken nuggets where the meat core is seen coated with batter and breading. Photo by S. Barbut.

For example, a meat patty weighing 70g which is battered and breaded to 91g has a pick-up of (91-70)/70 * 100 = 30%. In the US, there is a restriction indicating that a product with > 30% pick-up must be labeled as fritter. Therefore, many of the products in the US do not exceed a 30% pick-up. It is important to note that different countries have different definitions for pick-up which are not necessarily based on the initial raw meat weight. Therefore, local regulations should always be checked. The term "yield" is commonly used (including in the US) for cooking and is expressed as a gain/loss of weight based on the initial weight.

Overall production starts with either forming (e.g., nuggets) to the desired weight and shape, or getting whole muscle pieces (boneless/bone-in chicken thigh meat) to the desired weight range and shape. This is followed by pre-dusting, battering, breading and frying as described below.

14.3 Forming

If the breaded product is not a whole muscle product, the product must be formed into the desired shape (e.g., oval, rectangular, star). The meat batter usually includes small muscle chunks, ground meat, or finely comminuted meat. It can

be formed by hand or by a machine into a nugget or patty. The two types of machines on the market today are the so-called high and low pressure formers. High pressure formers have been on the market for the past half a century, and basically consist of a pump to fill cavities within a mold. The meat is later punched out by a plate mimicking the shape of the mold (Fig. 14.3.1). Within the past ten years, low pressure formers have been introduced and they only utilize air pressure to push the product out of the mold (Fig. 14.3.2). This is possible due to the development of porous metal that allows air movement from the back of the mold. This method has some advantages as it allows producing detailed 3D shapes, eliminating the need for a water spray (used as "lubricant" for the plates in high pressure equipment), eliminating the need to use high pressure that can affect water holding, as well as reducing noise at the plant. This concept of operation is becoming more main stream; e.g., some fast food chains have already adopted it as their main production method.

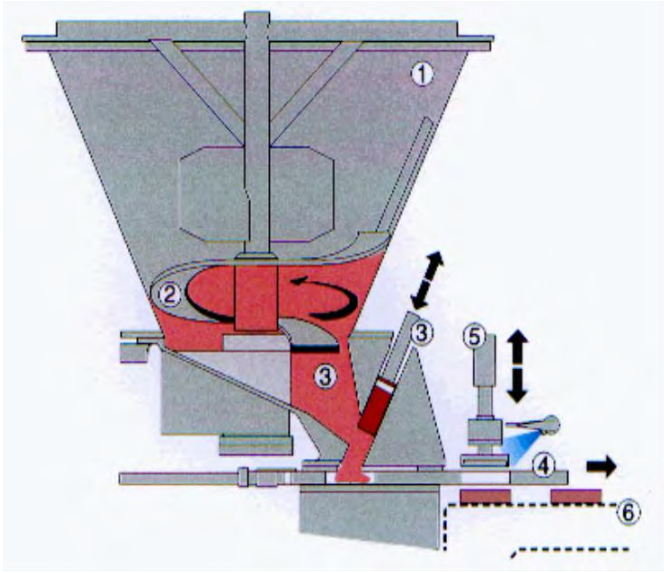


Figure 14.3.1 High pressure forming machine equipment used to produce nuggets and patties. 1. The hopper; 2. Coil-shaped screw; 3. The pressing block; 4. The form plate; 5. The ejectors; 6. The discharge conveyor. Courtesy of Marel.

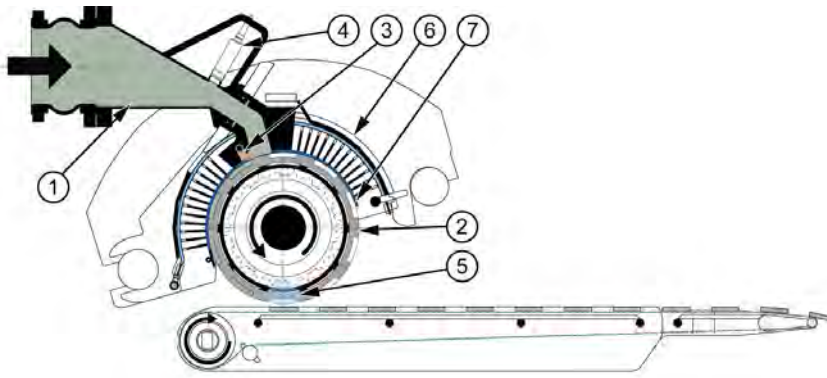


Figure 14.3.2 Low pressure forming machine used to produce nuggets, patties as well as 3D forms. 1. Manifold; 2. Drum; 3. Knife; 4. Pressure Sensor; 5. Release Position; 6. Shoe Frame; 7. Shoe Plate. Courtesy of Marel.

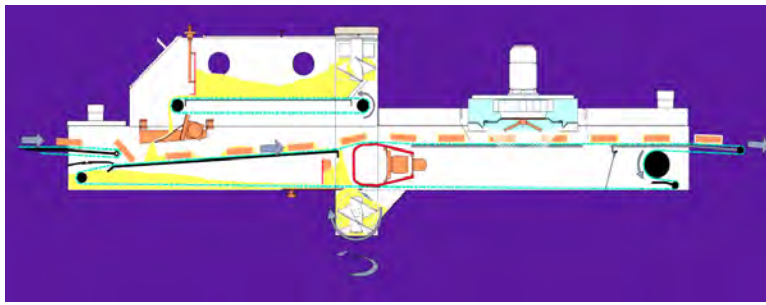
14.4 Pre-Dusting

Pre-dusting is the process of covering the meat with a fine coat of flour, or sometimes with very fine bread crumbs. An example of a flatbed pre-duster is shown in Fig. 14.4.1. Pre-dusting is commonly used as the first layer before batter and breading are applied. However, it should be noted that it is not used in all products and the decision to apply pre-dust depends on factors such as the wetness of the surface, the extracted proteins on the surface (i.e., results from tumbling/massaging the meat prior to starting the battering and breading operation), and availability of equipment. The pre-dust adheres to the surface by absorbing free water on the surface. This is later used to form a mediating layer between the product and the next batter layer. It is important to note that the surface of the product must be ready prior to pre-dusting. A frozen surface, or surface with ice patches will interfere with good adhesion; i.e., establishing homogeneous fine flour layer on the product. Therefore, attention should be given to the meat temperature and amount of free water on the surface. Enhancing pre-dust adhesion can be achieved by supplementing the dry mix with proteins such as soy, egg albumen and whey, and/or by extracting the meat proteins (by tumbling with a brine containing salt) to the surface of the product. This layer would look like a whitish sticky layer after tumbling.

During a continuous operation, it is important that the pre-dust material does not clump and keeps on flowing well through the equipment. Clumps can result in an uneven surface on the product and interfere with the application of the next

coating of batter (e.g., dry areas that do not absorb batter). Flour, which is most commonly used for this application, usually does not flow very well by itself, so certain flowing agents are often added. During the pre-dusting operation, flour and other ingredients (see discussion in the Battering section below) are applied from both sides, while the product is moving on a mesh-type conveyor belt (Fig. 14.1.2). The product arrives to the pre-duster from another belt, and falls onto a layer of flour which is evenly distributed on the bottom (Fig. 14.4.1). Later, free falling flour is applied from the top and then the product is passed under pressure rollers (e.g., inflated with air so pressure can be easily adjusted). The rollers ensure close contact between the pre-dust and the product (i.e., similar to a manual operation in a small kitchen). As indicated above, close contact with the surface is important but removing excess flour is also necessary. Therefore, the product is transferred to another perforated belt where air blowers (also known as "air knives") are used to blow off the excess pre-dust. Other methods of removing the excess pre-dust include a vibrating conveyor belt that shakes off the excess amount, or a flip mechanism, whereby the product falls onto a lower belt and the excess pre-dust is shaken off. The flatbed application is ideal for uniform meat products (e.g., preformed nuggets or patties) which have an even surface and geometry. However, flatbed is not satisfactory for uneven products such as bone-in chicken wings, drum sticks, or thighs. For such applications, a drum applicator is commonly used (Fig. 14.4.2), where the product falls onto a bed of dry pre-dust material. The drum, which works like a cement mixer, is positioned on an angle and rotates at a relatively low speed. The product, which starts at the top, is slowly rolled forward while it is covered with pre-dust. The processor can adjust the dwell time as well as degree of surface wetness to achieve the desired amount of pick-up in the drum. Removing the excess pre-dust is also important in this case. It can be done by an air blower, vibrating wire type conveyor belt (see an example of a belt in Fig. 14.4.3) or a flip mechanism as indicated before. Another advantage of using a drum coater is the ability to enhance pick up by continuously creating small cracks within the coating layer (i.e., as the products are picked up by the baffles inside the drum and then dropped).

a)



b)



Figure 14.4.1 Flatbed pre-dusting equipment (a), and actual products going through the equipment (b).

Since the pre-dust layer is the first coat on the product, it is often used to carry seasonings and spices, as they are going to be most protected during the frying and/or heating operation. This is advantageous because flavour components are fairly volatile and embedding them under the batter and breading layers can assist in "protecting" them, and therefore reducing the amount needed as compared to seasoning the outer layer.

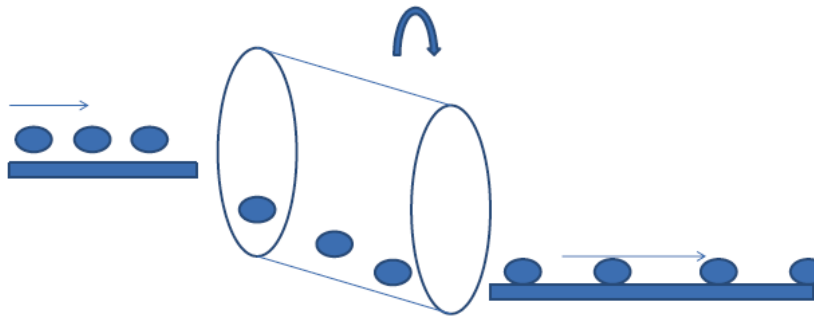


Figure 14.4.2 Application of pre-dust/breading within a drum applicator (drum turning at slow speed) where products with an uneven surface are tumbled within dry flour/breading material.



Figure 14.4.3 Typical stainless steel conveyer belts used during the production of battered and breaded meat products. The picture also shows the transfer point between the two belts and the drive mechanisms. Photo by S. Barbut.

14.5 Battering

In this step the product is coated with a wet solution. Batters consist of a suspension of dry ingredients (e.g., flour, starch, proteins) used to coat the product and create the base for adhering the next layer of dry bread crumbs. Special equipment is used for coating the product, and depending on the type of batter, different set ups can be used (e.g., immersion, overflow).

14.5.1 Types of batter

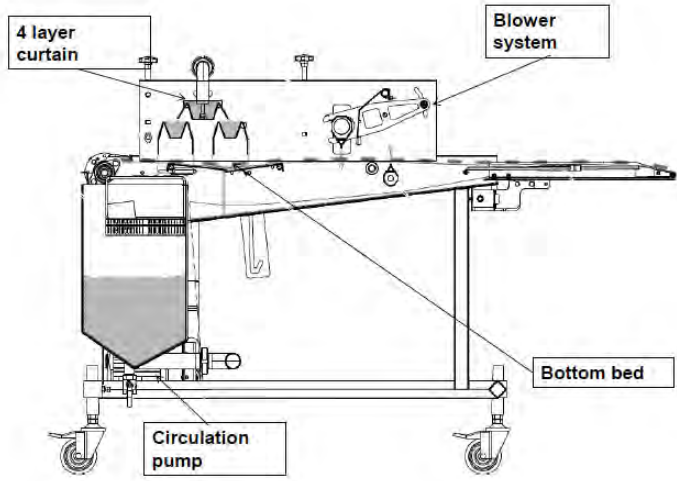
There are different batters which can be separated based on viscosity, solid content, carbohydrate, and/or protein source. It is important that a certain degree of binding or "gluing" is achieved between the batter and the product. The drying speed is another crucial factor in maintaining an adequate batter layer. This is especially important with automated equipment where the product continuously moves on wire-type conveyor belts. Overall, there are three main types/categories of batters:

a. Adhesion batters which are designed to adhere to the meat product.
b. Cohesion batters which are designed to form a shell around the product.
c. Tempura batters which are usually not supplemented with breading, and are used to create a puffed layer around the product.

Overall, most of the batter mixes used by the meat industry are produced by ingredient companies specializing in baked goods. Therefore it is always a good idea to discuss with them the exact product profile and characteristics desired by the supplier prior to starting a new line of products.

a. Adhesion batters – are usually starch based with a high solid content and low viscosity. The main ingredient is corn starch or modified corn starch (see additional discussion about the nature of each specific group of ingredients below). The batter is commonly applied as a relatively thin coat which can adhere well to the surface of the meat. A layer of salt soluble proteins extracted from the meat (e.g., by tumbling) can be helpful in enhancing adhesion. The batter is used as a base for the following breading layer. It is important that such a batter dries fairly quickly, so that a significant amount stays on the product to provide a good support layer for the breading. This is especially important for low viscosity batters in which the next layer of bread crumbs will not absorb an excessive amount of moisture from the batter. To control the drying period, the type of starch is usually matched to the line speed. The nature of the starch used and the percent solids dictate the flow properties of the batter. The common ratio of dry ingredients (solids) to water used in the food industry falls in a range from 1.0:1.4 to 1.0:1.9. Equipment used for the application of this type of batter is shown in Figure 14.5.1.1.a, b which shows products moving on a continuous line with an over flow of batter. A pump is used to move the batter and also to ensure good mixing (Fig. 14.5.1.2) at all times (i.e., starch can settle down over time). Batter preparation can be done away from the equipment or with an automated system attached to the equipment (Fig. 14.5.1.3). The system has sensors to gather information about parameters such as viscosity, % solids and temperature. After processing the data it can add ingredients to maintain a certain viscosity and/or make a new batch according to predetermined specifications. On-line viscosity measurement is an important quality control tool as it can assist in monitoring the process and quickly correct deviations resulting from low/high pick up. Manual viscosity determination is common where either a rotational viscometer or a simple funnel (like you have at home) is used to determine the time it takes for a specific volume of batter to flow through a narrow opening. The latter is a fast and very inexpensive way to get a good handle on the process. It is known in the industry as Zhan/Stein cup method; flow time values for different batters are provided below.

a)



b)

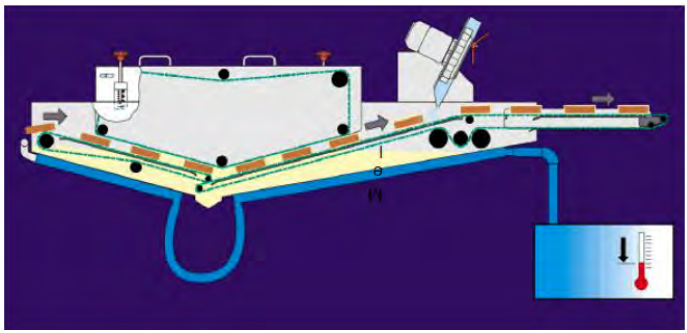


Figure 14.5.1.1 An overflow batter applicator equipment (a), and a submerge applicator for tempura application (b). Courtesy of Marel.

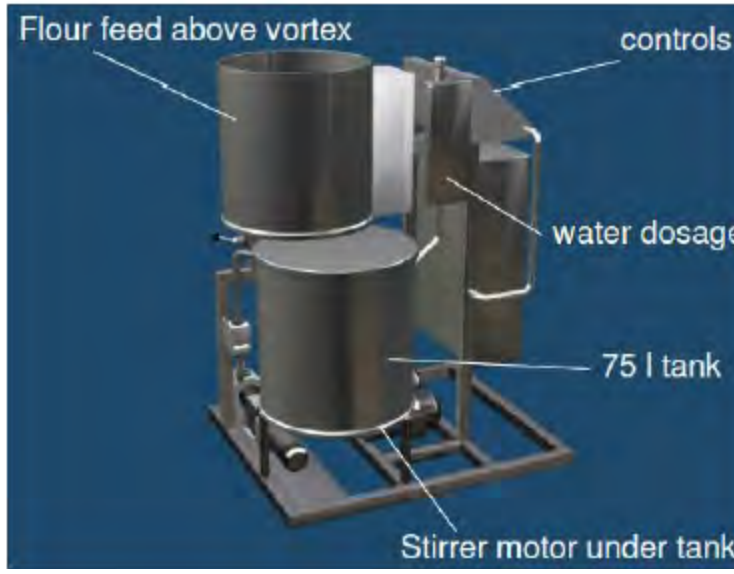


Figure 14.5.1.2 A mixer configuration for batter preparation and for keeping starch and other ingredients in suspension. Courtesy of Townsend.



Figure 14.5.1.3 Moving coated products through an overflow application.

b. Cohesion batters – are used to form an envelope around the meat product, and as a base for "cementing" the next breading layer. These batters are thicker than adhesion batters and are usually flour based. They contain a medium amount of solids and are used to provide texture to this layer. The drying time is longer than for adhesion batters, but since they are more viscous (28-30 sec, as measured by the Stein cup), they will not run off as quickly.

The common dilution of dry ingredients (solids): moisture is 1.0:1.5 to 1.0:2.0. Figure 14.5.3 shows the process of coating the product using an overflow process.

c. Tempura batters – are cohesion batters which include a significant amount of leavening agents. These batters are used as an outer coating which is commonly not supplemented with breading. The final product, after deep fat frying, has a puffed coating layer that is crispy with a lot of air spaces. Tempura batters are usually made from a mixture of flour and starch, and have a high solid content. This results in a high viscosity of the batters (around 45 sec in the Stein cup at a temperature of 5-10°C). The batter is designed to have good cohesive characteristics and as a result of the leavening ingredients, forms a layer rich in air pockets. The inclusion of leavening agents makes the batter sensitive to over-mixing and pumping. A high degree of mixing/agitation will result in a fast release of the gases (e.g., CO_2) which are supposed to be released during the frying operation. Overall, it is recommended that the product be fried very soon after applying tempura batter.

The common dilution in tempura batters of dry ingredients (solids): water is 1.0:1.0 to 1.0:1.3. This results in a high pick-up of the batter and a slow drying rate. The batter is applied by dipping/submerging, and not by overflow as is the case with the other two batters. The time between coating and frying should be carefully controlled. Tempura batters usually contain corn starch which helps to open the structure (or a tenderizing effect) when the wheat flour hardens during the frying operation. Different tempura batters are available to the meat industry and can be designed to address various products' needs. To illustrate the effects of the main ingredients, a simple home recipe for a tempura batter is provided here: 1 cup of flour, 1 tablespoon corn starch, 1 teaspoon salt, an ingredient to produce gas bubbles such as 1.5 cups club soda. Some of the more fancy recipes call for beer as the source of gas bubbles. An industrial recipe will usually include sodium bicarbonate (see discussion below). Eggs can also be included to provide more binding.

14.5.2 Dry Ingredients

The main ingredients found in a batter are wheat flour, corn flour, proteins, gums and leavening agents. Not all are always present in a single batter, and different ingredients are used to achieve certain functional properties (e.g., binding of

breading, a crispy outer layer). Overall, the two most commonly used ingredients are wheat flour and corn starch.

a. Wheat flour – is obtained from finely ground wheat's endosperm. It contains both carbohydrates and proteins. The carbohydrate component, mainly consisting of starch, is useful in providing good adhesion to the product. Modified starch can be used to further enhance adhesion. Starch also contributes to the drying time of the applied batter and the development of a crispy texture during the frying operation. In some batter applications, the ratio of highly branched starch polymers (amylopectin) and linear polymers (amylose) has a profound effect on the starch functionality. The ratio is quite variable and ranges from 99% amylopectin in waxy rice, to high amylose content in cornstarch. Overall, starch molecules absorb water during batter preparation, and some starches hold water better than others (e.g., modified starches). The type of starch can have a strong effect on the batter's viscosity (Fig. 14.5.2.1). Xue and Ngadi (2006) studied the viscosities of batters prepared with blends of wheat and corn, wheat and rice, and corn and rice. The viscosity decreased with increasing shear rate in all batters, which is typical for these kind of batters. In the case of wheat and corn, the viscosity decreased faster with increasing the proportion of corn flour, suggesting that it diluted the strengthening influence of the wheat flour gluten. Rice flour also exerted a diluting effect on wheat gluten, and as suggested by the authors – increased the available free water in the batter system. This free water could lubricate particles, enhance flow, and result in lower viscosity values. Overall, the addition of corn flour caused greater viscosity reduction than rice flour.

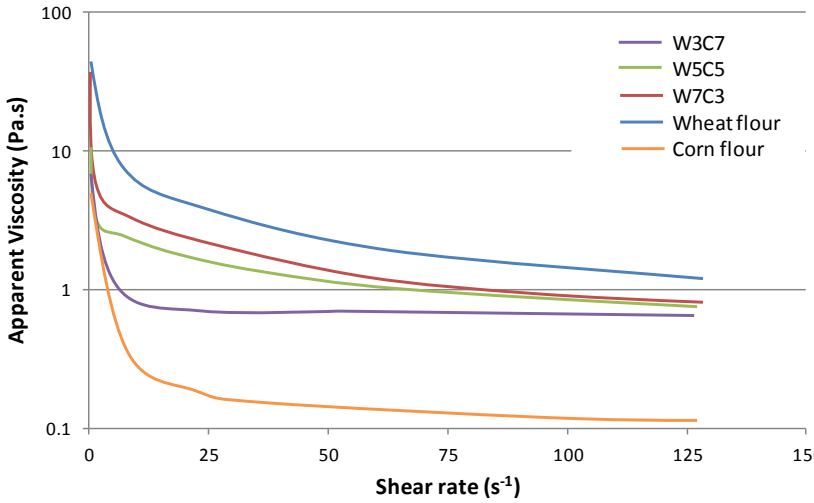


Figure 14.5.2.1 Effect of starch type on batter's viscosity and behavior during shear application. The notations W (wheat) and C (corn) and the numbers refer to the proportion of the starch used (W3C7 = 30% wheat and 70% corn). From Xue and Ngadi (2006).

b. Gums – are used to increase the viscosity of batters and assist the suspension of different solids through controlling viscosity and water binding capacity. Hydrocolloids such as xanthan, guar and modified cellulose are commonly used to thicken sauces and gravies. In battering application, they are used to increase viscosity and reduce run-off during the process (i.e., controlling the amount of batter adhering to the product). Gums, such as methyl cellulose, are used because they can increase the viscosity and also form a gel during heating. The latter is also used in reducing fat absorption during the frying operation; i.e., by producing a "protective film" around the product.

c. Proteins – are used for their adhesion and texture binding properties. Wheat proteins (mainly gluten), egg proteins, dairy proteins and soy proteins can all be used. Initial binding is achieved during the raw batter application and this is greatly enhanced during the cooking operation when the proteins denature and form a rigid matrix. As a texture building ingredient, proteins firm up during the heating process to form a self-supporting gel structure (e.g., liquid scrambled egg proteins transform into a firm gel structure during cooking). Emulsification can also be achieved by employing proteins which are capable of forming an intermediate layer between fat and moisture. Some proteins have better emulsification characteristics (e.g., caseinates) than others and should be used when needed for creating/maintaining a water-fat interphase (e.g., batter applied to skin on chicken drumsticks).

d. Leavening agents – are used to create air bubbles/spaces within the coating layer. This subsequently provides a unique textural characteristic (e.g., crunchiness) to the fried product. The most common agent is sodium bicarbonate which is added with one or more acids to help release the gas. When hydrated, CO_2 is released and most is expected to be entrapped within the batter. Therefore, it is important to only prepare this kind of batter a short time before its application onto the product and the frying stage. The entrapped air bubbles also assist in increasing the volume of the final product and making the outer layer less dense. The rate of CO_2 release depends on factors such as the type of acid being used, the bicarbonate granulation, temperature, and time.

e. Flavouring – spices, salt and sugar are used to flavour the product. Pepper (black/white) usually represents the major component of the spices used, together with smaller quantities of dried thyme, celery, marjoram, rosemary oleoresin, etc. The amount of seasoning can vary considerably among products, but on average they account for 3-5% of the batter mix, with salt representing 10-15% of the mix of flavourings. When sweet flavour notes are desired, various sweeteners can be used.

f. Colouring – spices such as paprika are used to enhance the red/dark shade of the outside layer (artificial food colourings are not so commonly used today because they take the product away from the all-natural label). Caramel ingredients or ingredients that will enhance the Maillard browning reaction (i.e., interaction between reducing sugars and amino acids) are also commonly used to enhance the golden colour development of the final product.

14.5.3 Mixing and Application

It is important that the batter material has good flow characteristics and forms a homogenous mixture that will not separate into its components shortly after mixing the dry ingredients with water. If separation is a problem (e.g., corn starch can settle down fairly quickly), a gentle continuous mixing is required. As indicated before, monitoring the batter's viscosity (flow characteristics) is essential in determining the amount of batter remaining on the product and hence amount of pick-up. A viscosity cup or an automated measuring system can be used to monitor the viscosity on the line. The ratio of dry ingredients to water and the type of dry ingredients are the intrinsic factors affecting the flow characteristics/time, while temperature is an example of an extrinsic factor. It should also be noted that overworked batters (e.g., too much pumping/circulation) can result in lower viscosity values (or time to drain the cup).

Some typical time values for flowing through the so-called Stein cup are:

a. adhesion batter, which mainly contains starch: 9 to 12 sec;
b. cohesion batter, which mainly contains flour: 28 to 30 sec;
c. tempura batter, which contains a mixture of starch/flour: 45 sec.

As shown above, an adhesion batter is considered to be thinner than both cohesion and tempura batters. That also translates to the amount of pick-up which is rated as low, moderate and high for adhesion, cohesion and tempura batters, respectively. Since the drying rate is also affected by the thickness of the batter, it is usually rated as fast, moderately slow and slow, respectively.

Overall, the meat industry usually obtains the dry pre-mixed batters from an ingredient supplier. The ingredients arrive in bags or drums are kept in a dry area to eliminate potential moisture absorption. Prior to use, the dry batter is mixed with water at a predetermined rate. Manual/semi-automatic/automatic mixers are used for preparing the batter (Fig. 14.5.2). Some mixers are equipped with a refrigeration unit as batters should be kept cold to minimize microbial growth, as well as preferentially being at a similar temperature as the meat products. A cold

water supply (5°C) is also important. Some mixers have a built-in viscometer with an external readout panel or are connected to a microprocessor used for automated quality control procedure. Attention should be given to creating a homogenous mixture and preventing clump formation during the entire production period. If ingredient settling is a problem, such as with high native corn starch batters, constant mixing should be applied.

Creating an even layer of the batter is essential. Usually it is easier to achieve this with uniform, flat products as compared to uneven surfaces (e.g., chicken drumsticks). But in both cases, as indicated before, a curtain-application also known as an overflow application (Fig. 14.5.1.3) is used for adhesion and cohesion batters. In this case, the batter is pumped from a reservoir or directly from the mixer into a trough which overflows and cascades to coat the product from the top. Later, the product is dipped in a tub-like cavity and coated from underneath. This is commonly used for an unleavened application where mixing and pumping do not adversely affect batter quality so much.

For leavened batters, a submerging application is used. This is also called top-submerging where the product moves into a pool of batter and is coated from both sides. It is important to remember that the conveyor belt is a mesh-type belt (has opening at the bottom) which allows the batter to be applied from the bottom. Top-submerging application is designed to minimize pumping, since too much agitation and circulating of the batter will result in a fast release of the gases from the leavening agents prior to frying.

14.6 Breading

Coating with breading is commonly done after batter application (an exception can be after the pre-dust application, if the surface is quite wet), and is used to create a unique appearance, texture, as well as increase the volume and weight of the product. The type of breading can range from a simple flour, to structured baked crumbs. Usually, the breading is a cereal based product which has been baked and later ground into fine, medium or large size crumbs. Today, ingredients like sesame seeds are also incorporated by some processors. The dry breading material adheres to the product via the sticky batter (note: some processors are using today soft fresh breading). Therefore, it is important to match the batter with the right breading. Most commercial breadings are manufactured within very large continuous baking lines owned by major baked goods companies. Such lines start with a large mixer to form a dough consisting of flour, water, salt, sugar, etc. The dough is extruded and mechanically rolled, to form loaves, or continuous sheets of

dough which are baked fairly quickly (if chemical leavening agents are used). If yeast is used, the dough goes through a resting period prior to baking. The loaves or continuous sheets of dough are baked and then allowed to cool and dry to a certain degree. This is followed by crumbling through a granulation mill or a slow speed grinder. The crumbs are sometimes allowed to further dry. Later, the crumbs can be sifted and blended as needed for an appropriate granulation.

14.6.1 Types of breading

There are many products on the market but they can be divided into four major groups (Fig. 14.6.1.1.a) plus a few subgroups (see discussion below and Fig. 14.6.1.1.b).



Figure 14.6.1.1.a Examples of the four main categories of breading used to coat food products. (A) flour; (B) cracker type; (C) American/home-style; (D) Japanese style breading. Photo by S. Barbut.

a. Flour – is the simplest form and is used as an economical way of coating a product (commonly used for a full-fry product). The resulting fried coating provides relatively low surface browning and a very dense coating matrix. Special

equipment has to be used for this fine and dusty material as to prevent it from blowing around the plant. The expected pick-up is fairly low, meaning that the increase in the product's weight is low unless a double/triple coating cycle is used. It is interesting to note that because of recent economic constraints, flour is becoming popular today with certain battered and breaded products in both Western and Eastern markets.

b. Home-style or American bread crumbs – resemble the type of crumbs consumers can prepare at home and are therefore called home-style. The crumbs come in different sizes and provide a distinct crust and attractive highlighting during the frying operation - a medium to high browning can be achieved. It has a more open structure compared to the flour or the cracker-type crumb (discussed below) which results in a more crispy texture of the fried product. In terms of pick-up, medium to large quantities can be used to coat the product. The cost of this crumb is higher than flour (and cracker-type crumbs), but not as expensive as the Japanese crumb.

c. Traditional/cracker-type crumbs – are usually white or coloured bread crumbs, with minimal or no crust on the surface. This is an inexpensive type of crumb and is considered by some to be a commodity item. The breading has a flat, flake-like structure which is easy to use on a high speed processing line. It is usually made into a fine granulation, which results in an even surface on the coated product. The browning, achieved during the frying operation, is considered low and the crumbs can be used for full-fry or oven-heated type products. This cracker-type crumb can also be used in a pre-dust application. The flakes themselves are fairly dense and give the final product a crunchy texture.

d. Japanese-style crumbs (Panko) – these crumbs have a very defined shape which resembles an elongated spindle/shredded cheese. Since the delicate, three-dimensional structure is fragile, special equipment with minimal friction should be used for its application. The texture of the crumb is fairly open/porous (see Fig. 14.6.1.1) and is produced as white or coloured material. The crumbs are commonly produced by an electrical induction heating process, rather than conventional baking. This allows the production of a very light density crumb without the formation of the dark crust seen in home-style crumbs. Because of the light structure, it is possible to produce a large-sized crumb without the sensation of hard particles that is prevalent in other crumbs. The product can be used for full-fat fried or oven-heated products. It's usually the most expensive crumb of the ones described here, and used in special applications where the substrate can justify the cost. The amount of pick-up can be set from medium to high. In addition, the degree of browning during the frying operation can be controlled to be medium light to dark.

e. Fresh Crumbs – This is a relatively new concept for high speed industrial lines. It consists of soft crumbs resembling material coming out from the center of a bread loaf. The crumbs are soft and can be easily deformed so special equipment should be used to apply them and recirculate the leftover crumbs (used for the following batch of products). Some of the advantages of using them include the unique texture and appearance they provide to the product.

f. Mixture of/with seeds and grains – in today's market the popularity of natural seeds and whole grains has resulted in the development of coating systems that contain such ingredients. Items such as sesame seeds, pumpkin seeds, and corn flakes are among the popular materials. They can help increase the highlights (i.e., difference in appearance/roughness of the surface) as well as increase the "good-for-you" image of the product.



Figure 14.6.1.1.b Examples of different types of coating and breading, also showing the availability of coloured breading (see text), corn flakes, and dry spices used by the industry. Photo by S. Barbut.

Breading granulation – is usually divided into three sizes/categories (Mallikarjunan, 2010). The different sizes can be used to achieve different functional and textural attributes as well as pickup rates:

a. Fine – refers to particles (greater than 60 mesh), such as flour, but can also be used to describe other types of small bread crumb particles. Sometimes a free-flow agent is used in a flour-type application to reduce the stickiness and clumping problems. The amount of pick-up is considered low compared to the medium and coarse size breading, discussed below. For a straight flour application, special equipment with sifters for breaking down the "recycled" clumped material should be used. In addition dust collectors should be used within/around the equipment.
b. Medium – refers to particles with a size distribution of 20-60 mesh. These crumbs can have a higher pick-up volume and, therefore, can increase the weight of the product more significantly than the fine crumbs. The medium crumbs can provide a nice uniform coverage all around the product. The amount of pick-up can be controlled to address market preference and cost; e.g., based on meat versus the breading value. It is interesting to note that sometimes the coated substrate is less expensive than the breading (e.g., onion rings), whereas in others the substrate is much more expensive (e.g., chicken fillet, shrimp).
c. Coarse – refers to fractions up to 20 mesh size. These crumbs can provide the highest amount of pick-up, but will sometimes result in a poor coverage compared to the fine or medium crumbs. The coarse breading provides a crispier texture because of its larger size. Overall, as breading size increases, perceived crispiness, by the consumer, will increase. In addition, the appearance of coarse crumbs is very distinct on the surface of the product and provides significant "highlighting" on the surface.

The amount of oil absorbed by the crumbs, during par-frying or full-fry, also depends on factors such as the size and porosity of the crumbs. Dense structures will absorb less oil than very porous structures (e.g., cracker type vs Japanese style). The size of the crumb also affects absorption, where fine crumbs with a large surface area usually absorb more oil than coarse crumbs; i.e., due to surface area differences. As mentioned above, certain gums and/or coating can be used to reduce the amount of fat absorbed during the frying operation.

14.6.2 Application of Breading

Automated equipment used for breading application is shown in Fig. 14.6.2.1. The product coming from the battering operation is transferred, on a wire mesh conveyor belt, to the breading applicator, where it lands on a layer of dry breading while more breading is sprinkled from the top. The amount of breading in the

container is much larger than the amount the product can pick up. After coating, the product usually goes under gentle pressure rollers which help to push the breading onto the product. Certain rollers are filled with air while others are solid but have a spring mechanism; both the height and pressure are used to control the force applied and hence control the amount of pick-up. Later, air blowers (air knives) are used to remove the excess breading, so an even coat is created. Not removing the excess breading could result in losses on the conveyor belt, but more troubling is the discharge of loose breading particles in the fryer. Excessive breading losses in the fryer will cause cleaning problems which require additional filtering of the oil, as excessive burning of fall-out crumbs is damaging to the oil quality and subsequently the meat product. Fall out crumbs that stay in the fryer for an extended period of time will turn to charcoal which can later be deposited on the product. For Japanese-type crumb application, the same basic equipment is used; however, moving and transferring the crumbs is done in a much gentler way, in order to minimize damage to the fragile structure of the crumbs. It should be remembered that the crumbs are recycled, meaning that the crumbs which are not picked up during the first application are sent back, via an elevator, for another application. This continuous movement can damage the crumb structure if special care is not provided.

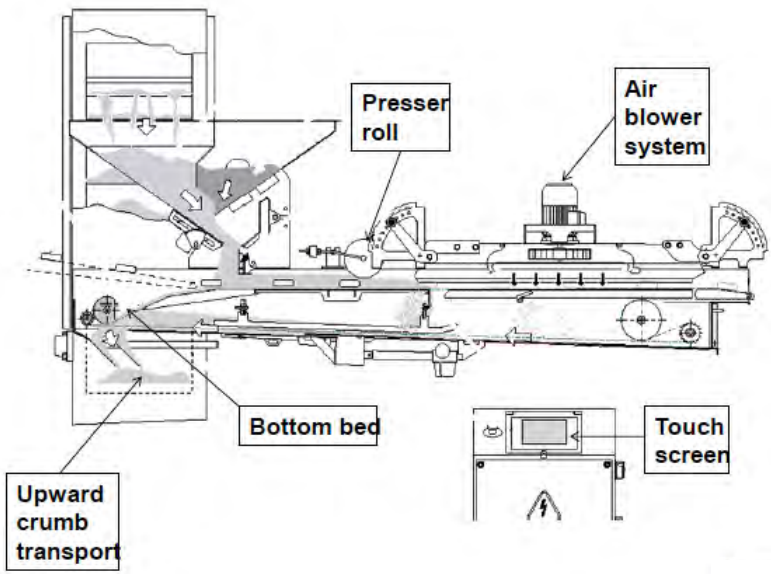


Figure 14.6.2.1 An example of a breading applicator for cracker type and home-style crumbs. Courtesy of Townsend.

When fine crumbs or flour are used, the equipment should be able to handle more dusty components and provide an even coating of the product. At the end of the operation, the air blowers "air-knives" are used to remove the excess amount of fine breading/flour but a good air recirculating system is needed (for both economic and health & safety reasons).

14.6.3 Ingredients

The main basic components used in breading are similar to the ones used for battering (e.g., flour, starch); however, they are used after a baking step. The other important ones are highlighted below:

a. Flour – represents the highest volume fraction of the breading material. Different flours can be used (e.g., hard/soft wheat) depending on the application needed.

b. Leavening agents – added to the raw breading ingredients and are used to produce gas bubbles during the baking operation, and add porosity. They may consist of live yeast cells that produce CO_2 over time (fermentation of a few hours) or chemicals such as baking powder that can quickly release CO_2. By incorporating gas into the structure, the texture is enhanced and volume is increased.

c. Flavours – different spices or spice extracts are be added to provide unique flavour notes. As indicated earlier, spices added to the outer layer are not as protected during the frying operation as spices used in the pre-dust layer or injected with the marinate into the meat. The types of spices and degree of flavouring is wide open and depends on market preferences and cost.

d. Modifying agents – ingredients such as fat conditioners and emulsifiers may be added to modify the textural characteristics of the breading. Such ingredients can also affect the volume of the breading layer during the par-fry operation, and modify the bite characteristics of the crumbs.

e. Colouring and browning agents – the final colour of the coating on a meat product is very important to the consumer. The final colour depends on many factors (e.g., colour of the applied breading, ingredients in the breading, frying temperature, and time) and their interactions. The actual breading can be white, have some brownish crust and/or include coloured spices. In addition, caramel ingredients are often used to obtain a distinct darker shade (depending on consumer preference). Spices or spice extracts such as paprika provide red or other colours. Since most consumers prefer a brown/golden colour on breaded products, colour

development during the frying/baking operation is very important. Ingredient suppliers can provide a so-called fast or slow colour developing coating systems. The decision depends on where and how the product will be marketed (e.g., cafeteria style where product might be exposed to an extended period of heating). Overall, colour and appearance are extremely important because most buying choices of a new product are based on appearance (e.g., today we see a trend of moving to international flavours, such as chili style products that have a reddish/ orange appearance). The meat inside the breaded product is obviously invisible to the consumer, therefore, the outside appearance, including browning and "highlighting", are of utmost importance.

Breaded products are either fully cooked or par-fried prior to shipment. Special ingredients can be used to result in fast browning of par-fried products so the product quickly develops some of the desirable golden appearance. Depending on the breading and cooking time, more colour is expected to be developed in the oven at home/restaurant. The degree of browning during the par-fry operation can be enhanced by adding proteins and reducing sugars (e.g., dextrose), to enhance the Maillard browning reaction. For products designed for the food service industry, slow browning crumbs are commonly used as most browning is achieved during the second cooking/heating operation (i.e., just prior to consumption).

f. Ingredients to reduce fat absorption – special ingredients have been evaluated over the past few years as a final coating application on fried products (e.g., battered meat products, French fries) to reduce oil absorption during frying. As soon as a food product is placed in hot oil, sizzling starts. This indicates that water boils on the surface and exiting the product (i.e., oil temperature of 185 -195°C is much higher than water boiling at 100°C). The spaces created by water leaving the product (see Fig. 14.6.3.1) are filled with oil. In addition some of the open spaces between the breading particles also pick up oil (hence the difference mentioned before between fine and coarse breading). The coating materials used to reduce oil absorption include ingredients such as modified starch and hydrocolloid gums that can form a film around the breading particles (i.e., several of these ingredients/ mixtures have been patented). Huse et al. (2006), evaluated the effectiveness of edible formulations with methyl cellulose, hydroxyl-propyl methyl cellulose, corn zein, and amylase on restricting oil absorption during deep fat frying of Akara (traditional food made from cowpea paste) when coating was applied by either spraying or dipping. The amylase spray coated Akara was the only treatment resulting in a significant reduction of core oil absorption; however, all treatments absorbed significantly less oil in the crust and total oil than the non-coated control. Compared to the control, a 49% reduction in total fat content was seen in the samples dipped in methyl cellulose. The authors explained that as the product

cooks, the core temperature rises and moisture is converted to steam which is released from the product. The escaping steam forms small capillaries, and later oil gets into these voids. The decrease in oil absorption is an indirect result of the barrier to moisture removal by the edible film. Therefore they suggested that, for example, the increase in barrier properties of the methyl cellulose coating may have been due to the increasing film thickness.

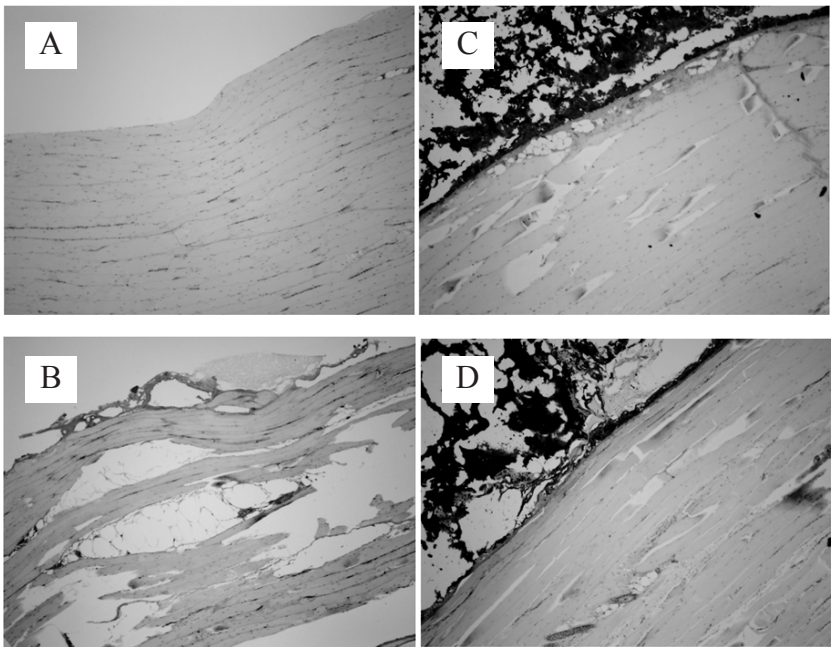


Figure 14.6.3.1 Microstructure of battered and breaded and non-coated whole muscle products fried in oil for different times: (A) the upper part of a raw uncoated chicken breast fillet showing a typical arrangement of muscle fibers; the black dots are the nuclei; (B) the result of frying the chicken fillet at 190ºC for 3 min, note the excessive splitting of the muscle fibers and drying of the surface; (C) fillet coated with batter and breading after frying for 0.5 min; (D) after frying for 3 min. From Barbut (2013). With permission.

14.6.4 Binding of coating materials

The different coating components (i.e., pre-dust, batter and breading), should be developed to match the final meat product's desired characteristics. Overall, the surfaces of the raw meat product can vary from a skin covered portion (poultry drumstick), to an exposed lean muscle (chicken breast), and ground/minced meat

(nugget). These three surfaces represent very different physical properties and each requires a different approach to coating. Furthermore, a cut muscle surface can be salted or pre-marinated to create a more sticky surface by extracting meat proteins (e.g., myosin, actin). Good adhesion of the pre-dust, batter and breading to the meat surface is essential in obtaining an acceptable final product. Suderman and Cunningham (1980) studied batter adhesion to chicken skin using scanning electron microscopy and developed a model for describing adhesion to broiler skin with and without the cuticle layer (Fig. 14.6.4.1). The latter applies to broilers exposed to a high scalding temperature (about 60°C; see Chapter 5) which results in removing the outer cuticle layer. According to the model, removing the cuticle improves the batter's adhesion to poultry skin. The reason is that particles can lodge between protrusions extending from the *stratum germinativum* layer of the skin. Overall, it is important to note that the meat can be processed in different ways (e.g., with or without skin, skin exposed to high/low scalding temperature, salted meat) which significantly affect the surface or the product prior to coating.

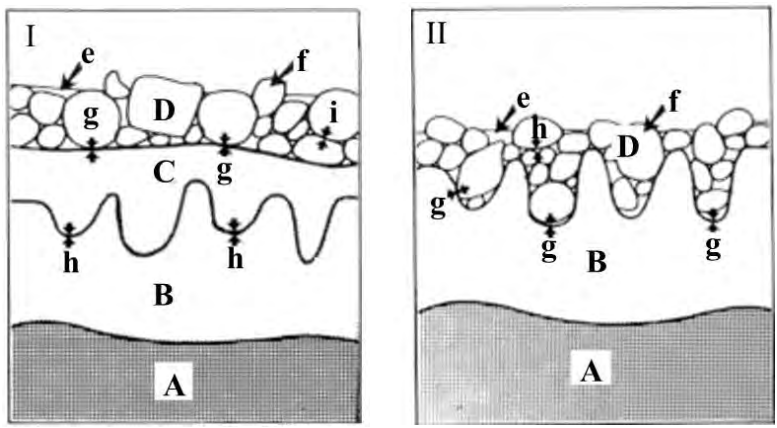


Figure 14.6.4.1 Schematic illustration of potential batter and breading adhesion to chicken skin with and without cuticle (I and II, respectively). The model shows: (A) dermis layer, (B) *stratum germinativum*, (C) *stratum corneum*, also called cuticle, (D) coating matrix, (e) coating ground substance, (f) coating particles, (g) primary binding forces, (h and i) secondary binding forces. From Suderman and Cunningham (1980).

The temperature of the meat and especially the surface can significantly affect the adherence of the coating material. A frozen or partially frozen surface can create problems with the pre-dust or batter adhesion. It is not uncommon to use tempered/partially frozen meat. Reasons can vary from ease of forming (meat mass is more rigid at low temperature) to plant's operational constraints and regulations. Ice

crystals on the surface will result in poor adhesion and an uneven distribution of the dry coating ingredients. If the product is too warm, problems such as "marriages" and tails can also occur (see Trouble Shooting section below).

The amount of "free" moisture on the surface is critical to the proper adherence of the pre-dust and batter. In some cases, formed nuggets have an excess amount of water on the surface (e.g., resulting from condensation, or spray nozzles used in a high pressure former to wet the product). This can cause an uneven deposition of dry ingredients (e.g., thick and thin regions of the coating material), and later show as "bald" spots on the finished product.

Overall, when developing a battering and breading system, a clear picture of the desired final product should be drawn. It is important to include the consumers' expectations in terms of appearance, price and textural characteristics; all determine the type of batter and breading materials to be used. After designing the product, different ingredients can be selected, the amount of pick-up determined, as well as heat treatment parameters to achieve a certain colour, texture and appearance.

The coating line can include different station arrangements (Fig. 14.1.3). The simplest arrangement consists of a single pre-dusting, battering and breading units. Such a system usually results in a pick-up of < 30%. A repeated (e.g., double, triple) battering and breading operation can be established to obtain a higher pick-up. A tempura battering line, which commonly includes a pre-dusting operation followed by a thick batter application, usually results in 30-55% pick-up. The immediate use of a fryer in a tempura operation is necessary to solidify the batter on the product and create the puffed texture. The same is usually true for conventional battering and breading operations (immediate par-frying is strongly recommended) but is not as crucial as in tempura systems.

The texture of the coating system can be designed to be tender or hard, porous or dense. This is usually done by varying the type of breading as well as starch and protein type and quantity. The level of crunchiness and crispiness can be modified by using different leavening agents and particle size. Appearance can be determined by the size of the crumbs (Fig. 14.6.1.1) and vary from an even surface to a highly detailed surface when small or coarse crumbs are used, respectively. Additional ingredients, such as corn flakes, sesame seeds and dried parsley, can be added to achieve a more distinct highlight (differentiation on the surface). The intensity of the brown/golden colour can be controlled by spices/food colouring, incorporation of ingredients contributing to the Maillard browning reaction (e.g., reducing sugars, proteins), as well as heating time and medium (oil, air). The equipment available in the plant obviously determines the type of applications possible (e.g., Japanese-type crumbs are very delicate and require special equipment).

14.7 Frying and Cooking

14.7.1 General

The frying operation is used for several reasons. The first is to "solidify" the soft coating system so it will stay on the product (e.g., batter not run off, so products will not stick together, breading will not fall off the product). The second reason is to develop a brown/gold colour on the surface. The third is to cook the meat and non-meat ingredients and provide a unique texture and mouth feel. Another essential reason is to inactivate pathogenic microorganisms. Frying, at the processing plant, can be done for a short period of time (par-fry/flash fry; less than 1 min) or for a long period of time which results in a fully cooked product. The decision depends on product requirements. A schematic diagram of a fryer is shown in Figure 14.7.1.1 which consists of a heat resistant belt (e.g., metal, Teflon) going through the 185-195ºC oil. The appearance of the products after full fat frying can also change depending on the ingredients and colouring used (Fig. 14.7.1.2). By talking to the breading supplier the processor can decide about the final colour the product will have after the par fry and the full cooking cycle (see discussion in the ingredient section above). The inside of the fully cooked products is shown in Figure 14.7.1.3.

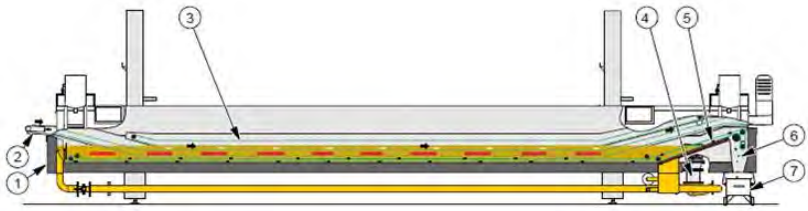


Figure 14.7.1.1 An illustration of a continuous deep fat fryer where products are moved on a conveyer belt. A top belt/guides can be used to keep the products submerged and moving at a certain speed. 1) insulated oil tank, 2) product entrance, 3) belt for moving the product, 4) circulating pump for oil, 5) continuous removal of debris/charred particles from the bottom of the tank, 6) fall off debris, and 7) collection of debris. Courtesy of Marel.



Figure 14.7.1.2 Par fried products arriving frozen from the processing plant (right side), and after being fully fried and served (left side). Also showing the potential for further colour development during full frying; i.e., this option depends on the initial breading ingredient selection.
Photo by S. Barbut



Figure 14.7.1.3 Cross section of fully cooked coated products. Photo by S. Barbut.

14.7.2 Oil

The different oils/fats commonly used can be divided into: vegetable (e.g., corn, soybean, peanut, and canola) and animal fats (e.g., tallow). Using one type of oil versus another depends on factors such as cost, consumer demands (e.g., unsaturated oils to address health concerns), stability and flavour.

Since the oil can be exposed to high temperature, for a long period of time (production line constantly running for a few days, or even a full week), oil quality should be monitored on a continuous basis. Filtering and oil replacements (i.e., products going through the fryer pick up oil) are commonly employed to maintain oil quality. The high temperature can induce chemical changes in the oil and affect its quality. As time progresses, oil hydrolysis (release of free fatty acids) and oxidation take place. In addition, polymerization of free fatty acids causes a further deterioration of the oil's quality in terms of flavour, colour and nutritional value. Darkening of the oil is the most visible since it also results in darker products coming out of the fryer. Breaking down of the fatty acids and foaming of the oil can also result in bubbling and splashing, and thus safety problems may also be encountered.

In terms of products' quality, the increase in viscosity of the oil over time can result in higher oil pick-up and an insufficient heat transfer. In most conventional operations, the oil is continuously filtered to remove charcoal particles (e.g., fall off bread crumb) and fresh oil is added to replace oil absorbed by the products. Usually, about 10% of the oil is absorbed by the passing products and therefore must be continuously replaced. This oil turnover, coupled with constant filtering, is usually sufficient to run an adequate continuous frying operation. As indicated before, oil absorbed by the product is mostly replacing water lost during the frying operation. Figure 14.6.3.1 illustrates the spacing created by shrinking of the muscle fibers during heating. These spaces are also filled with oil.

Overall, there is a trade-off between oil temperature and the product's quality. At a lower temperature, more oil will be absorbed by the product, whereas at a higher temperature, the oil will deteriorate faster. In cases where the product is fully cooked at the plant, the processor has two options: a) fully cook the product in oil, b) use a hot air spiral oven (see chapter on heating) after an initial par-fry stage. Each option provides some unique characteristics to the product. Generally speaking, a hot air oven can be run at different air temperatures, speeds and relative humidity. These factors determine cooking time and yield of the product. Advances in oven design permit the production of breaded and battered product with a texture pretty similar to a fully fried product. For example, including an impingement heating module can help achieve a more crusty texture on the surface.

14.7.3 Final Cooking/Reheating

If the product is only par-fried at the processing plant, it must be fully cooked by the consumer/food service operator. Fully cooked products (at the plant) are usually reheated/ warmed up by the consumer prior to consumption. The way the product is going to be prepared/ heated by the consumer dictates the type of coating system used by the processor. Battered and breaded products requiring full cooking can be prepared in an oven, deep fat fryer or sometimes in a microwave oven. Each of these cooking methods requires a different combination of ingredients. Whereas microwave heating is employed for a relatively short period of time, oven cooking usually requires a longer period of time (> 30 min) since heat is transferred from the outside to the inside of the product. During microwave heating, problems such as sogginess can occur and therefore, breading suppliers should be involved in the entire design of the coating system.

14.8 Freezing

As described in this chapter, the initial raw coated product is soft, pliable, and sticky. The par-fry or fully cooked operation provides the product with a hard shell and/or interior that can be handled and packaged. The product is commonly frozen after frying in order to preserve its texture, freshness and appearance. The frozen product is less prone to coating material breaking/peeling off, and to lipid oxidation. The typical freezing methods include:

a. Mechanical freezing – a blast freezer with a fast/slow blowing cold air is used. Different freezer configurations (e.g., stationary selves, linear, spiral belt) can be used.
b. Cryogenic freezing – is popular for small size products, where CO_2 or liquid nitrogen is used to dip or spray the product and freeze it very quickly.

The cryogenic freezing operation is more expensive than mechanical freezing, but results in very small ice crystal formation and less damage to the product. For example, individual quick freezing (IQF) is used for products such as nuggets by a number of fast food chains around the world. In such a case, adequate cold chain storage and shipping is also required to maintain the product quality.

The freezing operation should be monitored and controlled to prevent the coating from cracking and other problems associated with rapid freezing of the outside surface. In some cases, the initial freezing is done in a freezing tunnel (crust

freezing) and the rest is achieved in the warehouse where the product is commonly stored at < -20°C. Regardless of the freezing method, it is important to remember that the product should be kept at a low temperature as increasing the temperature or fluctuations in the freezer will cause ice crystal growth and damage to the product.

14.9 Troubleshooting

The commercial battering and breading operation is a complex operation with many intrinsic and extrinsic factors involved; i.e., various problems can develop during the process. The problems are usually more visible in the finished product, but may be detected and corrected during the process itself (i.e., prior to frying, when it is still possible to correct). A description of some of the common problems and potential solutions are provided below.

a. Bald spots on a cooked product – is a serious visual defect to the consumer and should be avoided as much as possible. It can result from not picking up the coating material at certain areas, or breading falling off the product after it has been par-fried/fully cooked.
The reasons in the first case can be attributed to:

a. Air knives/blowers running at very high speed
b. Partially frozen or icy surfaces that results in insufficient pre-dust and/or batter adherence.
c. A low viscosity batter which result in an uneven batter deposition and later insufficient breading sticking to this area.
d. An oily surface or greasy patches on a meat preventing batter adhesion.
e. Fast moving conveyor belt and overloading the system; i.e., enough time and spacing among products should be allowed for each operation.
f. Inadequate transfer can result in excessive shaking and damage the integrity of the previous coat deposited on the product.

b. Insufficient or excess coating layer – A low or high pick-up can result from mismanaged batter where the viscosity is too high or too low, respectively. As the batter is circulated, viscosity can change as some dry ingredients (pre-dust) can come off the large number of products passing by. For this reason, batter's viscosity should be continuously monitored as well as the batter's temperature. The belt speed used within the different sections (pre-dust, batteries, breading) should be adjusted to obtain adequate dwell time for pick-up. Adjusting the amount of pressure applied by the rollers and the air speed of the "air knives" used to strip

off excess amounts of batter and later breading should be precisely controlled (including an even air pressure across the belt). In general the belt speed is slightly increased after each operation (pre-dust, battering, breading). The whole system should be adjusted and synchronized together. This is easier to do today when computerized controls are used to synchronize all the units from one control box.

c. "Marriages" – result in fried products connected to each other.

a. Inadequate line speed during transferring from a fast moving belt to a slower moving belt can result in products falling on top of each other and sticking together; also called "doubles". The solution is to provide adequate spacing and adjustments to line speed.
b. Sticky batters can also result in "gluing" two adjacent products.

d. Belt marks – seen as stripes on the product.

a. Too much pressure applied by the rollers in the breading operation.
b. Inappropriate absorption of breading to the surface (can also cause uneven surfaces). This usually requires adjusting the breading formulation.
c. High viscosity of the batter can also result in visible belt marks.

e. "Tails" and flares – an excess amount of batter staying attached to the fried product.

a. High batter viscosity can cause "tails" remaining on the edges of the product. The excess batter can be removed by increasing the air pressure used for the "air knives" and, where required, adjusting the batter's viscosity.
b. High amounts of breading attached to the product can also result in flares and "tails". This might require changing the type of breading used or adjusting the pressure applied, by the rollers, at the exit from the breading machine.

f. Dark colour – seen as dark fried products coming out of the fryer/oven.

a. A high temperature in the fryer can cause fast deterioration and darkening of the oil, which is then transferred onto the product.
b. An excessive frying/oven heating period will result in burning of the surface. This requires adjusting the belt speed, oil temperature and exposure time to the oil.
c. The components added to the breading can also be adjusted to control the browning rate (see previous section).

g. Shelling – usually seen in tempura-type batter where a hard shell is formed prior to allowing hot water vapor/steam to escape from the product.

a. A thick batter deposited on the product can produce a hard shell around the product during frying. Viscosity should be checked on a continuous basis and adjusted as needed. In addition, the "air-knives" should be adjusted to control the thickness of the coating.
b. Temperature too high prior to the frying operation can result in excessive amount of gas released (note: tempura batters include a relatively high level of leavening agents). This will lower the amount of gas being released during the actual frying operation and reduced porosity of the batter. The hard coating can trap the hot air and water vapor inside the product and eventually a shelling problem will be seen.
c. A high amount of pre-dust deposited on the product can also cause this problem. This might require a change in the type of pre-dust material, and/or the formulation of the batter.

h. Ballooning – seen after frying as a separation of the coating from the product itself. Such a separation can later cause cracking and breading falling off the product.

a. This can result from fast hardening of the outside coating system during the par-fry operation, while not allowing water vapor to easily escape from the product.
b. If the batter is becoming too cohesive (e.g., pre-dust falling into the continuously circulating batter), the problem can be magnified. Therefore, the viscosity should be monitored and adjusted as well as monitoring the thickness of the batter deposited on the product. The latter can be controlled by the "air knives" at the end of the battering operation.
c. Changing the pre-dust from fine to medium particles (or medium to coarse) can create a more porous layer which makes it easier for water vapor/steam to quickly escape from the product during the frying operation and minimize coating separation.
d. Increasing the breading size can also help by creating a more porous surface.
e. Adjusting the batter's ingredients, such as adding fat or gums, can help modify the porosity of the coating system and allow moisture to easily migrate/escape during frying.

14.10 HACCP Generic Model – Battered and Breaded Chicken Fillets

The preparation of battered and breaded meat products has been described in this chapter and a HACCP generic model proposing critical control points is discussed below. The model was prepared by the Canadian Food Inspection Agency (CFIA, 1998). A review of the HACCP concept and the seven HACCP principles are provided in Chapter 6. The model is representative of a range of par-fried/full fried products, while the specific example given here is for a breaded chicken fillet product (Fig. 14.2.1). The document starts with a description of the product which outlines the product name, important characteristics, intended use, special labeling and distribution control (Table 14.10.1). The table is actually an example of an official form included in an approved HACCP document.

Table 14.10.1 Product description – battered and breaded. From CFIA (1998).

Product name	Seasoned battered and breaded chicken breast fillets
Important product characteristics	Par-fried (i.e., 30-60 sec frying), individually quick frozen (IQF) product; no preservatives or low pH which will inhibit bacterial growth
Product use	Frozen before cooking; must be fully cooked to an internal temperature of at least 72°C
Packaging	Shipping carton packaged in bulk plastic liner/sealed with tamper-evident tape
Shelf life	A year if kept at -18°C or below
Distribution	Hotels, restaurants, institutions and retail
Labeling instructions	Lot number; keep frozen; cooking instructions; ingredient list
Special distribution control	Use refrigerated truck at -18°C or colder

In the flow chart (Fig. 14.2.1), the first critical control point is "Receiving" raw materials which include: meat, water, wheat flour, sugar and spices (see also detailed list in Table 14.10.2). The Table identifies potential bacteriological hazards in the incoming raw materials, which might harbor bacteria (B-biological hazards), carry some antibiotic/pesticide residues (C-chemical hazards), or might contain small particles such as metal, plastic or bone chips (P-physical hazards). These hazards should be addressed by CCP-1, where the raw ingredients need to be inspected prior to being accepted. Later, CCP-4, which is a metal detector check

point (Fig. 14.2.1), is an example of a step to be used in the process to reduce/eliminate the risk of metal particles (e.g., metal shavings that might have been falling into the meat, needles that might have been breaking during injection), in the final product. However, if one suspects (or has previous experience) that metal particles are a common problem in the raw materials, a metal detector can/should be also added at the receiving point. It should be mentioned that this approach is different to the one presented in the fresh poultry processing model (Chapter 6) where receiving the raw materials is handled by letters-of-guarantee and/or pre-requisite programs. Overall, one can see both approaches used in the field. In this fried product model, the first CCP is important to assure the microbial load is controlled when raw ingredients are received. Starting with highly contaminated meat (e.g., can be due to long storage time, high temperature, not processed under good hygienic conditions) will lead to an unsafe product. This can also result in off flavours/odours and short shelf life, but note that these are not safety issues related to HACCP.

Table 14.10.2 Biological (B), chemical (C) and physical hazards (P), and critical control points (CCP), related to ingredients, incoming material, processing and product flow for ready-to-cook breaded chicken breast fillets. From CFIA (1998).

Identified Biological Hazards (Bacteria, Parasites, Viruses, etc.)	**Controlled at**
Incoming Materials	
Chicken Breasts and Breast Fillets – Contamination with pathogenic bacteria (eg., *Salmonella sp., Campylobacter sp., Staphylococcus aureus, Yersinia enterocolitica, Listeria monocytogenes, Escherichia coli*, *Clostridium perfringens*)	CCP-1BCP
Water – Water not meeting the drinking water criteria established by Health Canada	Prerequisite program (Water Quality)
Wheat, Flour, Corn Flour, Toasted Wheat Crumbs and Starch – Presence of mycotoxins, high aerobic spore count, grain beetles	CCP-1BCP
Sugar, Glucose Solids, Dextrose – Contamination at source with pathogenic bacteria (eg., *Clostridium perfringens, Bacillus cereus, Listeria monocytogenes, Salmonella sp.*)	CCP-1BCP
Spices – Contamination at source with pathogenic bacteria or spores (eg., *Clostridium perfringens, Bacillus cereus, Salmonella sp, E. coli)* or presence of mycotoxins	CCP-1BCP

Process Steps:	
#1 Reception of non-compliant material – See Incoming Material (above)	CCP-1BCP
#2 Holding Cooler – Pathogenic bacterial growth due to excess time (improper stock rotation) or inadequate refrigeration	Prerequisite programs (Storage)
#3 Water Distribution System – Pathogenic bacterial contamination & growth within water pipes due to back siphonage of contaminated water or due to "dead ends"	Prerequisite program (Water Quality & Maintenance)
#4 Dry Ingredients Storage – Pathogenic bacterial contamination from rodents, insects or improper handling (damaged containers with contamination of exposed product)	Prerequisite program (Pest Control & Employee Training)
#7 Breast Boning and Sizing – Pathogenic bacterial contamination due to improper handling procedures	Prerequisite program (Employee Training)
#8 Breast Fillet Sizing – Pathogenic bacterial contamination due to improper handling procedures	Prerequisite program (Employee Training)
#9 Ice Machine & Storage – Pathogenic bacterial contamination due to inadequate cleaning & sanitizing of equipment	Prerequisite program (Sanitation)
#10 Brine Mixing – Pathogenic bacterial contamination due to improper employee hygiene, work habits and equipment operating practices	Prerequisite program (Employee Training)
#11 Massaging – Pathogenic bacterial contamination due to improper handling & growth due to time/ temperature abuse or due to inadequate cleaning of equipment	CCP-3BC
#12 Pre-dusting – Pathogenic bacterial contamination due to improper employee hygiene, work habits and equipment operating practices	Prerequisite program (Employee Training)
#13 Batter Mixer – Pathogenic bacterial contamination due to improper employee hygiene, work habits and equipment operating practices	Prerequisite program (Employee Training)
#14 Batter Application – Pathogenic bacterial contamination due to improper employee hygiene, work habits and equipment operating practices (time/ temperature control)	Prerequisite program (Employee Training)
#15 Breading Application – Pathogenic bacterial contamination due to improper employee hygiene, work habits and equipment operating practices	Prerequisite program (Employee Training)
#17 I.Q.F. Freezer – Pathogenic bacterial growth due to failure to adequately freeze the product	Prerequisite program (Storage)

#19 Weighing System – Pathogenic bacterial contamination due to improper employee hygiene, work habits and equipment operating practices	Prerequisite program (Employee Training)
#20 Carton Assembly (& plastic liner insertion) – Pathogenic bacterial contamination (eg. *Salmonella sp.*) associated with dust contamination of product contact surfaces of inserted and opened liners	Prerequisite program (Employee Training)
#21 Carton Filling – Pathogenic bacterial contamination due to improper employee hygiene, work habits and equipment operating practices	Prerequisite program (Employee Training)
#22 Coding, Sealing & Labeling – Pathogenic bacterial contamination due to improperly sealed bags or cartons (exposed product)	Prerequisite program (Employee Training)
#23 Holding Freezer – Contamination due to damaged cartons and pathogenic bacterial growth due to inadequate temperature	Prerequisite program (Storage)
#24 Shipping – Pathogenic bacterial contamination due to damaged cartons & growth due to time/temperature abuse	Prerequisite program (Transportation)
Identified Chemical Hazards	**Controlled at**
Incoming Materials	
Chicken Breasts & Breast Fillets – Antibiotics, sulfonamide residues, pesticides, heavy metals	See Table 12.3
Water – Toxic chemicals e.g. heavy metals	Prerequisite program (Water Quality)
Wheat flour, corn flour, toasted wheat crumbs & starch – Pesticide residues, allergens	CCP-1BCP
Spices – Fumigant & pesticide residues, allergens	CCP-1BCP
Vegetable oil – Pesticides residues, allergens	CCP-1BCP
Plastic bags & liners – Chemical migration from non-food grade ingredients	CCP-1BCP
Process Steps:	
#1 Reception of non compliant material – See "Incoming Materials" (above)	Prerequisite program (Sanitation)
#7 Breast Boning & Sizing – Chemical residue due to improper sanitation procedures (poor drainage of equipment, product contact surfaces)	Prerequisite program (Sanitation)
#8 Breast Fillet Sizing – Chemical residue due to improper sanitation procedures (poor drainage of equipment, product contact surfaces)	Prerequisite program (Sanitation)

#10 Brine Mixing – Chemical residue due to improper sanitation procedures (poor drainage of equipment, product contact surfaces)	Prerequisite program (Sanitation)
#11 Massaging – Chemical residue due to improper sanitation procedures (poor drainage of equipment, product contact surfaces)	Prerequisite program (Sanitation)
#11 Massaging – Allergens due to incorrect ingredients or formulation	CCP-3BC
#13 Batter Mixer – Chemical residue due to improper sanitation procedures (poor drainage of equipment, product contact surfaces)	Prerequisite program (Sanitation)
#22 Coding, Sealing & Labeling – Allergic reactions due to incorrect list of ingredients (wrong label)	CCP-5C
Identified Physical Hazards	**Controlled at**
Incoming Materials	
Metallic particles:	
Chicken Breasts & Breast Fillets – eg. knife chips, metal chips & pieces from equipment	CCP-4P
Breading, Batters, Pre dusts, Salt & Spices – Metal chips and pieces from grinders	CCP-4P
Non-Metallic particles:	
Chicken breast fillets – Bone and plastic particles	CCP-1BCP
Breading, Batters, Pre dust & Salt – Hazardous extraneous material	CCP-1BCP
Spices – Wood slivers	CCP-1BCP
Process Steps:	
#1 Reception of non compliant material – See "Incoming Material" (above)	CCP-1BCP
#6 Packaging Material Storage – Nails from skids (palettes), metal devices from packaging (staples) & other environmental contaminants due to improper handling eg. exposed packaging material contaminated due to open or damaged cartons	Prerequisite programs (Receiving/Storage & Employee Training)
#7 Breast Boning – Bone particles and plastic particles from cones or cutting boards	CCP-2P
#7 Boning – Metal chips from knives, mesh glove links, etc.	CCP-4P
#8 Breast Fillet Sizing – Metal chips from knives, mesh glove links, etc.	CCP-4P

#9 Ice Machine & Storage – Metal chips & pieces due to metal fatigue & improper maintenance	CCP-4P
#10 Brine Mixing – Mixer blade chips due to metal fatigue, machine parts eg. screw, due to improper maintenance, and fragments from cracked scoops	Prerequisite programs (Employee Training)
#11 Massaging – Metal chips and pieces due to metal fatigue or improper maintenance	CCP-4P
#12 Pre dusting – Cracked scoops & pieces of metal belt links & particles from ingredient containers	CCP-4P
#13 Batter Mixer – Mixer blade chips due to metal fatigue, machine parts eg. screw, due to improper maintenance & cracked scoops; particles from ingredient containers	CCP-4P
#14 Batter Application – Pieces of metal, belt links & machines parts eg. screws due to improper maintenance	CCP-4P
#15 Breading Application – Cracked scoops & pieces of metal belt links; particles from ingredient containers	CCP-4P
#16 Fryer – Pieces of metal belt links	CCP-4P
#17 I.Q.F Freezer – Pieces of metal belt links	CCP-4P
#18 Metal Detector – Failures to detect unacceptable metallic fragment(s) due to improper calibration or malfunction	CCP-4P
Identified Hazards	**Indicate the way the Hazard could be Addressed (Cooking Instructions, Public Education, Use Before Date ...)**
Incoming Materials	
Chemical – Chicken Breast & Breast Fillets – Antibiotics, sulfonamide residues, pesticides, heavy metals	Growers' education Control at the farm level

The model continues by providing detailed description of the different steps involved, potential hazards and the use of a Decision-Tree process (similar to the process described in Chapter 6) to identify the critical control points.

Table 14.10.3 describes information about setting up critical limits, monitoring procedures, deviation procedures, verification procedures, and record keeping according to the seven HACCP principles. Limits for each control point should be established by plant personnel and later the whole HACCP plan (including the limits) need to be approved by the appropriate government agency.

Table 14.10.3 Details about the suggested Critical Control Points (CCP), monitoring, deviation and verification procedures for the generic HACCP plan for ready-to-cook breaded chicken products. From CFIA (1998).

Process Steps	CPP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#1 Receiving	CCP-1BCP	Chicken Meat: (contamination with pathogenic bacteria)	Plant specific contractual specifications for eg., bacteria ("X" APC/Coliforms per ml, gr or sg. cm.), absence of specific bacterial pathogens, hygienic handling procedures during evisceration/boning, transportation temperature, maximum "X" days from slaughter/pack date. Internal temperature less than or equal to 4°C when received. Shipping containers clean and not damaged. No sign of spoilage on organoleptic inspection.	For each lot receiver to ensure that the contractual specifications are respected by the supplier. Record and compares kill/ pack date (age of product), temperature and container condition to specifications. One carton/pallet subjected to organoleptic inspection by receiver and record observations and product temperature	Receiver place non-compliant product on "hold" Inform supplier, QC and processing foreperson Product returned or QC test and proper disposition	QC to verify receiver's records "X" times/ week QC to verify product temperature and take sample for micro testing "X" time/ month	Receiver's records QC verification records Bacteria test results
		Chicken Meat: (bone and plastic particles)	≤2mm for bone or plastic particles	Receiver perform boneless chicken reinspection for each shipment until "X" consecutive lots passed, then select every "X"th shipment	QC notified. Shipment placed on "hold" and either returned or reworked	QC to observe and verify records for boneless chicken reinspection "X" times/month	Receiver's reinspection records QC verification records

Process Steps	CPP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#1 Receiving (cont'd)	CCP-1BPC	Spices and Vegetable Oil: (pesticide residues, mycotoxins and allergens and for spices, fumigant residues) Chicken Meat: (antibiotic, sulphonamide and coccidiostat residues)	Health Canada Standards	For each lot received, receiver ensure signed contract with supplier on file and record same. Contract to include plant specific specifications and compliance with Health Canada standards, eg., extraneous material less than 2 mm and freedom from allergens as applicable	Receiver place non-compliant product on "hold" and inform QC, supplier and processing foreperson pending signed contract or refuse shipment	QC verify receivers records "X" times/ month	Receiver's records QC verification records
		Spices and Salt (hazardous extraneous material)	less than or equal to 2mm	For each lot received, receiver ensure signed contract with supplier on file and record same. Contract to include plant specific specifications and compliance with Health Canada standards, eg., extraneous material less than 2 mm and freedom from allergens as applicable	Receiver place non-compliant product on "hold" and inform QC, supplier and processing foreperson pending signed contract or refuse shipment	QC verify receivers records "X" times/ month	Receiver's records QC verification records
		Spices, Sugar, Glucose Solids, Dextrose (contamination with pathogenic bacteria)	Plant specific Contractual specifications	For each lot received, receiver ensure signed contract with supplier on file and record same. Contract to include plant specific specifications and compliance with Health Canada standards, eg., extraneous material less than 2 mm and freedom from allergens as applicable	Receiver place non-compliant product on "hold" and inform QC, supplier and processing foreperson pending signed contract or refuse shipment	QC verify receivers records "X" times/ month	Receiver's records QC verification records

Process Steps	CPP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#1 Receiving (cont'd)	CCP-1BPC	Wheat flour, Corn flour, Toasted wheat, Crumbs and Starch: (mycotoxin(s) Pesticide residue and allergens	Health Canada Standards	Signed contract specifying absence of mycotoxins & compliance with Health Canada Standards	Receiver place non-compliant product on "hold" and inform QC, supplier and processing foreperson pending signed contract or refuse shipment	QC verify receivers records "X" times/ month	Receiver's records QC verification records
		Packaging material (non-food grade material)	No packaging material not listed by AAFC to be received	For each lot received, receiver ensure packaging material is listed	Receiver place non-compliant product on "hold" and inform QC, supplier and processing foreperson pending signed contract or refuse shipment	QC verify receivers records "X" times/ month	Receiver's records QC verification records
#7 Boning & Sizing	CCP-2P	(bone or plastic particles)	less than or equal to 2mm	Designated employee perform Boneless chicken reinspection on each lot after or during (on line) boning	Notify QC and hold product Rework entire lot then reinspect again Correlate/retrain employees	QC to verify reinspection procedure and records "X" times/ month	Reinspection records QC verification records
#11 Massaging	CCP-4P	(Growth of pathogenic bacteria)	Maximum "X" hr per cycle at "X"°C maximum	Designated employee record time and product temperature in/out and room temperature	Designated employee "holds" product and notifies QC If deviation does not exceed "X"o C or "Y" time, then product can be redirected to cooked product. If it exceeds these limits, QC decide on product disposition	QC verify records and product tags "X" times/month	Massage and QC verification records

Process Steps	CPP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#11 Massaging (cont'd)	CCP-4P	(Allergens)	Correct ingredients as per recipe	Designated employee performs recipe ingredient check off/ formulation records, completes and tags/ID product	QC hold product Relabel (correctly) product	QC verify records and product tags "X" times/month	Formulation records QC verification records
#18 Metal Detector	CCP-4P	Metal particles in meat product	Max. 2 mm ferrous & non ferrous	Foreperson will check/ recalibrate every "X" hours to ensure metal detector is working and record findings	Foreperson to notify QC and to hold the previous "X" hours production Repair detector Recheck held product for metal Product rejected by metal detector examined by foreperson and QC to establish probable cause and correct source of metal piece(s) if of processing plant origin or notify supplier if applicable	QC to verify records and test metal detector "X" times/week	QC records on metal detection audit Metal detector records
#22 Coding, Sealing & Labeling	CCP-5C	Allergic reactions due to incorrect list of ingredients	Correct label	Foreman to check every "X" hour to ensure correct code and label	Foreperson notify QC and hold product from last "X" hours production. 100% reinspection. Correct condition	QC verify records "X" times/week and correlate label vs formulation records	QC records on coding and labeling

In most cases, the battered and breaded products are distributed frozen, where proper labeling (i.e., keep frozen) should clearly appear on the package. Instructions aimed at proper cooking for the consumer are critical to ensure pathogen destruction since the product can be sold as partially cooked (e.g., par-fry for only 30-60 sec used to "cement" the outside coating, but the meat inside is not cooked). Breaded meat products can be fully cooked by the processor where a HACCP model referring to a fully cooked product, is used (i.e., clearly indicated in the product description form).

Table 14.10.4 provides an example of a record keeping sheet for the metal detector (see Chapter 10 for description of a metal detector) and carton sealing operations. As indicated in Chapter 6, part of the verification process can be the inclusion of a test sample containing metal particles (sample should be very clearly marked) to ensure that it is identified by the metal detector. The information collected within the HACCP record sheets should be shared with all parties concerned, so effective and immediate corrective actions can be taken. The forms should also be kept on file so a government inspector can access it at any given time. Some countries require that forms will be kept on file for five years.

Table 14.10.4 Example: HACCP record keeping sheet – metal detector used to scan products. From CFIA (1998).

Time	Product Name	Good Carton Seal		Correct Code Date *		Correct Label *		Metal Detector Rejects Metal Test Samples	
		Yes	No	Yes	No	Yes	No	Yes	No
Y = Yes N = No * Note: Attached a copy of label(s) with code date(s)									

Figure 14.10.1 shows a safe handling instruction label suggested by the American Meat Industry and the USDA. The label is based on simple icons to remind the consumer to use common sense when handling perishable meat products. The use of icons is important, as not all customers can read the text.

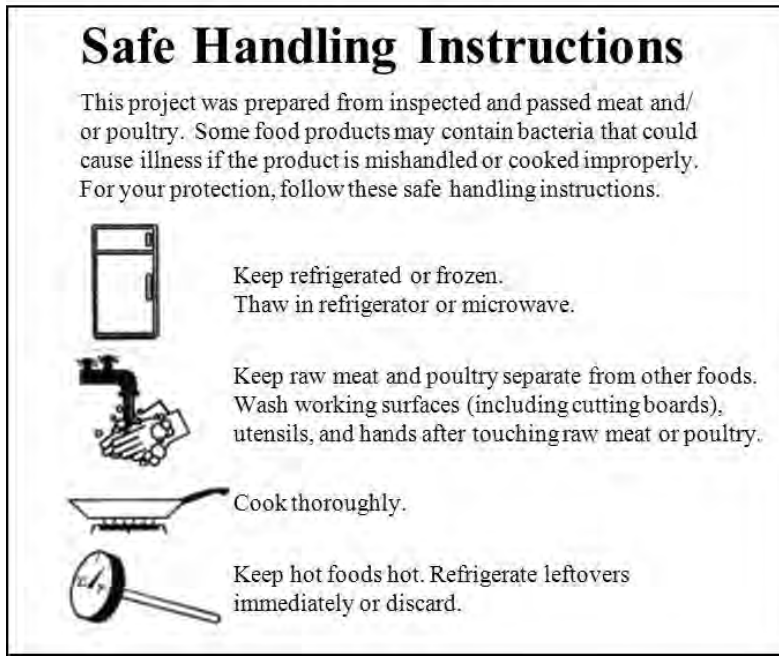


Figure 14.10.1 An example of a safe-food handling label, used by several companies in North America.

Overall, the benefits of a good HACCP plan are: preparing food products in a safe way, meeting government regulations in a systematic way, as well as being able to quickly respond to production problems. The last point can also be used as a strong argument to implement HACCP as the plant will save money, time, and product. From a government point of view, a good national HACCP system can help streamline resources for inspection agencies. As mentioned in Chapter 6, continuous improvement of HACCP programs should be an important part of the HACCP plan since it will assist in enhancing procedures in the plant (Barbut and Pronk, 2013).

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15

MICROBIOLOGY AND SANITATION

15.1 Introduction

The overall goal of the food industry is to produce wholesome, nutritious, and tasty food for the consumer. Producing a wholesome, safe food with a reasonable shelf life is a challenge especially when there are so many steps involved in production (e.g., growing farms, processing plants, distribution channels). Today most food is produced far from the consumer and it could be days or weeks before the food is consumed. This presents challenges to all involved in the production chain (e.g., farmer, processor, retailer, food handler), but this is definitely not a new issue (Newell et al., 2010). There is still a big difference between developed and developing countries in terms of dealing with food safety and food borne diseases (e.g., surveillance, budget allocated to deal with the problem). According to the World Health Organization, about 1.8 million people in developing countries die each year as a result of diarrheal diseases related to contaminated food and water. However, food borne diseases are not just a problem of the developing world.

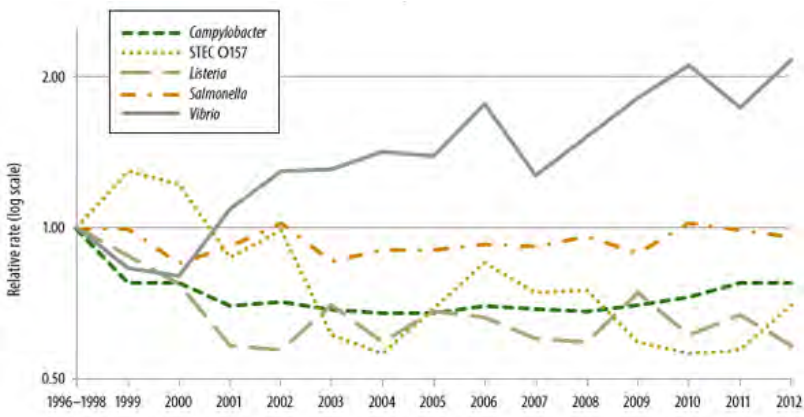


Figure 15.1.1 Relative rates of laboratory-confirmed infections with *Campylobacter*, STEC0157, *Listeria*, *Salmonella*, and *Vibrio* compared with 1996-1998 rates, by year – Foodborne Diseases Active Surveillance Network, United States, 1996-2012. From CDC.

Even in developed countries like the US, roughly 1 in 6 people get sick (~48 million people), 130,000 are hospitalized, and 3,000 die from food borne diseases, with an estimated cost of about $51 billion annually (Scharff, 2011). The good news is that, for most food borne diseases, the incidence is decreasing. Figure 15.1.1 shows the decline in some of the major pathogens seen in North America from 1996 to 2012. The increase in *Vibrio* appears to be large but it should be kept in mind that the 2012 rate per 100,000 inhabitants was 0.41 compared to 14.3 for *Campylobacter*. Data from England and Wales also shows general reduction trends (Fig. 15.1.2).

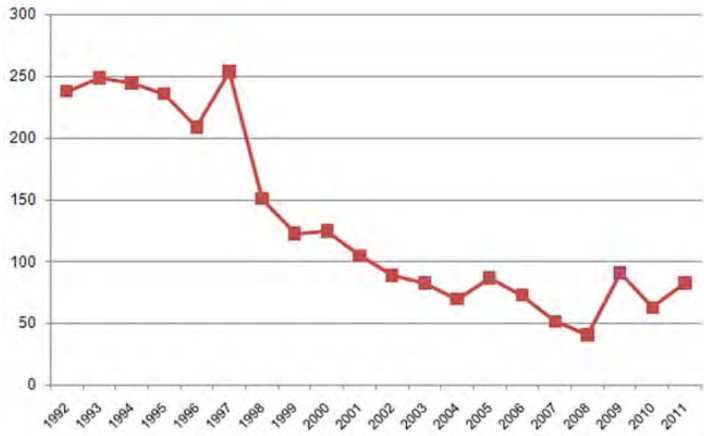


Figure 15.1.2 Total number of foodborne outbreaks in England and Wales, 1991 – 2011. From Health Protection Report (2012). http://www.hpa.org.uk/hpr/archives/2012/news1812.htm

These data represent a concentrated effort of both government and industry to enhance food safety programs and reduce associated costs (e.g., lost work days and productivity). When discussing food borne diseases it is also important to consider pathogen distribution and illness severity. Figure 15.1.3 shows that in the USA about 60% of the cases are associated with Norovirus outbreaks (note: some are associated with food and some with person to person transmission). In 2008 there were about 5.4 million cases but only 150 deaths (0.050 deaths/100,000 inhabitants) whereas *Salmonella* resulted in about 1.0 million cases and 38 deaths (0.126 deaths/100,000 inhabitants). The symptoms of Norovirus include fever, vomiting, and diarrhea and usually only last for a day or two (sometimes called the 24-hour flu). Mortality is very low and usually occurs due to complications from other diseases.



Figure 15.1.3 Top pathogens 2000 – 2008. From CDC. http://www.cdc.gov/Features/dsFoodborneEstimates/dsFoodborneEstimates_270px.jpg

Figure 15.1.4 summarizes the outbreaks and total number of illnesses associated with different food commodities. While meat is a cause of illness, produce (fruits and vegetables) that are grown in or close to the ground represent a higher risk to the consumer. Additionally, often produce is not heat treated prior to eating. This brings to light the importance of looking at the entire production chain (farm to fork) in terms of an integrated prevention approach.

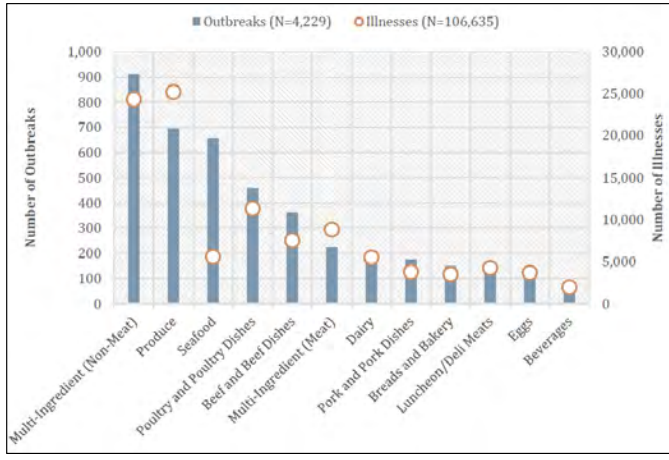


Figure 15.1.4 Outbreaks and illnesses due to food commodities, 2001-2010. From CSPI (2013).

Figure 15.1.5 shows a schematic illustration of the different points along the chain that is applicable for most food products. More information related to this topic and to Figure 15.1.4 is found in the report by Gould et al. (2013), who surveyed food borne diseases in the US from 1998-2008.

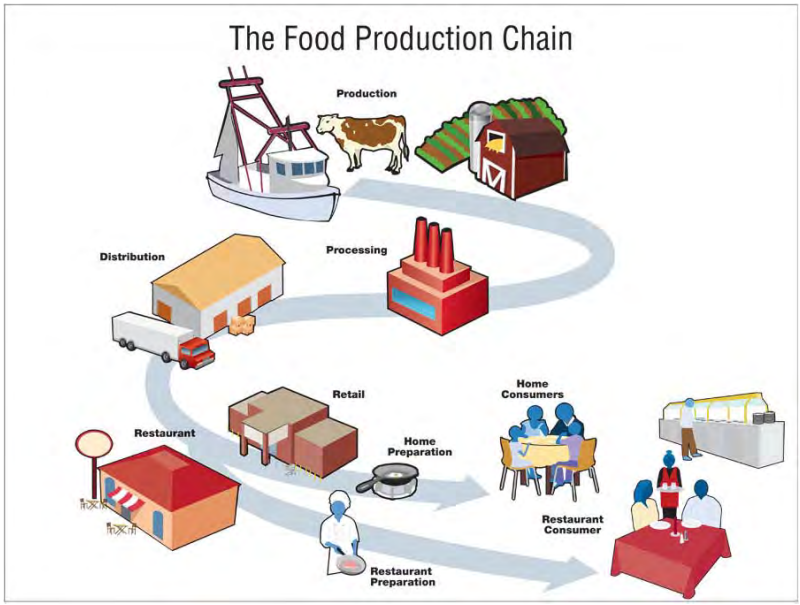


Figure 15.1.5 Food production chain. From CDC. http://www.cdc.gov/foodsafety/outbreaks/investigating-outbreaks/figure_food_production.html

In the US, incidence of food borne disease has been significantly reduced over the past decade (Fig. 15.1.6) where the number of *Yersinia*, *E. coli* O157, and *Shigella* cases were reduced by 53%, 41%, and 55%, respectively (note: the US has one of the best surveillance programs, which helps to look at overall trends). *Campylobacter*, *Listeria*, and *Salmonella* were reduced by 30%, 26%, and 10%, respectively. These decreases have been the result of implementing better surveillance and reporting (i.e., problems are flagged and dealt with faster), mandatory implementation of specific programs such as Hazard Analysis Critical Control Points (HACCP) and the mandatory Microbial Performance Standards for the meat industry (see Chapters 6 and 12 on HACCP).

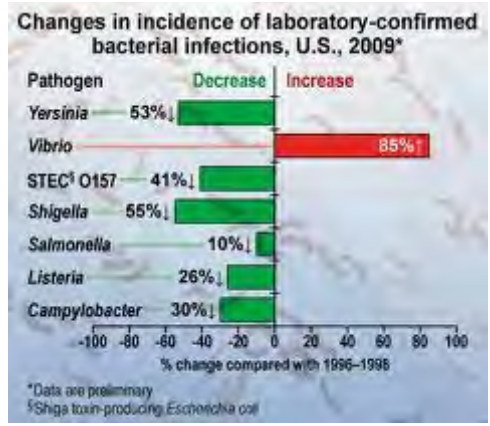


Figure 15.1.6 Changes in bacteria infection 2009. FromCDC. http://www.cdc.gov/Features/dsfoodnet2012/figure1.html

Table 15.1.1 shows the Progress Report for some major pathogens in the US and includes the current infection rate per 100,000 inhabitants and regulatory target values. Most years there is a positive move towards approaching these targets.

Table 15.1.1 Food safety – progress report. From CDC. http://www.cdc.gov/foodnet/data/trends/trends-2012-progress.html



However the table also points out the well-documented problem of under reporting of food borne illnesses, where the cases of patients with relatively mild symptoms are not reported (i.e., they do not seek medical advice) and/or the cause is not fully identified (e.g., doctor sees a patient but no sample is sent to the laboratory). The same is seen in data from Australia (Table 15.1.2) and other countries. The table also allows comparison to the US data presented above. Information from different countries can be found in EFSA (2010) and on other websites. As indicated above, the goal of the food industry is to supply wholesome, nutritious, and safe food.

Table 15.1.2 Estimated incidence of diseases potentially transmitted by food and research summary findings - Australia. From Angulo et al. (2008).

Disease	No. of cases reported nationally	Estimated no. of annual infections[a] (95% credible interval)	Estimated percentage of foodborne diseases (95% credible interval)	Main food vehicles and research findings
Campylobacteriosis	~16,000	223,000 (93,800–362,800)	75 (67–83)	9.6 community cases per case reported to surveillance; infections acquired from chicken (50,000 cases), offal (3500 cases), and pets (8500 cases); low levels of fluoroquinolone resistance among human isolates; molecular typing (*flaA*) improves risk factor identification
Salmonella infection	~8400	48,700 (15,000–91,300)	87 (81–93)	7.6 community cases per case reported to surveillance; *Salmonella* Mississippi (~75 cases annually, 80% of cases in Tasmanian residents; drinking untreated was the water main risk factor, exposure to native birds was important); *Salmonella* Enteritidis (~380 cases annually, ~50 cases locally acquired annually, 75% of cases occurred in Queensland residents, predominantly phage type 26, absent in commercial egg-laying flocks)
Listeria infection	~60	120	98 (92–100)	Host factors were the most important predictor of disease, risky foods were commonly eaten; perinatal case-fatality rate, 25%; nonperinatal case-fatality rate, 25%
Shiga toxin–producing *Escherichia coli* infection	~80	3800 (1000–33,000)	65 (48–82)	High rate in South Australia because of intensive screening of bloody stool samples (2%-4% of bloody stool samples were *stx* positive); predominantly serotype O157; animal exposure was an important predictor of disease

[a] Adjusted for underreporting.

We know that this requires a farm to fork approach (Fig. 15.1.5), which also includes more emphasis on the consumers role in food handling at home (Fig. 15.1.7; see additional discussion below). In this chapter the microbiological issues at the major production/processing points (e.g., growing farm, transportation, processing plant, distribution, and home/restaurant food preparation) are discussed using evidence from several systematic reviews including meta-analyses and meta-regressions of a large number of primary studies. Additionally, you will find a general description of the six major bacteria associated with food borne disease, and discussion on cleaning and sanitary equipment design.



Figure 15.1.7 Logo of the Partnership for Food Safety Education. Safe food handling. www.fightbac.org/safe-food-handling.

15.2 Major Pathogenic Bacteria of Concern in Poultry and Red Meat

Fresh meat is a perishable commodity and therefore should be treated with care. The shelf life of fresh meat, which is related to the growth of spoilage microorganisms, depends on many factors. Among the most important are the initial microbial load (contamination), storage time and temperature, the intrinsic properties of the meat (e.g., pH, nutrient content), and the degree of processing. The latter will be discussed in more detail while focusing on poultry meat; however, the same processing parameters also apply to other meat producing animals and include steps such as evisceration, cutting and chilling. Healthy muscle tissue is basically free of bacteria but it can become contaminated during processing as it comes in contact with microorganisms from the "outside" of the animal (e.g., skin, feathers, hair), the environment (e.g., air, water used for rinsing), and the "inside" of the animal (e.g., intestine). The bacterial load in intestinal contents or in dirt adhering to feathers/skin can be as high as $10^8 – 10^9$ microorganisms per one gram or one ml. Meat sold at the store is definitely not sterile and usually contains $>10^2$ colony forming units (CFU) per gram when it is very fresh. Figure 15.2.1 shows a graph produced in the 1960s that represents the relationship between contamination level and shelf life. In addition to spoilage microorganisms, meat can also be a vehicle for human pathogens that cause food borne disease (e.g., *E. coli*, *Salmonella*, and *Campylobacter*), the cost of which can be very high. Some human pathogens

are carried asymptomatically in the intestine of healthy animals. For example, the prevalence of *Campylobacter jejuni* and *Salmonella typhimurium*, which are not pathogenic to animals such as broilers and pigs, can range from 0 to 100% as reported by Mulder and Schlundt (1999) who summarized numerous studies conducted in different countries. Mead (2000) also reviewed *Salmonella* contamination in fresh poultry meat in Germany, India, the Netherlands, the UK, and the USA between 1990-1994 and indicated levels varying from 4 to 100%. Other examples of common food borne pathogens that can be present in meat include *Clostridium perfringens* (i.e., a common intestinal microorganism), and *Staphylococcus aureus* (i.e., carried on the skin of animals, including humans).

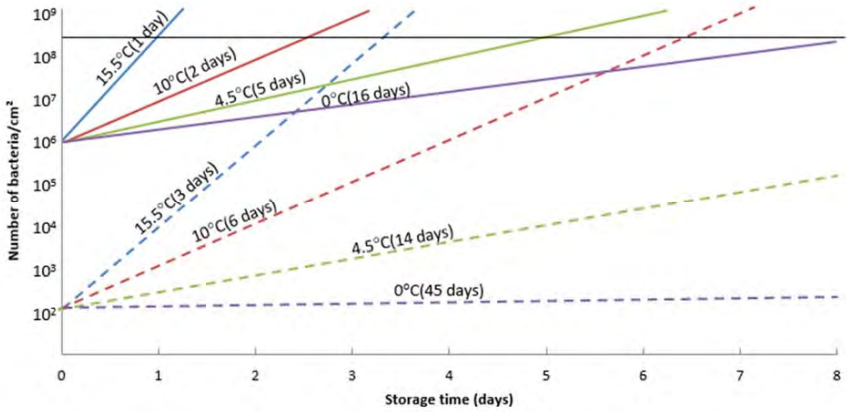


Figure 15.2.1 Effect of storage time, temperature and contamination level on time required for the spoilage of frankfurters (contaminated with high and low levels of psychrophilic bacteria). Spoilage detection (by slime formation) was at a population level of 150 million bacteria/cm^2 of surface area. The high level of contamination was 1 million/cm^2, shown by the solid lines; the low level was 100 bacteria/cm^2, shown by the broken lines. Redrawn from Zottola (1972).

The modern food/meat industry uses different interventions (physical, chemical, and biological) to minimize microbial contamination and multiplication that correspond with the varying modes of action of different bacteria. Food borne diseases are caused by microorganisms that invade the host and/or secrete toxins prior to or after their consumption. Invading microorganisms can cause gastrointestinal disturbances when they stay in the intestines or septicemia and other illnesses when they cross into the blood stream and reside in organs (e.g., *E. coli* O157:H7 in the kidney). It is important to note here that not all gastrointestinal

disturbances are caused by microorganisms, but can also result from overeating, allergic reactions, and chemical poisoning.

As indicated above, pathogenic bacteria can cause:

a. Infection resulting from the ingestion of pathogens that invade and grow inside the human body (e.g., *Campylobacter*, *Salmonella*)
b. Poisoning resulting from the ingestion of toxins. Toxins produced by non-invading microorganisms can be divided into exotoxins, which are secreted into the environment/food by bacteria such as *Clostridium botulinum*, and endotoxins, which are released upon the death of a microorganism

15.2.1 *Campylobacter jejuni*

Campylobacter jejuni is a Gram-negative, rod shaped (≈ 4 μm long and 0.3 μm wide), spiral curved, micro-aerophilic bacterium (Fig. 15.2.1.1) that can cause food borne infection. The infectious dose is fairly small; as few as 500 bacteria can cause illness. Symptoms include headache, fever, diarrhea, severe abdominal pain, and sometimes bloody stools.



Figure 15.2.1.1 Morphology of *Campylobacter jejuni* and *E. coli* http://commons.wikimedia.org/wiki/file:ars_campylobacter_jejuni.jpg

C. jejuni does not usually multiply at temperatures < 30°C. It is found in the digestive tract of warm blooded animals (poultry, beef, pigs) and also in contaminated water (e.g., by sewage). Cross-contamination of carcasses during processing and handling can be a challenge (Guerin et al., 2010). Data from sporadic cases suggest that handling, preparation, and the consumption of undercooked meat including poultry are particular risk factors. In the US, broiler chicken, Cornish game hen, and, to a lesser extent, turkey meat consumption has been linked to human campylobacteriosis. In most countries, *C. jejuni* is common in poultry meat and up to 100% of flocks may carry it. Counts from poultry skin can exceed 10^4 colony forming units (CFU) per gram, but levels of contamination are often reduced during processing to about 10^1 CFU/g or 10^3 to 10^5 per carcass. In poultry, the bacteria can be isolated from wings, thighs, breast meat, and abdominal cavities, which indicates a general carcass distribution. Some reports show a lower contamination rate for frozen versus chilled poultry as freezing can injure the bacteria. However, other reports suggest this may also be influenced by the method of isolation and whether or not damaged cells were recovered. *C. jejuni* can also be controlled by cooking since it is a heat-sensitive bacterium; normal cooking temperatures are sufficient to destroy it.

Between 2004 and 2008 campylobacteriosis was the most frequently reported zoonotic disease in the European Union and fresh poultry meat was one of the most important reservoirs of human infection (Pasquali et al., 2011). When it comes to live bird/pre-harvest control, the European Food Safety Association (EFSA, 2010) believes that reduction of *Campylobacter* prevalence and load in live poultry is one of the most effective ways of reducing the contamination of foodstuffs and the number of human *Campylobacter* cases. Current pre-harvest strategies available to reduce *Campylobacter* contamination in poultry production include the application of on-farm biosecurity measures, litter decontamination, feed supplementation with compounds that inhibit *Campylobacter*, and drinking water treatment (see additional discussion below about competitive exclusion). Moreover, novel strategies that specifically target *Campylobacter* control at the pre-harvest level include probiotic administration, vaccination, antibiotics, and antimicrobial alternatives (e.g., bacteriophages, bacteriocins).

15.2.2 *Salmonella*

Salmonella is a Gram-negative, facultative-anaerobic, rod shaped bacterium (Fig. 15.2.2.1) that is non-spore forming and found in both warm and cold blooded animals as well as the environment. It is a motile enterobacterium that is about 1 x 2-5 μm in size, with a peritrichous flagellum. *Salmonella* is one of the most commonly cited bacteria in reference to poultry consumption but it is also a concern

in red meat (e.g., pork). As with other bacteria, some strains are pathogenic to humans (e.g., *S. typhi*) but not to other animals. Salmonellosis is the name for the infection that can result from ingestion of any of about 2,600 serovars.



Figure 15.2.2.1 Morphology of *Salmonella*. From Wikipedia. Credit: Rocky Mountain Laboratories, NIAID, NIH. http://en.wikipedia.org/wiki/Bacteria

In the past microbiologists treated each serovar as if it were a separate species; however, significant changes in taxonomy have grouped all *Salmonella* serovars into two species: *S. enterica* and *S. bongori*. These are further divided into six subspecies or groups, most of which are classified under *S. enterica* (Jay et al., 2005). Only some serovars are associated with salmonellosis, which is caused by endotoxins released by bacteria ingested by the host. The common symptoms consist of nausea, vomiting, diarrhea (defense mechanisms of the body to quickly remove an infectious material from the body), fever, and abdominal pain. Symptoms usually appear 6 – 24 hr after consumption of contaminated food. The infectious dose is approximately 10^6 organisms for a healthy adult but would be lower for individuals who are very young (e.g., 10^3 of virulent strains), old, or have a compromised immune system. Mortality from salmonellosis is generally low (see discussion in Section 15.1), with fatalities occurring in infants (< 5 years old), the

elderly, or people who are already affected by other diseases. Because *Salmonella* can be present in animals' digestive tracts without causing symptoms, a major cause of transfer to the meat results from cross-contamination of carcasses during evisceration and chilling. Later, cross-contamination of raw and cooked food can also be a significant problem. *Salmonella* is a fairly heat sensitive bacteria and cooking procedures for meat are designed to sufficiently destroy most *Salmonella* serovars (e.g., 1 min at 65.0°C, 5 min at 62.2°C, 12 min at 60.0°C and 37 min at 57.2°C). Most cooking guidelines for poultry and red meat specify a minimum internal temperature of 70°C, which results in inactivation within a few seconds.

The industry is also working on preventative measures during the growing stage by using procedures such as competitive exclusion (Kerr et al., 2013; see later discussion in the chapter) and vaccination (Bohez et al., 2008), and during processing through procedures such as carcass decontamination with chlorine/acid washes (see further discussion below). Overall, controlling *Salmonella* in the live animal is becoming increasingly important (e.g., antibiotic resistant strains). Domestic poultry may acquire *Salmonella* from three main sources: parents/breeding stocks; the environment (contact with wild birds, mice); and consuming contaminated feed. During hatching, a few contaminated eggs can spread the bacteria. Later, on the farm, birds that carry *Salmonella* shed the organism, which can then be spread via drinking water, feed, or litter. Breeding flocks are routinely scanned for *Salmonella* and are either treated through antibiotics or competitive exclusion or culled when pathogenic strains are detected. Tests are also conducted in some growing farms (e.g., Europe) and problematic flocks are culled.

15.2.3 *Clostridium perfringens*

Clostridium perfringens is a Gram-positive, anaerobic, rod shaped, spore-forming, aerobic bacterium (Fig. 15.2.3.1) that can cause infection in humans. It is found widely in nature in soil, water, and the intestinal tracts of animals and humans. It can produce a variety of toxins and large volumes of gas when exposed to typical human body conditions. The infectious dose is large, $> 10^8$ vegetative cells, for a healthy host. Symptoms are relatively mild and include nausea, diarrhea, occasional vomiting, and abdominal pain that appear within 24 hr of consuming the contaminated food. Time to infection is relatively short because the toxins are already present in the food. Typical epidemic curves for the onset of *C. perfringens* gastroenteritis symptoms show time intervals between 1-24 hr with an average time of 11-13 hr. Variation among individuals can be the result of serving size, other foods consumed, sensitivity of the individual, etc. These times are important for physicians trying to diagnose and set up a treatment plan, as it can take a few days to culture a sample and identify the toxin.

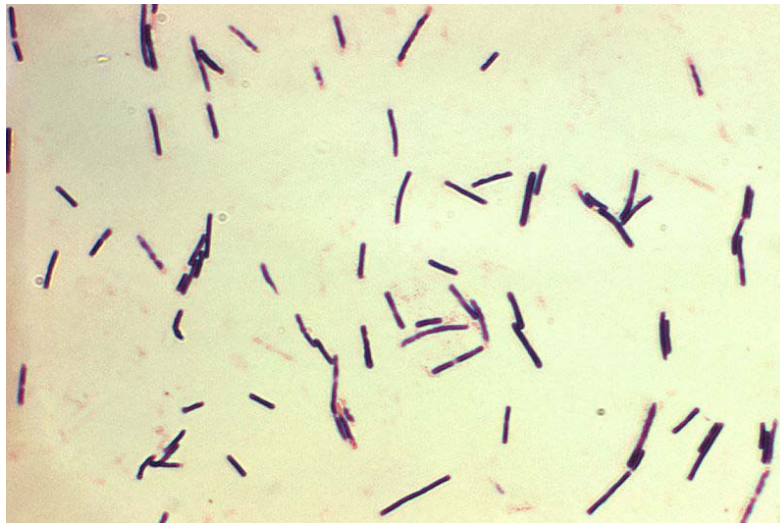


Figure 15.2.3.1 Morphology of *Clostridium perfringens*. From CDC. http://phil.cdc.gov/phil/home.asp

Risk reductions for *C. perfringens* infection focuses on fast chilling of cooked meat and other food products. Adequate refrigeration, especially of leftovers (i.e., best in small containers to achieve rapid cooling), and good sanitation are essential. *C. perfringens* is a special food safety concern because of its ability to form spores. During cooking most non-spore forming microorganisms are destroyed. If the food is cooled slowly this allows *C. perfringens* spores the chance to germinate with little or no competition. When foods are held on a steam table, temperatures should be kept above 60°C. In addition, when leftover foods are reheated, a thorough heating can help destroy the organism and its toxins.

15.2.4 *Listeria monocytogenes*

Listeria monocytogenes is a Gram-positive, non-spore-forming, catalase positive, rod shaped bacterium (Fig. 15.2.4.1). There are 11 species of *Listeria* and 17 serovars that are recognized by the antigen present. The primary pathogenic species, *L. monocytogenes*, is represented by 13 serovars. *Listeria* can produce lactic acid from glucose and other fermentable sugars and tends to be associated with bacteria such as *Lactobacillus* that produce lactate. The nutritional requirements are typical of those of other Gram-positive bacteria and they can grow in many common laboratory media. Although they grow best at pH 6 - 8, some strains, including *L. monocytogenes*, can grow over a pH range of 4.1 - 9.6 (Jay et al., 2005). *Listeria*

can also grow at refrigeration temperatures, with mean minimum growth at temperatures as low as 1°C. This makes it a special challenge for the food industry both in processing environments and in marketing products. The symptoms associated with listeriosis include fever, nausea, headache, vomiting, and, in severe cases, meningitis (bacteria gets into the nervous system), miscarriage in pregnant women, and septicemia. Symptoms usually appear within 1-4 weeks, but may appear more than 10 weeks later depending on the severity of the infection.

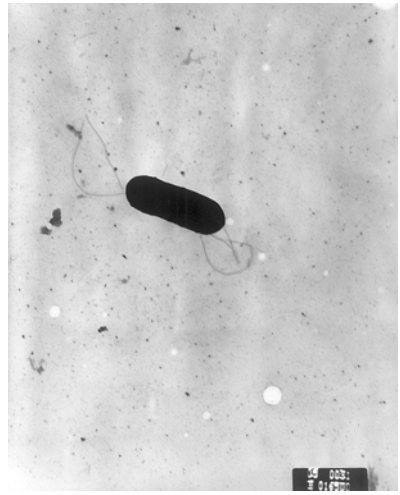


Figure 15.2.4.1 Morphology of *Listeria monocytogenes*. From CDC. http://phil.cdc.gov/phil/home.asp

Overall, *Listeria* is widely distributed in the environment and can be found in animal feces and in decaying organic material in soils, water, and sewage. Several reports have shown that a significant number of samples taken from the shoes of people living in a big city are *Listeria* positive. It is pretty well established that fresh foods of animal or plant origin may contain varying numbers of *L. monocytogenes*. Mead (2000) indicated that about 60% of raw chicken carcasses carry the organism in low numbers. The good news is that the bacteria is heat sensitive and is destroyed by normal cooking procedures (note: some countries require a time x temperature combination to achieve a 9 log reduction of *Listeria* in cooked products). It has been shown that a milk pasteurization protocol of 62.8°C for 30 min or 72°C for 15 sec is adequate to reduce normal population sizes to below detectable levels. In the past, cooked luncheon meat, chicken nuggets, and

cook-chill meats have been implicated in sporadic cases of listeriosis as a result of cross-contamination after cooking. In the US, a large recall of turkey hot dogs occurred after a multistate outbreak of listeriosis. This outbreak later changed the government's approach to food inspection. The bacteria was later isolated and identified (by DNA typing) in patient samples and hot dogs kept in the patients' refrigerators. Finding the outbreak source is an important part of identifying and correcting the problem. It can be a challenge to identify the causative agent, especially when symptoms appear weeks after the original infection took place. Most of us do not remember what we ate last week let alone last month and most opened packages are not stored long.

15.2.5 *Staphylococcus aureus*

Staphylococcus aureus is a Gram-positive, facultative anaerobic, coccus shaped bacterium (Fig. 15.2.5.1) that can cause food poisoning by ingestion of the exotoxins produced in the food prior to consumption. Some of the exotoxins act as enterotoxins in the host and cause an inflammation of the stomach and intestinal lining (called gastroenteritis). Usually, the infectious dose is high (10^5 - 10^6 growing cells) and, as with other food poisonings, the individual's age, state of health, and other illnesses affect the response. Symptoms can include nausea, abdominal cramps, vomiting, and possible diarrhea. The toxins affect the central nervous system and can also act as an antigen that triggers massive immune response, but mortality is low. If mortality does occur, the patient usually has a so-called co-morbidity. The organism is widely spread in nature (including on the skin of humans and other animals) and can be isolated from many healthy individuals. Therefore, food handling by infected people is one of the greatest sources of *Staphylococci* food poisoning and it is one of the most commonly reported food borne diseases in North America. Overall, the microorganism is a poor competitor that favours body temperature. Under favourable conditions, it will multiply to great numbers without significantly altering the flavour, colour, or smell of the food. Toxin production is most rapid around 20°C in foods with fairly neutral pH. However, the microorganism can grow at temperatures between 7 and 45°C. Foods associated with *Staphylococci* food poisoning usually include high protein foods (e.g., dairy, meat, custard and cream filled pastries) and foods that are handled frequently during preparation. While the microorganism is quickly destroyed by heat (e.g., 66°C for 12 min and < 1 min at 100°C), the enterotoxins require severe heat treatment for destruction (e.g., 121°C for 30 min).

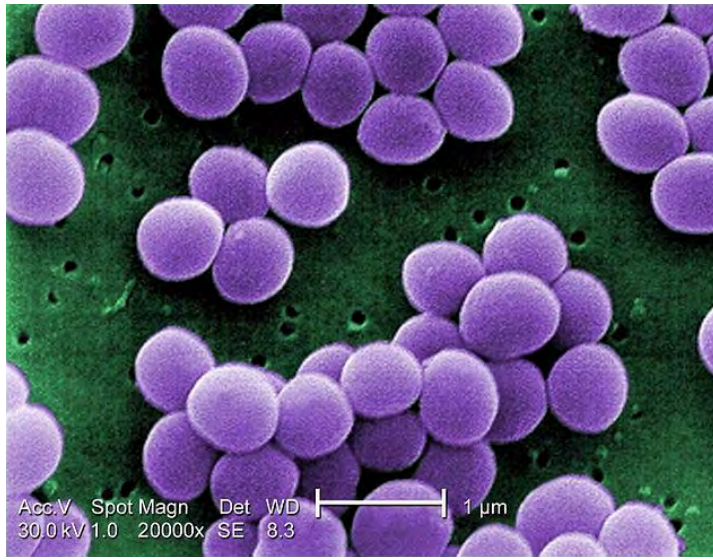


Figure 15.2.5.1 Morphology of *Staphylococcus aureus*.
From CDC. http://phil.cdc.gov/phil/home.asp

15.2.6 *Clostridium botulinum*

Clostridium botulinum is a Gram-positive, rod shaped, spore-forming, anaerobic bacterium (Fig. 15.2.6.1) that can cause food poisoning by a deadly toxin produced in the food during storage. The bacteria form spores that make them resistant to conventional cooking (i.e., in a commercial canning operation a temperature of 121°C is commonly used). *C. botulinum* is found primarily in soil and debris stuck to feathers and skin. The toxin is one of the most potent toxins known and nanogram quantities are extremely dangerous. It affects the central nervous system by blocking the chemical messenger acetylcholine (see Chapter 3) that is used to transfer messages among nerve and muscle fibers. By doing so, the toxin effectively blocks messages from the brain. Initial symptoms include impaired vision, speaking, and breathing as communication between the brain and peripheral organs is interrupted. Respiratory system failure is the first major danger to the victim, and therefore one of the most important initial treatments is breathing assistance where victims are placed in a pressure chamber used to treat diving accidents. The toxin is activated by the enzyme trypsin in the host's digestive system prior to being absorbed into the blood stream. Historically, improperly prepared, low to medium acidity home-canned vegetables, fruits, and meat constituted the largest potential source of botulism. Because the bacteria are

anaerobic, canned and vacuum packaged foods, including meat, are a potential medium for growth. In general, the prevalence of *C. botulinum* spores in meat is fairly low and poisoning from canned or vacuum packaged meats is rare. Severe heat treatments (e.g., 121°C, as used in the canning operation) are not common in meat products so the industry uses nitrite (a chemical) to inactivate the spores. This is an effective way of preventing spore growth in vacuum packed meat products (see Chapter 11). The toxin itself is relatively heat labile (inactivated at 85°C for 15 min, or 100°C for 1 min) while the spores are quite resistant to heat as indicated above. Other means of growth suppression are decreased water activity (< 0.94), low pH (< 4.65), added salt (> 10%), and refrigeration temperatures. Most *C. botulinum* serovars will not grow below 7°C. Canned products that show swelling due to gas produced by microbial activity should always be discarded as they indicate that some microorganisms (potentially including *C. botulinum*) survived the heat treatment.



Figure 15.2.6.1 Morphology of *Clostridium botulinum*.
From CDC. http://phil.cdc.gov/phil/home.asp

15.2.7 *Escherichia coli*

Escherichia coli is a Gram-negative, rod shaped facultative anaerobic bacterium (Fig. 15.2.7.1) that can be found in great numbers in the intestinal tract of healthy animals and humans, as well as in soil, water, and on the surfaces of fruits and vegetables. *E. coli* was established as a food borne pathogen in 1971 when cheese imported to the US was found to be contaminated with an entero-hemorrhagic

strain that caused illness in a few hundred people. Prior to that, at least five outbreaks had been reported in other countries, with the earliest being in the UK in 1947. However, evidence suggests that *E. coli* was recognized as a source of infant diarrhea as early as 1700. The six pathogenic strains of *Escherichia* are serologically typed in the same way as other members of the *Enterobacteriaceae* family. Over 200 "O" serovars (which indicate the presence of a somatic antigen) have been recognized. "H" antigenic types, which indicate the presence of a flagellar antigen, are also used for identification (Jay et al., 2005).

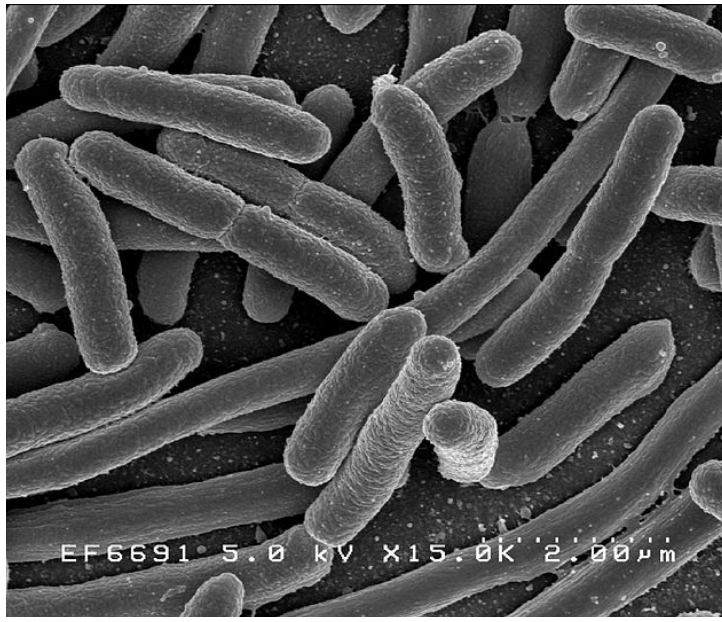


Figure 15.2.7.1 Morphology of *Escherichia coli*. Credit: Rocky Mountain Laboratories. From Wikipedia. http://en.wikipedia.org/wiki/Bacteria

There are four major types of pathogenic *E. coli*, but only the first two types are major causes of foodborne illness in North America:

a. Enterotoxigenic *E. coli* (ETEC) – associated with diarrhea and dehydration. A known cause of "traveller's diarrhea", which usually lasts a few days (note: host specific).
b. Enterohemorrhagic *E. coli* (EHEC) – e.g. *E. coli* O157:H7, where a low number of cells (10^1 – 10^3) can cause infection by penetrating the

intestinal wall and colonizing organs such as the kidney. Symptoms include abdominal pain, bloody diarrhea, vomiting, and in severe cases, kidney failure. It is often associated with undercooked beef and is also known as "Hamburger disease".

c. Enteroinvasive *E. coli* (EIEC) – high dose is needed (10^8 cells) for infection. Symptoms include diarrhea, dehydration, and fever.
d. Enteropathogenic *E. coli* (EPEC) – high dose required and symptoms mainly include diarrhea.

The presence of high numbers of non-pathogenic *E. coli* in fresh meat indicates poor sanitary conditions during its processing and handling. In fact, the presence of *E. coli* is used as an indicator of fecal contamination in drinking water.

15.3 Growing and Live Haul – Microbial Considerations

Farm animals are not raised in a sterile environment and microorganisms can be found on floors, soil, equipment, feed, skin, feathers, and in high numbers in the animal's digestive system. Live animals entering a processing plant carry a natural, diverse microflora that is mostly not pathogenic to humans. The microflora reflects the normal growth of animals on litter floors, exposure to the natural environment, and contact with wildlife (litter beetles, mice, birds). However, animals can also carry several human pathogens such as *Salmonella* and *Campylobacter*. Only occasionally do young poultry show symptoms of *Salmonella* infection; i.e., in most cases they are only healthy carriers of this pathogen (Bilgili, 2010; Jay et al., 2005). In some countries, such as Sweden, comprehensive *Salmonella* eradication programs have been initiated. They include monitoring the birds starting at the grandparent breeder flock level and all the way to the growing farms. Positive breeder stocks are usually eradicated through special indemnity programs while regular positive flocks are either eradicated on the farm or slaughtered, at a processing plant, under special arrangements (e.g., at the end of the day). This is an expensive way to control *Salmonella* and most countries have not adopted all these practices. However, monitoring breeder stocks is a common practice around the world and infected flocks are medicated, vaccinated, or culled.

A newer approach to control *Salmonella* at the farm level is competitive exclusion (Garcia and Brufau, 2010). This approach recognizes that newly hatched chicks are susceptible to *Salmonella* because the hatcheries are strictly sanitized environments. Because chicks have no contact with parent birds, they are slow to develop an intestinal microflora that could successfully compete with ingested

pathogens. Nurmi and Rantala (1973) studied the effect of establishing an adult-type gut microflora in young chicks by orally dosing them with suspensions of anaerobic cultures of gut contents from adult, *Salmonella*-free poultry. The treated chicks became resistant to an oral challenge of about 10^6 *Salmonella* CFU/bird. The protective effect was not significantly influenced by breed, strain, or sex, but depended upon the introduction of viable bacteria, especially anaerobes (Mead, 2000; Garcia and Brufau, 2010). Over the years, attempts have been made to specifically identify and isolate protective bacteria and to develop defined cultures with known composition. However, these isolates were usually less protective than anaerobic cultures of gut content, and tended to lose their protective capability over time. A number of commercial preparations are based on undefined cultures of caecal material. Although these cultures are screened to ensure the absence of avian and human pathogens, the FDA currently does not allow marketing undefined cultures in the US. The preparations are used for newly hatched chicks that are spray inoculated in the hatchery. Birds are wetted on the upper part of the body and later ingest treatment organisms while preening themselves. The treatment can also be applied to older birds/breeding flocks that have been identified as *Salmonella* carriers. Treatment in this case is given after an antibiotic therapy usually delivered via the drinking water. Overall, competitive exclusion must always be combined with good husbandry hygiene because, while the protective flora is becoming established, the birds will remain susceptible to infection. It should be pointed out that the complex mechanism of protection is not fully understood and is likely influenced by factors such as gut pH and Eh, inhibitory substances such as H_2S and bacteriocins, and competition for receptor sites (Mead, 2000; Kerr et al., 2013).

Competitive exclusion is currently used in numerous places and shows no adverse effects on bird health or growth performance. Kerr et al. (2013) performed meta-analysis and meta-regression on 200 studies in this area and reported that a number of competitive exclusion products were effective in reducing *Salmonella* colonization in broilers. The most common route of administration was oral gavage (64% of trials), but spraying chicks at the hatchery was just as effective. Overall, this is a very important concept to help reduce/eliminate the use of antibiotics during livestock growing.

Other factors also play a role in the level of microbial contamination during the growing period. A partial list includes the cleanliness of the barn (e.g., in between flocks, during the growing season), barn conditions (e.g., relative humidity that affects litter drying), contact with wildlife (e.g., bugs, small birds, mice), and feed preparation (e.g., pelleting using heat can inactivate microorganisms). However, it is beyond the scope of this book to cover all of these husbandry factors.

Live haul of birds starts with feed and water withdrawal (see Chapter 4) prior to catching and transporting the birds to a processing plant. The catching operation may be manual or mechanized and the transport crates/cages may be wood (hard to clean), metal, or plastic as described in Chapter 4. Minimizing stress during the loading and unloading operations is also an important step in reducing cross-contamination among birds. Stress during transport is known to cause changes in excretion patterns due to the disturbance of intestinal function. Excretion of pathogens, such as *Campylobacter* and *Salmonella*, will result in increased cross-contamination between birds in the same cage and possibly in the cages below if cage design does not prevent fallout of fecal material while allowing adequate ventilation.

During transportation animals/birds are placed in a new environment that consists of unfamiliar territory as well as different stresses (vibration, noise, wind, lack of food). A detailed description of the effect of factors such as travel time and temperature on live birds is provided in Chapter 4.

Cages should be cleaned and sanitized after each shipment to stop cross-contamination between flocks and farms. Rigby et al. (1980) and others showed that unclean transportation cages (from a previous batch) can transfer *Salmonella* to the next load. Jones et al. (1991) indicated that transportation does not necessarily result in uniformly increasing the frequency of *Campylobacter* contamination throughout the flock. As compared to wooden crates, cleaning and sanitation are much easier when plastic or metal cages are used because the surface is smoother. Modern poultry processing plants usually have an automated system for cleaning and sanitizing the crates. Proper cleaning should include the physical removal of visible dirt (feathers, manure) by scraping or a high pressure water jet, cleaning with chemical detergents, proper rinsing, and a final disinfection step (e.g., chlorine) should only be applied to a clean surface. The effectiveness of the cleaning procedure should be verified (see HACCP; Chapter 6).

15.4 Primary Processing – Microbial Considerations

Overall, the operations inside a poultry processing plant are complex (see Chapter 5) and usually performed at high speed (see Chapter 1). If done inappropriately, these operations can result in a high rate of cross-contamination. Cross-contamination may result from repeated contact with processing equipment, bird to bird contact, use of a common water bath for scalding and chilling, meat handling by employees, and contact with tools such as knives. Good manufacturing practices, hygienic

equipment design (see end of this chapter), and an adequate HACCP program can help reduce cross-contamination and improve the product's safety and shelf life. As in other food processing operations (dairy, fruits and vegetables), people working in the plant should be educated and work to minimize/eliminate contamination. Part of this training is included in the HACCP pre-requisite program (see Chapters 6 and 12), which includes instructions to wear clean clothes, hairnets, and use hand washing stations. It is important that employees recognize that animals arriving at the plant carry microorganisms on their skin (including soil, fecal material attached to hair/feathers) and inside their intestinal tracts (high numbers of 10^8-10^9 CFU/gram) and respiratory systems.

Regulatory guidelines dealing with specific meat pathogens differ among countries, but there has been a general trend of increasing regulations over the years (Barbut and Pronk, 2014; EFSA, 2010). This has required processors to employ more/new intervention strategies and to better understand the whole process. There appears to be more emphasis on physical decontamination methods in Europe while North American countries focus on both chemical (e.g., chlorine) and physical (e.g., hot water) decontamination methods. An example of the evolution of standards is the previous American *Salmonella* standard (USDA-FSIS, 1996), which required prevalence of less than 20% (12 positive out of 51 samples). Later, pathogen reduction data (collected during the USDA national baseline studies) became the driving force for updated performance standards. The new standards (USDA-FSIS, 2011a) include both *Salmonella* and *Campylobacter* (first time) and require prevalence of less than 7.5% (5 positive out of 51 samples) for *Salmonella* and 10.4% for *Campylobacter*.

15.4.1 Unloading

Unloading is the process of moving live birds from the transport cages to the shackle line. This can be done manually or semi-automatically with conscious or unconscious birds (i.e., after gas stunning; see Chapter 8). At this stage, bird stress and/or struggling can extract fecal material which can result in cross-contamination, so it is important to minimize stress.

15.4.2 Stunning and Bleeding

The stunning operation renders the animal unconscious prior to bleeding. Electrical stunning usually results in muscle contraction that can extract fecal material. This obviously depends on the strength of the current (voltage and frequency) used. Gas stunning can also result in convulsions (especially anoxia conditions). In both cases care should be taken to prevent/minimize cross-contamination.

Bleeding results from opening the neck blood vessels mechanically or manually. In both cases, microorganisms can be transferred from the skin and feathers via the knife/blade to the blood stream that, in healthy birds, is virtually free of microorganisms. Even though most blood flows outward, some returning blood can deposit microorganisms in muscles and other organs. Therefore, care should be taken to maintain the cleanliness of the operation. Also, peri-mortem defecation is commonly observed at the end of the bleeding period.

15.4.3 Scalding

Scalding is used to loosen the feathers and facilitate their removal in the next plucking stage. Traditionally, the process is done in a scalding tank that consists of one or a series of water baths at 50-63°C (see soft, medium, and hard scalding in Chapter 5). Newer technologies that use steam (called Aeroscalding) to deliver heat to the feather follicles are also being used. This system eliminates a common bath, which decreases the risk of cross-contamination and significantly reduces water consumption (claimed to be 70% lower). In both water and steam scalding, temperature and time (e.g., 1-3 min) affect the amount of epidermis left on the skin as well as the number of microorganisms present on the skin. Several researchers have reported that scald water in a conventional water bath contains an aerobic bacterial count of about 50,000 microorganisms per ml. Usually, an initial increase is seen at the start of the day, but later the number stabilizes and remains relatively constant throughout the day (Bailey et al., 1987; Young and Northcutt, 2000). Although the external surfaces of the incoming carcasses are contaminated, the number of microorganisms usually stays fairly constant as a result of heat inactivation for some, the introduction of fresh, clean water (requirements depend on the country), the continuous overflow of contaminated scald water, and the use of antimicrobial agents (where permitted). The water bath represents an opportunity for cross-contamination, but usually does not result in a significant difference in the nature or degree of contamination in birds from the same flock. Total bacterial count on broiler skin just after scalding is usually less than 10,000 CFU/cm^2 (Bailey et al., 1987). Some of the heat sensitive bacteria, such as *Salmonella* and *Campylobacter*, are more affected by the scalding process (NACMCF, 1997) and are less likely to be isolated from a hard scald operation. Cason et al. (2000) reviewed 10 studies and found different levels of *Salmonella* contamination in water samples from the scalding tanks; four tanks had none, three had 1-10% positives, two had 20-40%, and one tank had 100%. Companies that design scalders have developed several modifications to improve the situation: a counter-current flow design (clean water flows from the bird's exit point towards the entrance point), a multistage scalding system, and the addition of fresh, clean water for every new bird. A counter-current flow has been shown to be effective

and, together with a multistage scalding system (consisting of several tanks), it was reported to significantly reduce the aerobic counts on broiler carcasses (Cason et al., 1999, 2000). By using a series of three tanks (Fig. 15.4.3.1), the processor can achieve a sequential reduction in bacterial load (Fig. 15.4.3.2). Mean scald water temperatures were 55.8, 55.9 and 56.2°C for tanks 1, 2 and 3, respectively and the mean coliform concentration (8 sampling days after 6 week old broilers were processed for 8 hr) was reduced from 3.4 to 2.0 and 1.2 log10 CFU/ml, respectively. *Salmonella* was isolated from 7 of 8 water samples from tanks 1 and 2, but only 2 of 8 samples from the last tank (3). The average number of *Salmonella* (over 8 testing days) was reduced from tank 1 to 3. Their previous study also demonstrated a successive cleaning effect, where suspended organic and inorganic solids and aerobic counts were reduced from the first to the last tank (5.12 to 1.04 g/L and 4.61 to 3.85 log10 CFU/ml, respectively; Cason et al. 1999).

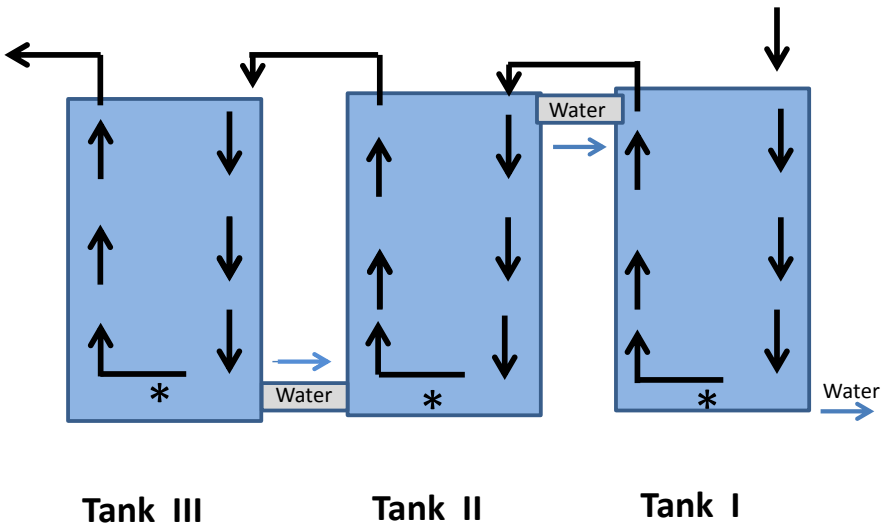


Figure 15.4.3.1 Diagram of the three-tank, two-pass, counterflow scalder as seen from above. Movement of broiler carcasses through the scalder is shown by the large arrows. Potable water is added to tank 3 and flows by gravity through tank 2 and tank 1. The sampling point in each tank is marked with an asterisk. From Cason et al. (2000).

James et al. (1992) suggested an addition to the counter-current flow tank in the form of a post-scald hot water rinse cabinet (240 mL of 60°C water spray at 40 psi/bird). The water is then collected and sent to the scalder. They showed a reduction

in aerobic and *Enterobacteriaceae* counts at the pre-chill station (after scalding) over their 7-day study period. However, the percentage of *Salmonella*-positive carcasses increased slightly due to cross-contamination in the scalder. Overall, they reported that scalding resulted in a lower microbial load in both the modified and baseline processes. Psychrotrophic bacteria, those that prefer cooler temperatures, are commonly present on the skin, feathers, and feet of live birds. The most common genera include *Achromobacter*, *Corynebacterium*, and *Flavobacterium*. Their numbers usually decrease after scalding.

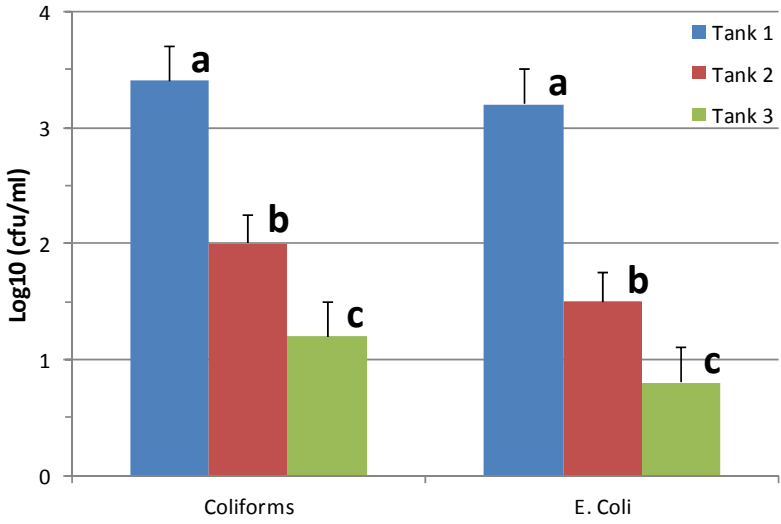


Figure 15.4.3.2 Mean counts (log10[CFU/ml] ± SD) of coliforms and *E. coli* in water samples from a three-tank, counterflow scalder operating in a broiler processing plant. Bars labelled with different letters are significantly different ($P < 0.05$, $n = 8$ for each bar). Adapted from Cason et al. (2000).

Sometimes there is also a potential for scald water to enter the trachea, which might contaminate the lungs. Such contamination is decreased when the Kosher cut is used, the bleed time exceeds 2 min, and the birds are electrically stunned (Bailey et al., 1987).

Several reports, but not all, indicate that high scald temperatures (> 58°C) reduce shelf life of the bird. This may be associated with the degree to which the epidermal layer is removed as higher temperatures can remove more of the cuticle

layer during subsequent mechanical feather picking (rubbing action of the fingers). On the other hand, semi-scalding (around 52°C) does not damage the cuticle (see Chapter 3 for the different skin layers). It is possible that cuticle removal improves the skin's suitability as a substrate for spoilage microorganisms (e.g., *Pseudomonas*). When a hard scald (> 58°C) is used, the skin must be kept moist to prevent discolouration. Therefore, processors usually use water rather than air chilling for these birds. When soft-scalding (52-54°C) is used, the skin can dry more without discolouration and therefore air chilling can be used.

15.4.4 Feather Removal (Picking)

The picking operation is used to remove/rub off the feathers. It is usually a fully automated process. Manual and batch-type (i.e., carcasses are placed in a rotating drum, see Chapter 4) operations are not commonly used in large processing plants, but can represent the same microbiological challenges as with automated lines. One problem is potential cross-contamination caused by the rubber fingers (a few thousand in a fast speed line; see photo in Chapter 5) that contact each passing bird. The conditions within the plucker (high humidity and warm temperature) are also favourable for some microbial growth. Mead and Scott (1994) colonized the defeathering equipment with a marker microorganism and showed that the level of cross-contamination increased with each subsequent carcass. Worn or cracked rubber fingers can allow bacteria to penetrate below the surface, where they are more protected against cleaning and sanitizing compounds. It has been reported that plucking can result in higher numbers of non-psychrotrophic bacteria and pathogens (NACMCF, 1997). *S. aureus* has been identified as one of the bacteria that best flourish under these conditions (Mead, 2000). This is of interest because this bacterium is not noted for its ability to compete with other microorganisms. Nevertheless, it has been shown to persist in defeathering equipment for months when routine cleaning is not effective. Pathogens may be transferred to the birds and enter into the feather follicles as the feathers are removed and before the openings are closed. Clouser et al. (1995) observed significant *Salmonella* cross-contamination during conventional defeathering in a turkey operation when a series of four pickers was used (after a 58°C scalding operation for 1.3 min). When they studied another plant that used a steam-spray scalding and defeathering operation they found no significant increase in *Salmonella* level before and after defeathering. Turkeys with a high initial bacterial load (> 10^4 CFU) showed a load reduction between bleeding and chilling. Carcasses with lower counts (< 10^4 CFU) were cleaner initially but did not show lower total counts at the end of the process.

Most, if not all, poultry operations position a spray washer to rinse the carcass just after plucking. This helps remove loose feathers, debris, and some bacteria

present in the water film on the bird's surface. The concept of removing bacteria and maintaining a water film (i.e., not allowing the skin surface to dry) before bacteria have a chance to attach to the skin is getting a lot of attention today from academics and industry personnel. A constant water spray (chlorinated or not) during the defeathering operation has also been shown to help reduce or prevent bacteria from colonizing the equipment. However, caution must be exercised when a water spray is used, as aerosol droplets from the high speed finger rotation can transmit bacteria to other plant locations. Therefore, most plants use covers around the equipment to minimize aerosol particles and also reduce noise. In any case, this step should be given attention and should be well contained. Many processors today position the equipment in a separate room (e.g., build walls around the pluckers).

In waterfowl operations (e.g., duck, geese) feather removal is more complicated. The birds are scalded at 60°C, plucked by machine, and then immersed in molten wax at 90°C to trap the small feathers. To speed up cooling and harden the wax, the birds are immersed in cold water and then the cold wax is stripped from the birds by hand or machine. The wax is later melted, filtered, and reused. Mead (2000) reported that the high temperature treatment appears to have a beneficial effect on the microbial quality of the final product, as water-chilled ducks treated with wax usually carry very low numbers of coliform bacteria on their skin.

15.4.5 Evisceration

The evisceration process consists of opening the abdominal cavity and removing the digestive system, heart, and lungs. In small plants, the operation may be carried out manually while in high volume plants the entire process is automated (see Chapter 5) by using equipment to perform individual tasks (e.g., vent cutting, opening, drawing). Automated equipment is used to perform labour intensive, repetitive motions in a fast and efficient manner. In both manual and automated operations there is potential for contamination if the digestive tract is ruptured and contents leak on the equipment and/or other carcasses. Ruptures may occur due to an incorrect cut by an employee (e.g., manual operation), poor equipment adjustment, or the condition of the birds (e.g., time of feed withdrawal affects the fullness of the gut, disease conditions; see Chapter 4). As indicated in Chapters 1 and 5, modern processing lines handle over 13,000 broilers per hour and the evisceration process is performed quickly, so adjustment of machinery can be an issue. Investing in high quality equipment designed to minimize cross-contamination (e.g., application of a vacuum to the cloaca while automatically pulling it out) is very important and offers a great return on investment. A well adjusted, automated system can help minimize potential bird-to-bird cross-contamination problems. There is also focus

today on in-line continuous cleaning where equipment is commonly fitted with a cleaning-in-place (CIP) system with or without the application of a sanitizer. Similarly, in manual operations employees should wash their hands often and/or dip their knives in hot water.

The opening process usually includes three steps. The first is cutting out the cloaca (known as vent cutting) without separating the attached large intestine. In an automated process this is done using a cylindrical rotary blade (in some cases vacuum and pressure are applied to the area in order to empty the distal end). The next step is opening the abdominal cavity. Care should be taken to prevent rupturing the intestine and spilling the gut content, since 1 mL may contain up to 10^9 CFU (i.e., a small volume can result in a high contamination level). Height adjustment of the equipment is required when the size of the bird changes (e.g., new flock arrives) and/or when high variation among birds within the same flock is expected. The equipment must be monitored and adjusted on a continuous basis. After the body cavity is opened, a scoop is used to draw out the intestines, giblets, heart, and lungs. The pack is either left attached to the carcass or separated from the carcass and hung on a separate line for inspection (see Chapter 5). The latter system was introduced about 20 years ago to improve microbial quality by reducing cross-contamination (i.e., the intestines no longer attached to the carcass). Another improvement in reducing cross-contamination was the introduction of automated carcass transfer systems (e.g., from the defeathering line to the evisceration line, and later also to the chilling line; see Chapter 5). This reduces handling/touching by the plant's employees, and cross-contamination as a result of carcass accumulation (dumping) at the transfer point.

15.4.6 Cropping

Crop removal also presents a potential contamination point. Hargis et al. (1995) indicated that there is an 80 times greater risk of carcass contamination from crop rupturing than from removing the intestinal tract and caecum. They also mentioned that *Salmonella* is more readily extracted from the crop than the caecum. Fifty-two percent of the 500 bird samples were positive for *Salmonella* in the crop, but only 15% were positive in the caecum. They later reported similar trends for *Campylobacter* (60% vs. 4%, respectively) and emphasized that special care should be taken when the crop is removed. Therefore this processing station should be maintained clean (e.g., by continuous spray washing) to minimize cross contamination among birds.

15.4.7 Washing and Other Interventions

Carcasses are often rinsed after the evisceration process to clear away any debris, loose tissue, residual blood, and some microorganisms (Notermans et al., 1980; EFSA, 2010). This is done with low/high pressure nozzles and inside/outside bird washers. Over the past few decades, various antimicrobial rinses have also been suggested (see below) as demand for lower microbial counts increased (USDA-FSIS, 1996; USDA-FSIS, 2011a and b; Barbut and Pronk, 2014). Chlorine, for example, has been used in spray water at a concentration of 20-50 ppm (Mead, 2000). As indicated earlier, the use of chlorine in processing water is not permitted in some countries (e.g., Europe). In the case of water, there are usually no regulations as to the amount or pressure used in the washer. Overall, the use of washers throughout primary processing has been shown to be effective in removing unattached microorganisms (Notermans et al., 1980). As indicated before, this is important in maintaining the water film on the skin as well as washing off some of the bacteria. Various pieces of equipment have been designed to perform outside and/or inside washes of poultry carcasses (see Chapter 5). Some of the old washers consist of a set of showerheads, while the newer washers are designed to wash the outside of the bird from top to bottom (e.g., washers are positioned at different heights along the line). Other inside/outside washers include a shaft equipped with spray nozzles that can be lowered into the body cavity and spray in a way that ensures effective cleaning. The water (with or without an antimicrobial agent) is then either drained from the crop opening (rotating shaft can exit from the crop) or the carcass is tilted to drain the wash water. This does not completely remove all microorganisms because some bacterial attachment to the skin/inner cavity membranes has usually already occurred.

Various groups of antimicrobial agents have been studied over the years. Loretz et al. (2010) reviewed different intervention strategies (physical, chemical, biological) to help decontaminate poultry carcasses. A list of strategies is provided in Table 15.4.7.1. Physical interventions include water-based treatments, irradiation, ultrasound, air chilling, and freezing (note: operational principles of irradiation, ultrasound, and freezing are discussed in Chapter 11). Among these methods, hot water, steam, electrolyzed water (EW), and irradiation have been shown to effectively reduce bacterial loads. Log reductions obtained by hot water, steam, and EW ranged from 0.9 to 2.1, 2.3 to 3.8, and 1.1 to 2.3, respectively. However, it should be noted that very hot water or steam might adversely impact carcass appearance. Chemical interventions are primarily comprised of organic acid, chlorine, and phosphate based treatments. Loretz et al. (2010) indicated that acetic and lactic acid, acidified sodium chlorite, and trisodium phosphate yielded log reductions in the range from 1.0 to 2.2. Organic matter can reduce

the antimicrobial activity of some chemicals such as chlorine. They also reviewed combination treatments, which have been used to enhance microbial decontamination (Table 15.4.7.2; additional tables are provided in their review). Furthermore, biological interventions (e.g. bacteriophages) constitute promising alternatives but further investigation is required. Loretz et al.(2010) cautioned that although the interventions reduced bacterial load to some extent, decontamination treatments must always be considered as part of an integral food safety system. Later, Bruckner et al. (2012) also provided a meta-analysis and review of the effectiveness of different interventions (e.g., chlorine, acids, phosphates, electrolyzed water, cetylpyridinum chloride, sodium bisulfate) on reducing *Salmonella* prevalence.

Table 15.4.7.1 Decontamination treatments for poultry carcasses. From Loretz et al. (2010)

Physical	Chemical	Biological and Combination
• Water-based treatments ▪ Water ▪ Steam ▪ Pressurized water ▪ Electrolyzed water ▪ Ozonated water ▪ Irradiation ▪ Ultrasound ▪ Air chilling ▪ Freezing	• Organic acids ▪ Acetic acid ▪ Lactic acid ▪ Citric acid • Chlorine-based treatments ▪ Chlorine and chlorine dioxide ▪ Hypochlorite, sodium hypochlorite, and sodium chlorite ▪ Acidified sodium chlorite ▪ Cetylpyridinium chloride ▪ Mono chloramine • Phosphate-based treatments ▪ Trisodium phosphate ▪ Other phosphate-based compounds • Other chemical treatments ▪ Hydrogen peroxide	• Antibacterial activity of biological decontamination treatments • Phages • Antibacterial activity of combined decontamination treatments

Today meat processing plants use a combination of interventions (Hurdle technology) to achieve safe products (as discussed at the end of this chapter). Examples of studies that include combinations of chemical and physical treatments are provided below. Bautista et al. (1997) examined the effect of three groups of antimicrobial agents (chlorine 0-50 ppm; tripolyphosphate 0-20%; lactic acid 0-8%) applied at pressures ranging from 40 to 90 psi (using a laboratory-type inside/outside bird washer) to clean contaminated turkey carcasses.

Table 15.4.7.2 Examples of antibacterial activity of selected combinations of chemical treatments on the surface of poultry carcasses and parts. Adapted from Loretz et al. (2010).

Combination	Microorganism	Reduction (log CFU)	Application[b]	Reference
Chlorine + acetic acid	Aerobic bacteria Coliforms *Escherichia coli* *Salmonella Typhimurium*	1.4 ml^{-1} 1.4 ml^{-1} 1.4 ml^{-1} 2.0 ml^{-1}	IM/SP	1
Chlorine + trisodium phosphate	Aerobic bacteria Coliforms *Escherichia coli* *Salmonella Typhimurium*	1.4 ml^{-1} 1.7 ml^{-1} 1.7 ml^{-1} 2.0 ml^{-1}	IM/SP	1
Lactic acid + potassium sorbate	Aerobic bacteria	0.7–1.2 g^{-1}	IM	2
Lactic acid + sodium benzoate	Aerobic bacteria	1.7–1.8 g^{-1}	IM	2
Lauric acid + potassium hydroxide	Aerobic bacteria *Escherichia coli* *Clostridium perfringens* Staphylococci	2.0 ml^{-1a} >3.4 ml^{-1a} >2.3 ml^{-1a} 2.6 ml^{-1a}	R	3
Levulinic acid + sodium dodecyl sulfate	Aerobic bacteria *Salmonella Enteritidis*	>7.0 g^{-1a} 7.0 g^{-1a}	IM	4
Salmide® + EDTA	*Salmonella Typhimurium*	1.7–2.7 ml^{-1}	IM	5
Salmide® + sodium lauryl sulfate	*Salmonella Typhimurium*	1.2–1.7 ml^{-1}	IM	5
Salmide® + trisodium phosphate	*Salmonella Typhimurium*	3.0 ml^{-1}	IM	5
Tripotassium phosphate + lauric acid	Aerobic bacteria *Escherichia coli* Enterococci *Campylobacter jejuni* *Pseudomonas* Staphylococci	1.5 ml^{-1a} 1.1 ml^{-1a} 1.3 ml^{-1a} 2.7 ml^{-1a} 1.3 ml^{-1a} 1.7 ml^{-1a}	R	6
Tripotassium phosphate + myristic acid	Aerobic bacteria *Escherichia coli* Enterococci *Campylobacter jejuni* *Pseudomonas* Staphylococci	1.1 ml^{-1a} 0.6 ml^{-1a} 1.4 ml^{-1a} 1.4 ml^{-1a} 1.2 ml^{-1a} 0.3 ml^{-1a}	R	6

[a] Highest reduction obtained.
[b] IM, immersion; SP, spraying; R, rinsing.
1. Fabrizio et al. (2002); 2. Ismail et al. (2001); 3. Hinton and Cason (2008); 4. Zhao et al. (2009); 5. Mullerat et al. (1994); 6. Hinton and Ingram (2005)

The results indicated that 4.25% lactic acid was the best in reducing the total microbial load as well as the coliform load, and that pressures above 40 psi did not

show a marked effect. Tripolyphosphate and chlorine were not as effective and did not show a significant improvement compared to a water spray rinse. Bautista et al. (1997) reported some discolouration (bleaching) when 4.25% lactic acid was used during a 10 sec rinse; however, this was not a problem after water chilling the carcasses. Mead and Scott (1994) reported that a post-evisceration spray of 20 ppm chlorine to birds inoculated with a "marker" strain of *E. coli* during the defeathering process did not reduce the proportion of carcasses that acquired the "marker" nor the number of organisms being transferred. However, they mentioned that while chlorine had little direct effect on carcass contamination, it did control bacterial buildup on equipment and destroyed spoilage bacteria present in the water supply.

Tamblyn and Conner (1997) examined the bactericidal effect of acetic, citric, lactic, malic, mandelic, propionic, and tartaric acids (concentrations of 0.5, 1, 2, 4, and 6%) on *S. typhimurium* loosely or firmly attached to broiled skin at different temperatures. They compared three application methods and, similar to Bautista et al. (1997), found that the greatest reduction was achieved by lactic acid at their "scalding application" (2 min at 50°C), followed by "chiller application" (60 min at 0°C) and post-process dip (15 sec at 23°C). However, use of a $\geq$ 4% acid in a scalding or chiller tank might be cost-prohibitive due to the large volume of water required in the tank. Therefore, some chiller manufacturers have recently developed smaller post-chiller finishing or dip tanks where a high concentration of antimicrobial agent can be maintained (see illustration in Chapter 5). This development can be seen today in several plants in North America.

15.4.8 Chilling

The chilling operation is very important in suppressing microbial growth (both pathogens and spoilage microflora) and is mandatory in most countries around the world. The time to reach a specific deep muscle temperature is often recommended (e.g., in the USA 4, 6, and 8 hr to reach 4.4°C in carcasses weighing < 1.8, 1.8 to 3.6 or > 3.6 kg. Note: in the past it was mandated in the US but now only recommended). As indicated in Chapter 5, meat can be chilled by water or air. Selection of a chilling medium is based on water availability, cost (to buy fresh water and treat waste water), energy cost, market demand, etc. There are also hybrid systems where both air and water are used (e.g., water chill for 10 min followed by air chill). Water chill systems are more popular in America whereas air systems are more popular in Europe. Both systems are used to reduce carcass temperature from ~ 40°C to < 10°C. Most air chilling operations employ a mist or water spray to facilitate chilling and to prevent drying during the operation (which usually takes more than an hour).

Various research groups have compared the microbial quality of poultry chilled by each system but there is no consensus as to which system is better; studies have shown conflicting results or no effect. James et al. (2006) reviewed the results of a few dozen research studies and wrote, "many people believe that there is some clear microbiological based reason behind the selection of air chilling. However, the published data do not appear to support this belief, and if anything, point to a microbial advantage of immersion systems". An earlier comprehensive comparison of the two systems was provided by Mead et al. (1993). They examined five plants (two water and three air) and showed that total microbial counts on carcasses were similar or lower after water chilling (Table 15.4.8.1). Levels of *Pseudomonas* spp. after chilling were relatively high in all processes for both broilers and turkeys.

Table 15.4.8.1 Effect of processing plant (5 different chicken plants; except #2 - turkeys) and water chilling method on *Pseudomonas* spp. contamination of neck skin. Modified from Mead et al. (1993).

Plant	#1		#2		#3		#4		#5	
Chilling method	**Water**		**Air**		**Water**		**Air**		**Air**	
After:										
• bleeding	2.3[1]	(8)[2]	2.5	(8)	< 2.0	(4)	< 2.0	(8)	< 2.0	(5)
• scalding	< 2.0	(3)	< 2.4	(6)	< 2.0	(1)	< 2.0	(1)	< 2.0	(0)
• defeathering	2.5	(13)	3.2	(15)	< 2.0	(1)	2.3	(8)	< 2.0	(3)
• evisceration	3.0	(15)	3.4	(15)	2.4	(11)	< 2.1	(6)	< 2.1	(6)
• washing	2.7	(12)	2.7	(15)	2.2	(13)	< 2.1	(7)	< 2.2	(7)
• chilling	3.3	(15)	3.9	(15)	< 2.0	(2)	2.6	(9)	3.2	(15)
• packaging	3.9	(15)	4.0	(15)	N/A	N/A	2.9	(13)	3.5	(15)

[1] Mean (log_{10}) CFU/g of neck skin.
[2] Number of samples positive out of 15, by direct plating. N/A, not available.

Some research has shown that the number of microorganisms in a water chiller also depends on the amount of water overflow (expressed as the amount of water used per 1 kg of carcass mass). Bailey et al. (1987) reported that an overflow of about 2:1 resulted in a skin microbial count reduction of 60-95%. This demonstrates that plain water can be used to reduce microbial load. However, researchers have pointed out that small populations of pathogens, present prior to chilling, may be distributed to other carcasses through the water bath. Several studies have shown no increase in *Salmonella* as a result of immersion chilling, while others have found higher incidences. Busta et al. (1973) studied chill water samples from 3 turkey processing plants and found *C. perfringens* in 53%, *S. aureus* in 22%, *Salmonella* in 17.6%, and coliforms in 100%. The incidence of these organisms on turkey skin

did not significantly differ before and after chilling (*C. perfringens* 87% before and 83% after; *S. aureus* 71% before and 67% after; *Salmonella* 28% before and 24% after; coliforms 100% before and after chilling). Waldroup et al. (1993) and Waldroup (1996) reported that the incidence of *Salmonella* spp. increased by 20% from pre-chill to post-chill and *Campylobacter* spp. by 5%. In a well-controlled chilling system, there is usually a net reduction in bacteria due to washing and chemicals (where permitted) that minimize cross-contamination. Figure 15.4.8.1 shows that microbial load plateaus about 2-3 h into the day (similar to what is observed in a scalding tank). Microbial loads on chilled carcasses obtained after 3 h were similar to those obtained at the end of an 8 hr shift. The addition of chemicals to an immersion water chiller can help control the microbial loads. Different forms of chlorine are commonly used and legal limits vary by country (0-50 ppm).

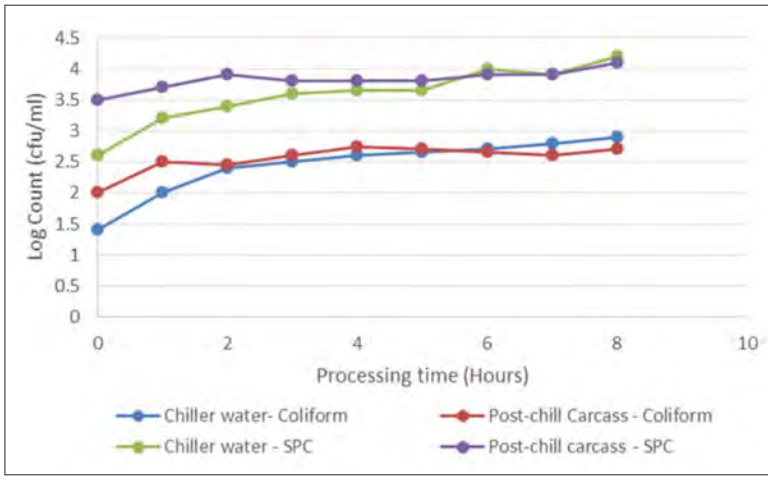


Figure 15.4.8.1 Standard plate count (SPC) and coliform populations (log CFU/mL) as a function of time of day in chiller water and on post-chilled carcasses. For each point, n = 5. Redrawn from Blank and Powell (1995).

A level of 20-50 ppm can help control microorganisms, but concentrations of 300 to 400 ppm would be required for a complete eradication of a pathogen such as *Salmonella*. Such high concentrations are not feasible as they would strongly affect the smell of the meat and bleach the skin. A lower active chlorine level in the chiller can help maintain a manageable level of microorganisms, but it should be frequently monitored as its concentration is reduced when chlorine reacts with organic material. Waldroup et al. (1992) reported that 5 ppm active/free chlorine in the chiller overflow was beneficial in reducing the microbial load on commercially

processed broilers. The authors also examined other modifications (carcass wash, counter current flow) that were suggested by the US National Broiler Council and approved by the Food Safety and Inspection Service. All modifications assisted in reducing microbial counts on processed broilers. Hydrogen peroxide is an example of another effective antimicrobial agent that can be used to control the number of microorganisms. However, in order to reduce microbial load by 95%, concentrations in excess of 6,000 ppm were required. Again, such levels are not feasible as they cause bleaching and blotting problems. The use of various acids, such as acetic acid, can assist in reducing *Enterobacteriaceae* and others (Tamblyn and Conner, 1997). This is similar to the idea previously discussed in the spray washing operation. In such a case, a smaller rinsing cabinet positioned before the chiller can allow the use of a higher concentration of acids/chlorine/phosphate in a more economical way, since the volume required per carcass is relatively low. However, as indicated above, a low level of chemical control does help in maintaining a large chilling water system at a manageable microbial load.

Air chilling operations have been shown to reduce some groups of microorganisms but the effect depends on the system used (e.g., dry versus a continuous water spray system). Demirok et al. (2013) evaluated three commercial systems: water, no spray air, and an in-line combination which included water immersion and air chilling. Water immersion showed the greatest reduction of *Salmonella* (40%) and *Campylobacter* (43%) due to the washing effect and the presence of chlorine. There was no significant difference in shelf life between methods. The water system showed the highest added yield (6.5%), followed by the combination system (1.9%) and the dry air system (-1.1%). However, breast meat was significantly tenderer for the air and combination systems. There were no other sensory differences in the quality of breast filets and drum meat among the systems. Allen et al. (2000) evaluated five commercial air chilling systems and one water chiller (conventional, counter-flow, three-stage unit with about 45 ppm chlorine). The residence time in the air chillers varied according to carcass size, staff break times, line stoppages, and whether or not carcasses were stored in the chiller overnight. The results of the microbial reduction are presented in Figure 15.4.8.2. The air chillers ran at a nominal 3°C and chlorinated water (50 ppm) was used in the sprays in the second, third and fourth systems (exact operating conditions are described in the paper). Overall, the results shown in Figure 15.4.8.2 indicate that the design and mode of operation of the air chiller strongly influences the residual microbial level on the skin. When a completely dry process was used (the sixth system) microbial numbers were reduced approximately ten-fold in the body cavity. The use of water sprays tended to increase the microbial level in the cavity, while heavy spraying with non-chlorinated water substantially increased the numbers of *Pseudomonas* spp. The results also confirmed that water immersion chilling can provide a washing effect to reduce microbial contamination of

carcasses, although initially the numbers of *Pseudomonas* spp. tended to increase. Sanchez et al. (1999) reported that air and water chilling resulted in similar counts of psychrotrophs and generic *E. coli*, but air chilling showed higher total aerobic and coliform counts. Incidence of *Salmonella* was about 20% lower in air chilled birds. Their results show that cross-contamination can occur in air chilling when a water spray is used. However, some skin drying, as a result of air chilling, can reduce certain groups of bacteria.

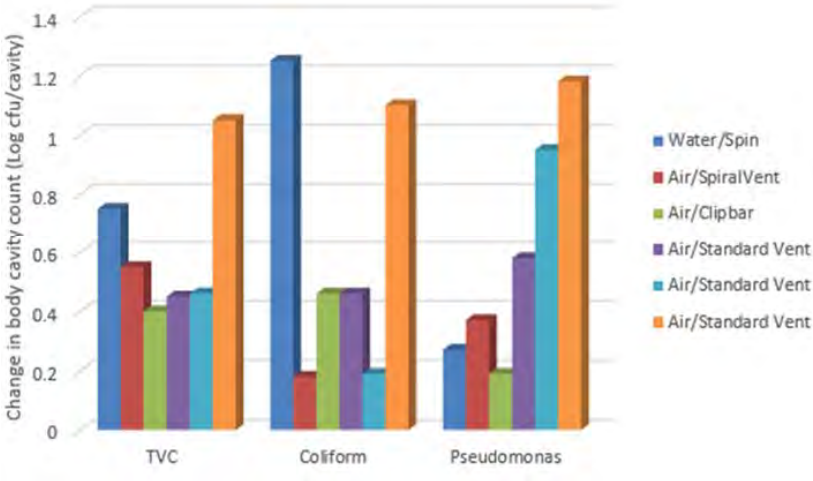


Figure 15.4.8.2 Microbial quality of chicken carcasses chilled by air or water; TVA = total viable count. Redrawn from Allen et al. (2000).

Recently, there has been a considerable increase in US poultry processing facilities that employ post-chiller antimicrobial interventions (Nagel et al., 2013). This is advantageous because post-chill antimicrobial intervention introduces an additional intervention or hurdle for pathogens. The smaller (400 – 600 gal) post-chill immersion tank resembles a traditional chiller but has a minimal footprint and results in a shorter dwell time (generally 30 s) with a higher concentration of antimicrobials. Primary chillers, which hold 20,000 to 50,000 gal (dwell time of 1.5–2.0 h), are less efficient and cost-effective. Additionally, because organic load may reduce the efficacy of these antimicrobials (e.g., chlorine), post-chillers can increase the efficacy of some antimicrobials. Post-chill tanks have now been installed in many plants. Nagel et al. (2013) studied them in order to control *Salmonella* and *Campylobacter* counts (Fig. 15.4.8.3) as per US government guidelines. The authors evaluated five post-chill water treatments consisting of 40

ppm total chlorine, 400 ppm or 1,000 ppm peracetic acid (PAA), and 1,000 or 5,000 ppm lysozyme. Treatment with 400 or 1,000 ppm PAA was most effective ($P \leq 0.05$) in reducing populations of *Salmonella* and *Campylobacter* as compared to the chlorine treatment at 40 ppm and lysozyme treatments at 1,000 and 5,000 ppm, as well as the water treatment and the positive control. Intervention strategies such as post-chill decontamination tanks have provided an alternative approach for pathogen reduction during poultry processing.

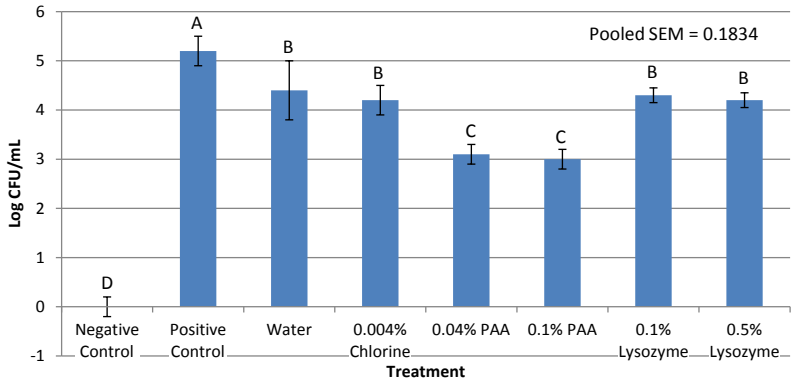


Figure 15.4.8.3 *Salmonella Typhimurium* recovered from inoculated carcasses (n = 160) treated with various antimicrobials in a post-chill immersion tank reported as mean log colony-forming units of *S. Typhimurium* per sample for each treatment group. PAA= peracetic acid. a–d Means with no common letter differ significantly ($P \leq 0.05$). From Nagel et al. (2013).

Antimicrobials that are currently approved for use in poultry applications are described in the FSIS Directive 7120.1 Revision 9 (USDA-FSIS, 2011b). In the US, chlorine has historically been used to prevent cross-contamination in immersion chilling systems and throughout the poultry processing plant. However, the efficacy of chlorine for bacterial reduction decreases with increasing pH and organic load (Nagel et al., 2013).

In recent years, peracetic acid (PAA), a combination of acetic acid and hydrogen peroxide, has replaced chlorine as the industry standard for antimicrobial application during poultry processing. This antimicrobial is effective due to its combined acidic and oxidizing properties. For antimicrobial applications in poultry, the maximum allowable concentration is 2000 ppm in a post-chill dip (USDA-FSIS, 2011b). Overall, validation of antimicrobials under commercial settings is extremely important because efficacy is affected by factors such as temperature, contact time, concentration, and coverage.

15.4.9 Hurdle Concept – Primary Processing

Reducing the number of microorganisms in meat requires a multifaceted approach. The importance of monitoring the health of parental flocks, growth conditions on the farm, transportation, and steps to prevent cross-contamination in the processing plant have already been highlighted. The concept is based on combining several approaches or 'hurdles' that pathogens have to overcome if they are to stay alive and active in a given food product. The hurdles can include high acidity, heat processing, salt addition, cold storage, etc. Below, combinations of different interventions within the primary processing plant are discussed.

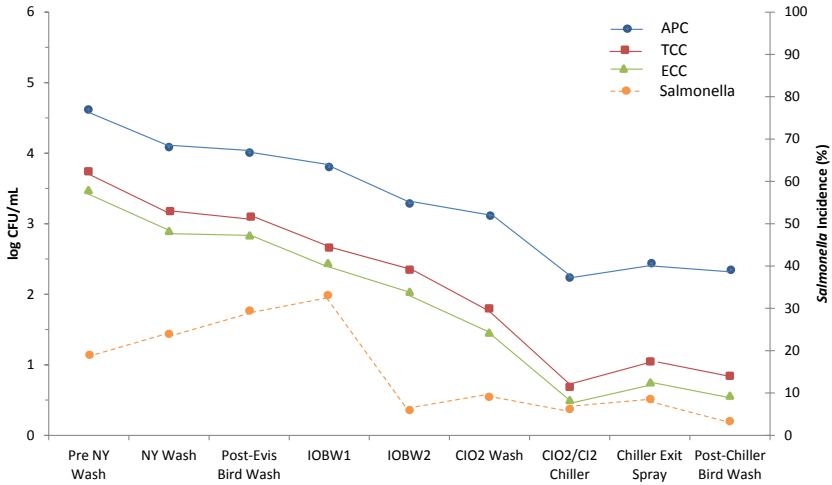


Figure 15.4.9.1 Microbial populations (log CFU per milliliter, mean ± SD) and Salmonella incidence (%) of carcasses following multiple interventions applied in sequence along the evisceration (slaughter) line at poultry plant A. The first point represents the stage before the first intervention, and every point thereafter represents the populations after the specific intervention. NY Wash, New York wash; Post-Evis, postevisceration wash; IOBW1, inside-out- side bird wash 1; IOBW2, inside-outside bird wash 2; ClO_2, chlorine dioxide wash; ClO_2-Cl_2, chlorine dioxide wash plus chlorine chiller. From Stopforth et al. (2007).

Stopforth et al. (2007) investigated the efficacy of individual and multiple sequential interventions to decrease microbial load. Figure 15.4.9.1 shows aerobic plate counts (APC), total coliform counts (TCC), *E. coli* counts (ECC), and *Salmonella* incidence on poultry carcasses processed at one of the plants (identified as Plant A; they studied and reported data for three different plants).

This plant processed 140 birds per min and included the following interventions: New York wash (spray application of 20 – 50 ppm chlorinated water following defeathering), post-evisceration wash (spray application of 20 – 50 ppm Cl_2), inside/outside bird wash 1 and 2 (IOBW consisting of 20 – 50 ppm Cl_2 following neck removal), chlorine dioxide spray application immediately before chilling (ClO_2 prepared by acidifying 500 – 1,200 ppm sodium chlorite with citric acid at pH 2.7), chlorinated chiller (using 20 – 50 ppm Cl_2; chiller operated at pH 6.5 – 7.0 according to the facility's HACCP plan), chiller exit spray (with 20 – 50 ppm Cl_2), and a post-chiller spray (with 20 – 50 ppm Cl_2) immediately following carcass sizing. Observations were made over 5 days with 15 samples taken each day before and after each intervention step. Results from all three plants showed that the majority of individual interventions significantly ($P < 0.5$) reduced microbial populations on or in carcasses, carcass parts, and processing water. Reductions in APC, TCC, and ECC due to individual interventions ranged from 0 to 1.2, 0 to 1.2, and 0 to 0.8 log CFU/ml, respectively. Individual interventions reduced *Salmonella* incidence by 0 to 100% depending on the process type and product. Sequential interventions also resulted in significant reductions ($P < 0.05$) in APC, TCC, ECC, and *Salmonella* incidence of 2.4, 2.8, and 2.9 log CFU/ml and 79%, respectively, at plant A. The other two plants had 6 and 3 intervention steps, respectively (figures not shown). At plant B the corresponding reductions were 1.8, 1.7, and 1.6 log CFU/ml and 91%. At plant C they were 0.8, 1.1, and 0.9 log CFU/ml and 40%. The authors concluded the results validated the poultry processing interventions and provided a source of information to help the industry in its selection of antimicrobial strategies.

Gill et al. (2006) also examined the effectiveness of different steps in a large poultry processing plant. The plant processed 1.3 – 1.6 kg broilers using a 90 sec scald (at 58 ± 1°C) and immersion chilling in chlorinated water. About half of the birds were packed and shipped without further processing, and those remaining were portioned, deboned, or marinated and tumbled in brine. The results presented in Table 15.4.9.1 are part of a larger study designed to look at the effectiveness of different intervention steps as well as evaluate the effects on specific groups of bacteria. The study was done to validate HACCP steps (see also Chapter 6) as it is currently recommended that HACCP systems be developed on the basis of objective assessments of hazards and risks associated with each individual intervention. Subjective judgments can be uncertain as the relationship between fecal or other visible carcass contamination and microbial meat condition is not consistent (Gill, 2004). Similar operations at different plants can have very different effects on the microbial conditions of the products. Gill et al. (2006) obtained samples from carcasses by excising a strip of skin measuring approximately 5 x 2 cm from randomly selected sites on each carcass (sampling procedure shown in Fig. 15.4.9.2) or by rinsing the carcass portion.

Table 15.4.9.1 Statistics for sets of 25 coliform and aerobic counts (CFU/cm^2) recovered from chicken carcasses or portions of such carcasses, at various stages of processing at a poultry packing plant. Adapted from Gill et al. (2006).

Product	Stage of processing	Statistics – Coliforms				Statistics – Aerobic			
		$\bar{\times}$	s	log A	N	$\bar{\times}$	s	log A	N
Carcasses	Before second wash	1.74A	0.79	2.45	3.63	3.53BCD	0.86	4.37	6.12
	After second wash	1.53A	0.84	2.35	3.9	3.19CDE	0.68	3.72	5.22
	After evisceration	1.79A	0.77	2.47	3.89	3.08DE	0.96	4.13	5.53
	Before third wash	1.39AB	0.76	2.05[a]	3.56	2.77E	0.46	3.02	4.39
	Before cooling	1.25ABC	0.77	1.93	3.3	2.94DE	0.52	3.24	4.68
	After cooling	0.17D	0.73	0.78	2.1	2.66E	0.89	3.58[a]	5.49
Skin-on thighs	Before packing	0.80C	0.44	1.03	2.36	3.73BC	0.6	4.14	5.53
Boneless breasts	Before tumbling	0.85BC	0.31	0.96[a]	2.35	4.51A	0.43	4.72	6.17
	After tumbling with brine	0.67CD	0.25	0.74	2.13	4.01AB	0.37	4.16	5.55

$\bar{\times}$, mean log; s, standard deviation; log A, log mean; N, log of the total number recovered from 25 samples. Mean logs with the same letter are not significantly different ($P > 0.05$).
[a] Set of log counts is not normally distributed ($P < 0.05$).

As indicated in the table, each value represents an average of 25 samples per sampling point where 5 samples were collected on each of 5 days (previously shown to obtain representative results; Gill, 2004). The log mean numbers of aerobes, coliforms, *E. coli*, and presumptive *Staphylococci* plus *Listeria* on carcasses after scalding and plucking were about 4.4, 2.5, 2.2, and 1.4 log CFU/cm^2, respectively. The numbers of bacteria on eviscerated carcasses were similar. After a series of operations for removing the crop, lungs, kidneys, and neck, the numbers of aerobes were about 1 log unit less than on the eviscerated carcasses, but the numbers of other bacteria were not substantially reduced. After water chilling, the numbers of coliforms and *E. coli* were about 1 log unit less and the numbers of presumptive *Staphylococci* plus *Listeria* were about 0.5 log unit less than the numbers on dressed carcasses, but the numbers of aerobes were not reduced.

When further looking at deboning and marinating, the numbers of aerobes were 1 log unit higher on boneless breasts and 0.5 log units higher on skin-on thighs and breasts that had been tumbled with brine than on cooled carcasses.

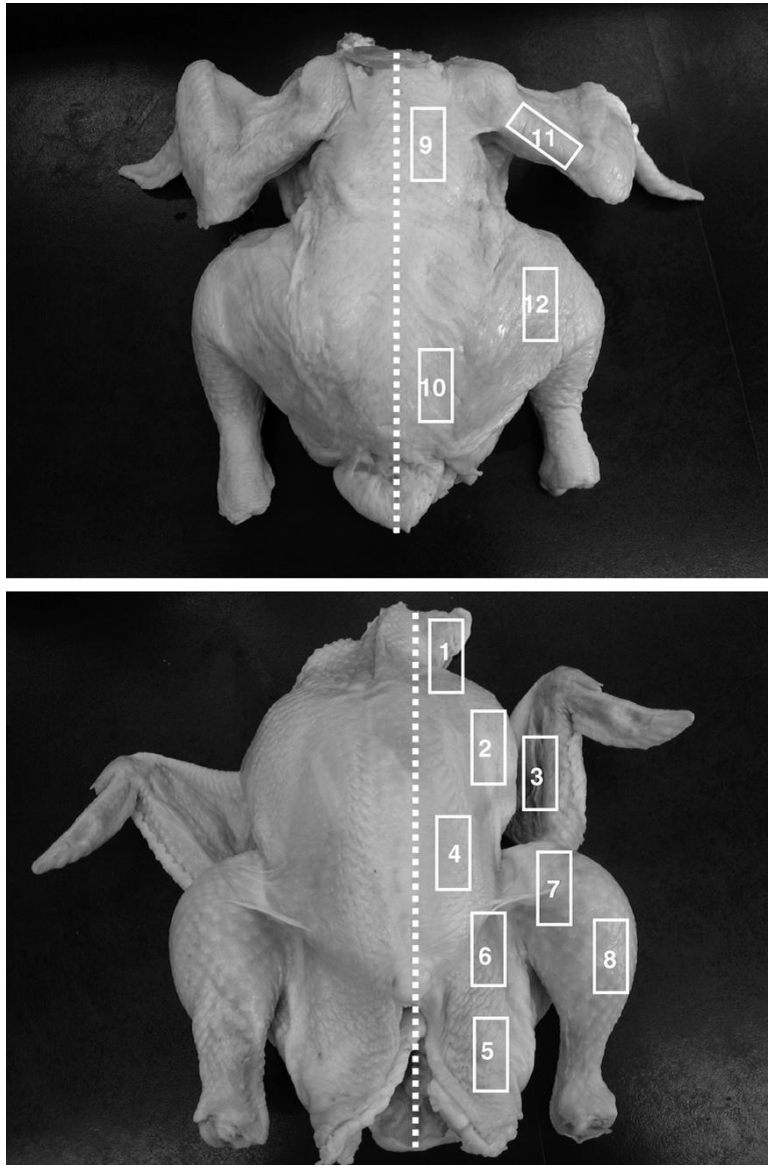


Figure 15.4.9.2 Pictures used for identification of sites from which to obtain samples of skin from chicken carcasses. From Gill et al. (2006).

The presumptive *Staphylococci* plus *Listeria* were 0.5 log unit more on thighs than on cooled carcasses. This is probably the result of the extra meat handling as will be discussed in the next section.

Guerin et al. (2010) reviewed changes in *Campylobacter* prevalence during processing. They looked at information from 8 electronic databases using key words for "*Campylobacter*", "chicken", and "processing" and identified 1,734 unique citations. Thirty-two studies described prevalence at more than one stage during processing and were included in the review. Of the studies that described the prevalence of *Campylobacter* on carcasses before and after specific stages of processing, the chilling stage had the greatest number of studies (9), followed by washing (6), defeathering (4), scalding (2), and evisceration (1). Studies that sampled before and after scalding or chilling, or both, showed that the prevalence of *Campylobacter* generally decreased immediately after a certain stage (scalding: 20 to 40% decrease; chilling: 100% decrease to 26% increase). However, the prevalence of *Campylobacter* increased after defeathering (10 to 72%) and evisceration (15%). The prevalence after washing was inconsistent among studies (23% decrease to 13% increase). Eleven studies reported the concentration of *Campylobacter*, as well as, or instead of, the prevalence. Studies that sampled before and after specific stages of processing showed that the concentration of *Campylobacter* decreased after scalding (minimum decrease of 1.3 CFU/g, maximum decrease of 2.9 CFU/g), evisceration (0.3 CFU/g), washing (0.3 – 1.1 CFU/g), and chilling (minimum 0.2 CFU/g, maximum 1.7 CFU/carcass) and increased after defeathering (minimum 0.4 CFU/g, maximum 2.9 CFU/mL). Guerin et al. (2010) indicated that "more data are needed to better understand the magnitude and mechanism by which the prevalence and concentration of *Campylobacter* changes during processing. This understanding should help researchers and program developers identify the most likely points in processing to implement effective control efforts".

Bruckner et al. (2012) published a large scale review (six databases searched) and meta-analysis of published material related to the application of carcass spray and dip treatments to reduce *Salmonella* prevalence and concentration on broiler chickens. Visual evaluation of the forest plots indicated overall reduction trends for six spray treatments:

a. trisodium phosphate (n=48 trials)
b. acidic electrolyzed oxidizing water (n=2)
c. cetylpyridinium chloride (n=43)
d. lactic acid (n=24)
e. sodium bisulfate (n=11)
f. potable water (n=36)

Note: references for these antimicrobials and others can be found in Bruckner et al. (2012). The authors indicated moderate to considerable heterogeneity between studies and methodological problems within the studies including a lack of research conducted under commercial conditions (i.e., precluding the full benefits of robust meta analysis). The review by Loretz et al. (2010), mentioned earlier in the chapter, also contains a section on combining interventions at different steps (Table 15.4.7.2).

15.5 Secondary Processing

Fresh poultry is commonly sold as whole carcasses, cut-up parts, minced meat (see Chapter 9), or as a fully cooked product (see Chapter 13). The meat can be packaged in individual bags, trays wrapped in polyethylene, or in bulk without individual wrapping (see Chapter 11). The secondary processes involve manipulation of the product (e.g., portioning, de-skinning, marinating, tumbling, cooking), which can also affect its microbial quality. Extra handling by people and machines (e.g., ground meat can be handled 10 – 12 times) can increase microbial load and/or change its composition. For example, bacteria from the surface are transferred to the deep tissue while grinding or injecting the meat. If ingredients such as carbohydrates are added they are used right away as a simple energy source for microbial growth (e.g., added to help fermentation in certain meat products). Extended handling and storage times also play a role in the shelf life of the product (see Fig. 15.2.1; relationship between initial bacterial load and storage temperature) as well as potential cross-contamination (Fig. 15.1.7). On the other hand, several secondary processing treatments (e.g. cooking) can lower the microbial load and help destroy pathogens.

15.5.1 Cutting and Portioning

Portioning the carcass involves extra handling and exposure to more surfaces (e.g., cutting boards, containers, blades installed on automated deboning equipment; see Chapter 6). An operation such as skinning poultry portions has been reported to increase aerobic counts in a high speed processing line (Table 15.4.9.1). As indicated above, ground meat is commonly handled 10 – 12 times, which results in a shorter shelf life compared to intact muscle pieces (e.g., 3-5 days versus 1-2 weeks).

15.5.2 Storage Shelf Life

The shelf life of fresh poultry depends on the initial microbial population (number and type), storage temperature, pH, additives, and other factors. Temperature fluctuations in the cold chain are particularly important. Bruckner et al. (2012) reported on this topic in the case of fresh poultry and pork meat (Fig. 15.5.2.1) and showed similar results for 4°C storage condition (note; this is similar to results published in 1972 shown in Figure 15.2.1). When temperature was increased for a certain period of time to 7 and 15°C, shelf life was reduced (Table 15.5.2.1). Overall, the authors indicated that fresh poultry and pork showed similar spoilage patterns under dynamic temperature conditions with a remarkable reduction in shelf life when short temperature upshifts occurred at the beginning of storage (reductions were up to 2 days or over 30% shorter). As expected, scenarios with shifts to 15°C led to greater reductions than 7°C for both meats.

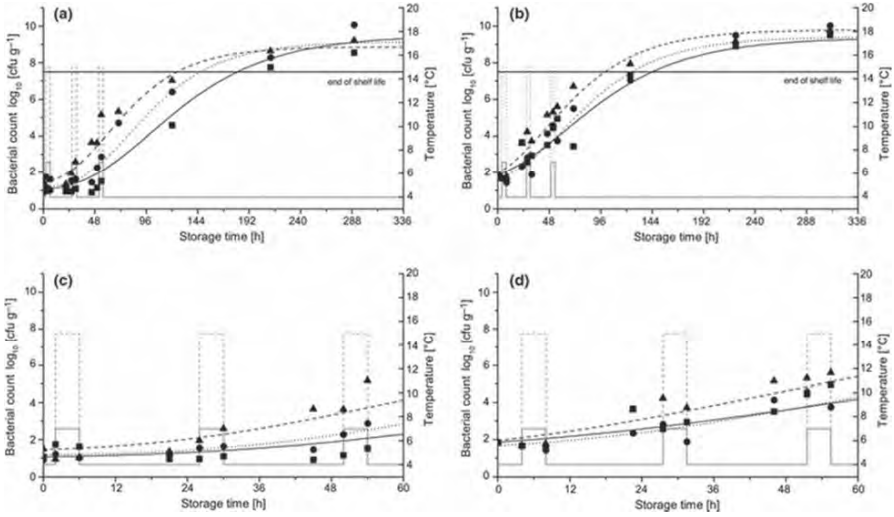


Figure 15.5.2.1 Growth of *Pseudomonas spp.* in trial B fitted with the Gompertz model on pork (left) and poultry (right), (a, b): during the complete storage, (c, d); during the first 60 h of storage; (■ —) scenario B0 at 4°C constant, (● ····) scenario B1 with shifts to 7°C, (▲– –) scenario B2 with shifts to 15°C (solid grey line; temperature profile B1, dashed grey line; temperature profile B2).
From Bruckner et.al (2012).

An early report (Ayres et al., 1950) on the effect of storage temperature on shelf life of fresh, eviscerated, and cut up poultry indicated shelf lives of 15-18 days when stored at 0°C, 6-8 days at 4.4°C, and 2-3 days at 10.6°C. Later studies indicated similar trends where meat stored at 10°C spoiled about twice as fast as at 5°C and three times as fast at 15°C (Cox et al., 1998). The type of spoilage flora that develops on eviscerated chicken is influenced by storage temperature. Barnes and Thornley (1966) noted that the predominant species found on freshly processed broiler carcasses were initially mesophilic such as micrococci, Gram-positive rods, and flavobacteria (50, 14 and 15 different strains, respectively). When the meat was held at 1°C, however, the number of detectable strains decreased to three. In that case, psychrotrophic strains of *Pseudomonas* eventually dominated the culture (the number of detected strains increased from 2 to 70) and caused spoilage. Since the publication of Barnes and Thornley's (1966) original article, *P. putrefaciens* (the principle spoilage bacteria on fresh poultry) has been reclassified as *Alteromonas putrefaciens*. This bacterium is present at relatively low numbers on carcasses immediately after processing (no strains detected; i.e., probably due to below detection level of the method used) but went up to 19, 4, and 4 when the storage temperature was held at 1, 10, and 15°C respectively. In living birds, this bacterium is found on the feathers and feet. Later, during processing, it can be isolated from chill tank water but is rarely found in the intestines. If the meat is held at 10°C, *Pseudomonas*, *Acinetobacter*, and *Enterobacteriaceae* spp. multiply fairly rapidly. At 15°C, *Acinetobacter* and *Enterobacteriaceae* spp. will dominate the microbiota because their optimal growth temperatures are higher than that of *Pseudomonas*.

Pooni and Mead (1984) have also indicated that bacteria isolated from temperature-abused fresh poultry are different from those isolated from meat held at an appropriate storage temperature (< 5°C). At 20-22°C, 70% of the bacterial population consisted of Proteus species (mesophilic) and only 20% were *Pseudomonas* (psychrotrophs).

Although spoilage bacteria grow at refrigeration temperatures, their growth rate is slower at lower temperatures. Most mesophilic bacteria will survive but will not multiply at refrigeration temperatures. The generation time of a mesophilic bacteria such as *E. coli* has been reported to be 0, 0, 20, 6, 2.2, 1.2, 0.7 and 0.4 hr at temperatures of -2, 1, 5, 10, 15, 20, 25 and 30°C, respectively (note: the lag phase time at 10 and 5°C might exceed 60 and 215 hr respectively; USDA, 2015).

Table 15.5.2.1 Calculated shelf life times and shelf life reductions for fresh pork and fresh poultry in different dynamic storage trials. From Bruckner et al. (2012).

			Pork			**Poultry**		
Storage Trial	Scenario[a]	Number of Shifts	Shelf life[b] (h)	Shelf life reduction[c] (h)	Shelf life reduction (%)	Shelf life (h)	Shelf life reduction (h)	Shelf life reduction (%)
Continuous temperature abuse during storage (trial A)								
Trial A	A0	0	148.6	–	–	140.0	–	–
	A1	4	144.2	4.4	3.0	130.5	9.5	6.8
	A2	4	126.5	22.1	14.9	122.4	7.6	12.6
Temperature abuse in the beginning of storage (trial B, C and D)								
Trial B	B0	0	180.9	–	–	138.4	–	–
	B1	3	146.6	34.3	19.0	125.0	13.4	9.7
	B2	3	124.7	56.2	31.1	100.0	38.4	27.7
Trial C	C0	0	169.1	–	–	140.2	–	–
	C1	2	157.5	11.6	6.9	133.5	6.7	4.8
	C2	2	121.1	48.0	28.4	106.7	33.5	23.9
Trial D	D0	0	138.9	–	–	133.5	–	–
	D1	1	124.0	14.9	10.7	122.1	11.4	8.5
	D2	1	103.5	35.4	25.5	102.9	30.6	22.9

Shelf life was estimated from time point zero of the laboratory investigations, which means 24 hr after slaughtering.

[a]Scenarios: A0 – control at 4°C; A1 - four shifts for 4hr from 4 to 7°C; A2 - four continuous shifts for 4hr from 4 to 15°C; B0 – control (no shifts, at 4°C constant); B1 – three shifts for 4hr from 4 to 7°C; B2 - three continuous shifts for 4hr from 4 to 15°C; C0 – control (no shifts, at 4°C constant); C1 – two shifts for 6hr from 4 to 7°C; C2 - two shifts for 6hr from 4 to 15°C; D0 – control (no shifts, at 4°C constant); D1 – one shift for 12 hr from 4 to 7°C; D2 – one shift for 12 hr from 4 to 15°C.

[b]Evaluated by count of *Pseudomonas* spp.: End of shelf life: 7.5 $\log_{10}$ cfu g^{-1}.

[c]In relation to shelf life at 4°C (Scenario 0 in each trial).

When spoilage microorganisms grow on poultry meat they produce by-products such as slime (a protective carbohydrate secretion) and off-odour molecules. The number of bacteria required to cause a noticeable change on the surface of the meat (e.g., appearance of slime) is estimated at about 10^6 to 10^8 CFU/cm^2. At the beginning of the storage period, a small psychrotroph population would mainly utilize glucose or other simple sugars as an energy source. The by-products of glucose metabolism do not contribute substantially to detectable spoilage. However, as glucose is depleted the bacteria switch to other compounds, such as amino acids, which cause the formation of odourous by-products (Pooni and Mead, 1984). Various spoilage signs have been reported, usually starting with the

appearance of small, translucent dots (i.e., microbial colonies) on the cut surfaces of skin/meat. Initially, the colonies appear as tiny water droplets, but later they grow, become opaque, and finally create a uniform, sticky, or slimy layer. At this stage, the meat usually develops an offensive ammonia odour or the so called "dirty dishrag" odour. Coloured colonies (e.g., gray, yellow, brown) are usually associated with a specific spoilage microorganism (e.g., pigmented *Pseudomonas*). In order to obtain meaningful bacterial counts, an appropriate incubation temperature should be used (e.g., 2-5°C is used to encourage psychrotroph growth and prevent the growth of mesophilic bacteria). In general, agar plates should be incubated at or near the temperature at which the product is stored. Enumeration of mesophilic bacteria can be more difficult than that of psychrotrophs because some psychrotrophs will also grow at elevated temperatures. For example, *Pseudomonas* and *Aerobacter* are capable of growth between 0 and 30°C; however, at 35°C they will be inhibited. Knowing the maximum growth temperature of the different psychrotrophs is important in determining the incubation temperature required to enumerate mesophilic bacteria in a mixed population.

Frozen storage is used to extend the shelf life of food products by weeks or months. At freezing temperatures water is unavailable to the microorganisms and most cannot grow (see also preservation discussion in Chapter 11). Poultry meat freezes at -1 to -2°C because of its salt and mineral content, which suppresses the freezing point. During freezing, a portion of the microbial population is killed or sub-lethally injured. Bacterial survival after thawing can range from 1-100% but is commonly around 50%. Survival depends on factors such as the food composition (e.g., high versus low fat content), freezing rate, and microorganism type (e.g., *Campylobacter* is more sensitive than *E. coli*; *S. aureus* is more tolerant of freezing and becomes significant during the thawing process). Slow freezing destroys more microorganisms than fast freezing because it forms intra- and extracellular osmotic gradients throughout the cell that damage its structure. During fast freezing, no/less such gradient is formed (Jay et al., 2005; Cepeda et al., 2013) and this process can actually be used to preserve bacteria for medical or food applications (e.g. very rapid freezing using liquid nitrogen at around -190°C can be used to save cells for later use in a starter culture). The effect of freezing on the shelf life of thawed chicken has been studied by various researchers and most reports indicate no major differences in shelf life after the meat has been thawed (Sauter, 1987).

15.5.3 Cooking

Cooking meat products in industrial facilities has become a common practice around the world (see also Chapters 1 and 11) as a result of consumer demand for convenience and extended shelf lives, as heating (commonly to 68-74°C)

inactivates pathogens and many spoilage bacteria. When a heating step is applied, the processor must adhere to strict food safety procedures (e.g., a minimum end point cooking temperature followed by a predetermined chilling rate). Destruction of the major groups of spoilage microorganisms and pathogens is discussed below. Over the past decade, post-cooking contamination of ready to eat (RTE) meat products with pathogens such as *Listeria* has been a topic of concern for both governments and their citizens (FSIS, 1999a and b; Borchert, 1999; Sofos, 2010). Overall, *Listeria* will be destroyed at 70°C, but post-cooking contamination problems have been associated with people and equipment (e.g., slicing cooked meat) recontaminating the product, the ability of *Listeria* to survive at low temperatures, and its widespread presence within our environment. Most large companies use specific measures to reduce listeriosis risk such as positive airflow in slicing areas, chemical additives, post-packaging heat, or high pressure treatments.

It should be remembered that cooking to 68-74°C does not sterilize the product, as would be the case in a canning operation where the product is heated to 121°C to kill all spore forming microorganisms. In pasteurized products spoilage microorganisms are still present and they will spoil/degrade the product over time. To illustrate what processors of cooked meat products are facing, a few examples of common problems and microorganisms involved in spoilage are provided below:

a. Gas production without a bad odour has been reported of *Leuconostoc* growth in vacuum packed, fully cooked meats such as chunked and formed turkey/pork ham, frankfurters, cooked sausages, and summer sausages (Ray and Bhunia, 2007). The pH of these products is usually about 5.0-6.0 and tests show the predominant presence of lactic acid bacteria. *Leuconostoc carnosum* and *L. mesenteroides* are likely responsible for the CO_2 production that causes package bloating. It is assumed that this problem is associated with post-heat contamination (e.g., slicing, packaging, handling operations).
b. Off odours and gas production in cooked, vacuum packed, refrigerated meats are usually associated with *Clostridium* spp. Gases, including H_2S, have been reported due to the growth of *Clostridium* isolated from the product (Ray and Bhunia, 2007), where some isolates show typical terminal spores. In one case, purge accumulating after about 3 weeks of cold storage was also due to a large number of *Leuconostoc* (10^8/ml of the purge) growing in the package. Ammonia off odours in cooked, vacuum packed, turkey breast rolls with gas and purge accumulation was reported to be due to high numbers (10^8/ml) of Gram-negative *Serratia*

liquifaciens and Gram-positive *Leuconostoc mesenteroids* (Ray and Bhunia, 2007). It was suspected that the product was contaminated post-cooking and the pH did not decrease significantly because of the alkaline phosphate used in the product. In that case, *Leuconostoc* produced gas and then *Serratia* spp. metabolized proteins (deamination), which released ammonia. Some products also showed pink discolouration that could be due to reduction of metmyoglobin (see Chapter 17). This is an example of "succession growth" where one group of microorganisms paves the way for the next group (e.g., this concept is also used to describe the steps in making sauerkraut).

c. Gray discolouration (spots, patches) was reported in stored turkey luncheon meat slices after 2-3 days of aerobic refrigerated storage (Ray and Bhunia, 2007). The bacterium responsible was a *Lactobacillus* strain that produced H_2O_2, which could oxidize myoglobin to produce a gray colour. Under vacuum conditions this strain will not produce H_2O_2.
d. Yellow spots/discolouration in vacuum packed cooked luncheon meat. The colour usually develops after 3-4 weeks of storage at 4-5°C. A picture of the product can be seen in Chapter 17 (see colour defects). The microorganism responsible has been identified as *Enterococcus faecium* ssp. *casseliflavus*, which survived a 71.1°C cooking temperature for 20 min.

15.5.4 Hurdle Concept – Secondary Processing

The ability to extend the shelf life of cooked meat products depends on combining different factors that control microbial growth (both spoilage and pathogenic microorganisms). This is called the hurdle concept/technology, where the combination of several antimicrobial tactics, each at a relatively low level, can substantially increase the shelf life. For example, the long shelf life of a hot dog (guaranteed by many manufacturers for 30-70 days) is due to the combination of a relatively low salt concentration (about 2%), ingredients that reduce the pH (e.g., lactate), cooking to 72°C (which eliminates pathogens, but not all spoilage microorganisms), vacuum packing, and refrigeration at ≈ 2°C. Removing even one of these measures (e.g., refrigeration) can result in a catastrophic effect on shelf life and food safety. Table 15.5.4.1 shows examples of the commonly employed technologies/ingredients that are used in combination to increase the safety and shelf life of food products (see also Chapter 11).

Table 15.5.4.1 Potential hurdle steps to improve safety and extend the shelf life of a cooked meat product. See text for more details.

Hurdle	Notes
Physical	
Temperature	• Keep raw meat and other perishable items at low temperature. • Cook meat to appropriate temperature to destroy pathogens and most spoilage microorganisms.
Clean Environment	• Maintain the cleanest possible environment and equipment.
Irradiation	• Use (where permitted) to inactivate microorganisms.
Drying	• Use to reduce water activity.
Chemical	
Nitrite	• Used at 100-200 ppm, in some products, to inactivate *C. botulinum* (i.e., in products heated to 70-75°C spores cannot be destroyed by heat).
Salt	• Commonly used at 1.5-3.0% to help suppress certain groups of microorganisms.
Lactate	• Added to reduce pH and suppress certain groups of microorganisms (Glass et al., 2002). In fermented products, live lactic acid bacteria are used.
Storage and Distribution	
	• Modified atmosphere (Genigeorgis, 1985). • Low temperature package kept intact in storage coolers, trucks, retail stores.

15.6 Cleaning/Sanitation and Equipment Design

Government regulations require that food processing plants be kept clean. Maintaining a clean food processing operation, on a continuous basis, is not an easy task as raw materials are coming in all the time from different locations (local /international suppliers). In addition, certain operations can result in contamination and/or cross-contamination (e.g., evisceration, deskinning, and defeathering). In order to achieve a clean operation, management needs good planning, adequate equipment design, employee commitment (i.e., production staff, maintenance, sanitation crew), knowledge of available cleaning compounds, and an adequate supply of clean water.

Aside from government regulations, there are obvious reasons for maintaining good sanitation:

a. The company reputation is on the line each time a consumer buys a product. Gaining brand loyalty is a time consuming and expensive process that can be lost as a result of a single food poisoning incident. It is also important to remember that in our competitive global economy, switching from one brand to another is easy for the average consumer (e.g., switching might only require moving a few steps along the display cooler in a store).
b. Lawsuits are becoming a major issue where consumers who suffer from using/eating a defective product seek financial compensation. Legal bills, compensation awards, and bad publicity can result in big financial losses, high insurance premiums, and bankruptcy.
c. Fresh meat and processed products are perishable ingredients that will quickly spoil without adequate sanitation and storage.
d. Avoiding recalls, either mandatory or voluntary, can save the company bad publicity and expenses. National and international recalls can be extremely complex, expensive, and difficult to conduct.

15.6.1 Cleaning a Meat Processing Plant

This section is intended to provide an overview of the important aspects of cleaning a food processing plant to help the reader realize the complexity of the process when so many raw materials, people, and services (e.g., water supply, electricity) are entering and leaving the plant. For an extensive review of the topic the reader should consult special text books written on this topic such as the one by Marriott and Gravani (2006). The methods and chemicals used for cleaning a food processing plant are based on the soil material present and sanitizer rotation required. Meat plants mainly deal with protein and fat under wet environments and, therefore, alkaline solutions are the most common cleaning solutions used. Today, a great number of cleaning compounds are available on the market. Some are based on alkali compounds (e.g., phosphates, carbonates, silicates), some on acids (e.g., citric acid, phosphoric acid), and some on synthetic detergents (e.g., anionic, cationic, nonionic base). In the meat industry today, the common cleaning solutions are often based on an alkaline solution, with about 1.5% sodium hydroxide. This is used to saponify the fat and hydrolyze the protein deposits. Various synthetic detergents are also used by the meat industry to remove meat deposits, fat, and dirt. After allowing adequate contact time at the right temperature, the solution (with/without a foaming agent) is washed away with water. Later, the remaining scale/

mineral deposits can be removed with a weak/strong acid. Another approach to cleaning involves the use of enzymes, where a solution containing proteases (i.e., to break down protein deposits) is used in a mild alkaline solution that saponifies the fat deposits. Because enzymes would be inactivated at high pH and temperatures, corrosion problems are minimized. However, enzyme solutions are not as popular for general use because they are still more expensive and also present a higher risk to the people using them.

When designing a cleaning procedure it is important to follow logical steps in order to minimize the costly use of chemicals, time, and heated water. Common cleaning procedures include:

a. Physical removal of soils from surfaces. This step is usually done manually (e.g., scrapers to remove meat chunks) to help reduce soil loads and later save on cleaning compounds and wastewater treatment.
b. High pressure water to rinse away the soil. The water temperature should be below 55°C to prevent cooking the meat on the surface. Note: in some plants, high pressure is not used in order to reduce aerosols.
c. Washing with an alkaline solution or a synthetic detergent to loosen the soil deposits. It is important to allow sufficient time for the chemical reaction(s) to occur. A contact time of 6-12 min and a cleaning solution temperature of 50-55°C is usually recommended. If vertical surfaces are cleaned, a foaming agent is used to keep the compounds in close contact with the surface. As indicated above, an enzyme solution can also be applied. When enzyme solutions are used, the water temperature should be lowered to prevent enzyme denaturation.
d. Rinsing with clean water to remove loose soil and alkaline or detergent solutions.
e. Washing with an acid to remove scale deposits. Mineral deposits (appear as a rusty or whitish scale) are not removed by an alkaline solution and therefore acids (e.g., phosphoric, hydrochloric, or organic acids such as citric, gluconic) are used.
f. Inspecting (visual, microbial) all equipment surfaces to ensure removal of all soil and cleaning compounds. Section 15.6.2 discusses equipment design and good drainage from surfaces.
g. Application of sanitizing agents. It is essential to apply this step only after all the equipment has been thoroughly cleaned. Otherwise the sanitizer would not be in close contact with the surface and its activity is diminished. A chlorine solution (100-200 ppm), iodine (20-30 ppm) or quaternary ammonium solution (150-200 ppm) are commonly used.

h. Washing/rinsing the sanitizer is a step that depends on the chemical used. Some sanitizers will react and become neutralized (e.g., chlorine), others have a prolonged residual effect and can be left on the equipment (e.g., quaternary ammonium), and still others need to be rinsed (e.g., iodine).
i. In cases where corrosion is a problem, oil is sprayed on sensitive areas/ equipment. Unless it is a food-grade, the oil is removed before the next processing shift starts.

Continuous cleaning using a cleaning-in-place (CIP) method is also used for some moving belts and other pieces of equipment. Another application of CIP is in a closed system such as a smokehouse at the end of the operation where a system is used to dispense heavy duty detergents that can be used to effectively remove soil deposits without exposing employees to harsh chemicals. This is an example of using automation to effectively clean a challenging area (e.g., a slippery stainless steel floor) exposed to soil deposits that are difficult to clean (e.g., smoke). In any case, today CIP systems are fairly limited to specific areas in a meat processing plant.

15.6.2 Hygienic Design of Processing Equipment

Equipment design can play a key role in minimizing microbial problems in a food processing plant. Recently, more emphasis has been given to designs that reduce cross-contamination by eliminating microbial growth niches and avoiding potential transfer points (e.g., product contact surfaces). The former refers to niches that are not easily accessible to cleaning and sanitation and can harbor microorganisms. The exterior of non-product contact surfaces (floors, walls) should also be arranged to prevent harboring bacteria, pests, etc. The food industry uses a lot of conveyer belts to transport raw and cooked food products (Fig. 15.6.2.1). Good hygienic design is therefore essential to ensure the highest level of food safety while reducing time, effort and cost of cleaning while providing economic benefits. A revised European guideline (EHEDG, 2014) is used here to illustrate the importance of the topic and provide an industry recognized source of information. Overall the document provides guidance specifically for the hygienic design of conveyor belts and is supplementary to the general requirements and standards for hygienic equipment design. The guidance applies where the foodstuff is in direct contact with the conveyor and also in those areas where there is a hygienic risk from indirect contamination. The major components of conveyors described in the document include: friction driven conveyers, positively driven conveyers, modular belts, metal and wire belts, round- and V-profile belts, frames, belt support systems, lateral guides for belts, drive stations, motors, and accessories. An example of improving the sprockets used for a positive belt drive

is shown in Figure 15.6.2.2, which made it much easier to clean and eliminate the risk of meat/food trapped in between the teeth.

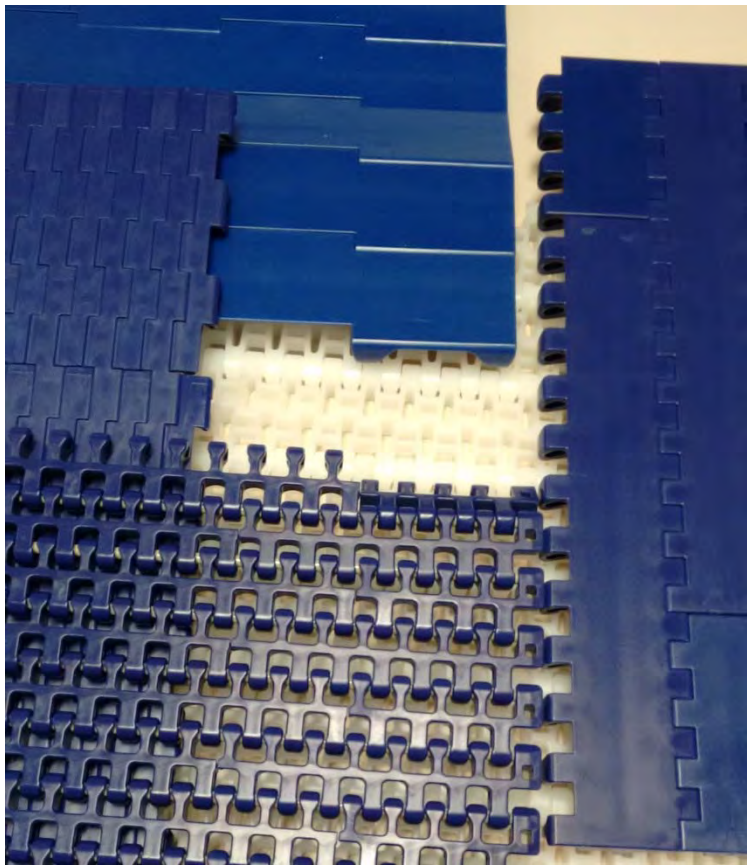


Figure 15.6.2.1 Examples of plastic conveyor belt designs used for moving fresh and cooked meats. Photo by S. Barbut.

The meat industry has only recently started to emphasize equipment design whereas the dairy industry developed its 3M sanitation standards for equipment much earlier.

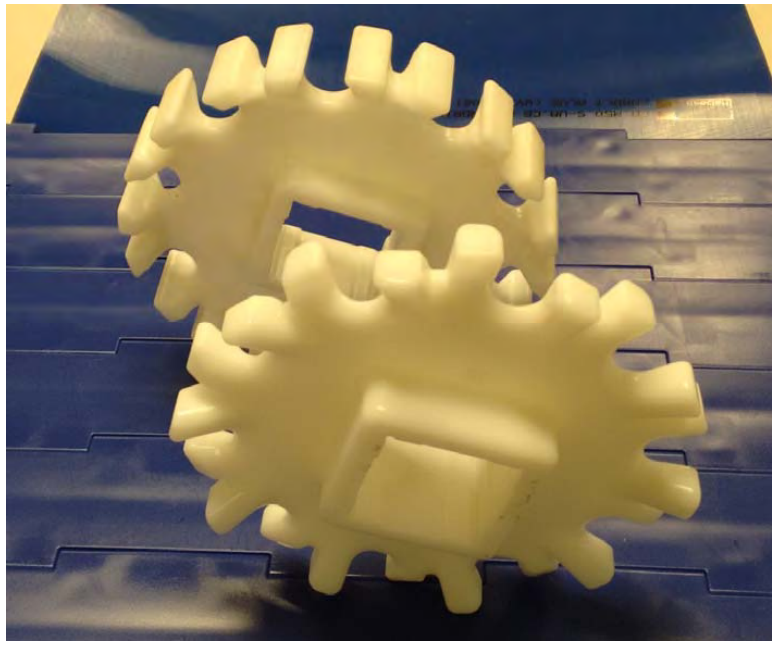


Figure 15.6.2.2 Improvement in sprockets for belt drive (front wheel with rounded teeth). Photo by S. Barbut.

Today, guidelines for hygienic design are based on different international standards (Bilgili, 2006):

a. Hygiene Requirements for the Design of Meat and Poultry Processing Equipment (American National Standard ANSI/NSF/3A 14159-1)
b. Hygiene Requirements for the Design of Hand Tools used in Meat and Poultry Processing (American National Standard ANSI/NSF/3A 14159-2)
c. Assessment for Cleanability of Belting Materials used in Meat and Poultry Processing Equipment (American National Standard ANSI/NSF/3A 14159-3)
d. 3-A Sanitary Standards
e. National Sanitation Foundation International Standards (NSF International)
f. European Norms for Food Processing Machinery
g. International Organization for Standardization (ISO)

Ten principles of sanitary equipment design were developed by the American Meat Institute (AMI, 2003) to guide new equipment design and/or modify existing equipment. The list also includes a checklist attached to each principle (see below), which allows processors to conduct an audit based on the assigned points. In such an audit the equipment must be used in the processing line for a 90-day period, disassembled to its normal daily level, and evaluated visually and microbiologically. Full points are assigned to satisfactory items, half points are assigned to marginal items, and no points are given to unsatisfactory items. An overall score of 1000 is considered acceptable whereas a score of < 1000 needs improvement. The ten design principles include:

a. Cleanable To A Microbiological Level

Food equipment must be constructed to ensure effective and efficient cleaning of the equipment over its life span (100 points total; as measured post-installation):

1. The equipment should be designed as to prevent bacterial ingress, survival, growth and reproduction on both product and non-product contact surfaces (20 points).
2. All surfaces are cleanable as measured by less than one colony-forming unit (CFU) per 25 square cm, less than one CFU per 10 ml when the item is rinsed, acceptable RLU (device specific) when measured by residual adenosine triphosphate, and/or negative for residual protein or carbohydrate when using swabs (20 points).
3. All surfaces are accessible for mechanical cleaning and treatment to prevent biofilms (20 points).
4. When requested, data is available to demonstrate that soiled equipment is cleanable as indicated above, by an individual using the cleaning protocol provided by the supplier (20 points).
5. Surfaces are clean visually and to the touch, and pass operational inspections using sight, touch, and smell (20 points).

b. Made Of Compatible Materials

Construction materials used for equipment must be completely compatible with the product, environment, cleaning, and sanitizing chemicals and the methods of cleaning and sanitation (100 points total).

1. Product contact surfaces are made with materials that are corrosion resistant, non-toxic, and non-absorbent as approved in NSF/ANBSI/3A 141159-1 (10 points).

2. In general, stainless steel shall be AISI 300 series or better (10 points).
3. Composites and plastics remain intact without changes in shape, structure, and function through cleaning and sanitation (10 points).
4. Plated, painted, and coated surfaces are not used for food contact surfaces or for surfaces above the product zone areas (10 points).
5. Coatings and plating must remain intact (10 points).
6. Cloth back belts are not used (10 points).
7. Materials such as wood, enamelware, uncoated aluminium, uncoated anodized aluminium, and others per NSF/ANSI/3A 14159-1 are not used (10 points).
8. Metals are compatible with one another (10 points).
9. Seals and O-rings are designed to minimize product contact (10 points).
10. Materials used in construction are compatible with the product, the environmental conditions to which they will be exposed, as well as cleaning methods and chemicals (10 points).

c. Accessible For Inspection, Maintenance, Cleaning and Sanitation

All parts of the equipment shall be readily accessible for inspection, maintenance, cleaning and sanitation without the use of tools (150 points total). See examples in Figure 15.6.2.3.

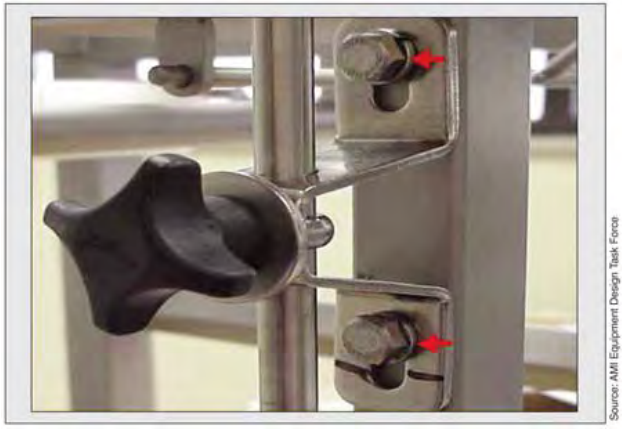
1. All surfaces in the product zone are readily accessible for cleaning and inspection (15 points).
2. Product zone components with inaccessible surfaces can be disassembled without tools and easily (15 points).
3. Where access or disassembly is not possible, the entire unit is cleaned by clean-in-place (CIP) or clean-out-of-place (COP) methods (10 points).
4. Parts remain attached or hung on the equipment for easy cleaning and to prevent damage and loss. Separate part carts are supplied as an alternative (5 points).
5. Machinery and chain guards drain away from product zones and are easily removed (15 points).
6. Product catch pans or drip pans are easily removable for cleanup, so they are not lost or separated from the equipment (10 points).
7. All belting is easily removable or the belt tension is removed easily without tools so the surfaces underneath can be cleaned (15 points).
8. All surfaces in non-product zones shall be readily accessible for cleaning and inspection (15 points).
9. Installation will maintain a 46 cm floor clearance for any product contact areas or conveyor travel paths. Equipment design provides 31 cm of clearance to the floor (15 points).

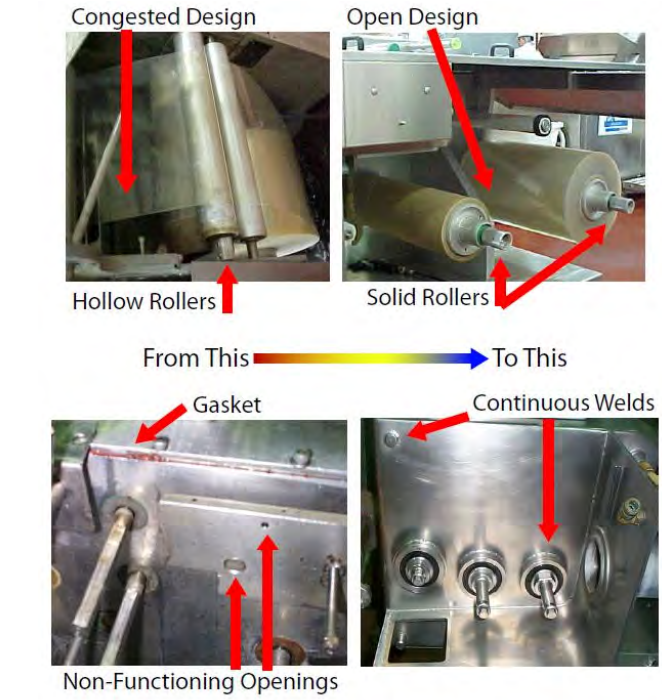
10. Equipment is located 77 cm from overhead structures and 92 cm from the nearest stationary object (15 points).
11. All air, vacuum, and product hoses and their assemblies on the equipment are easily removable for soaking and sanitizing (10 points).
12. All air, vacuum, and product hoses are transparent or opaque, and meet product contact surface guidelines (10 points).

a)



b)





c)

Figure 15.6.2.3 Principles of design. Pictures demonstrating potential problems and corrections related to equipment design: (a) showing the importance of using compatible materials, as related to 'Principle b' described in the text; (b) showing a potential problem with a hollow area that can trap food, as related to 'Principle c'; (c) showing how to improve on enclosure spaces needed for maintenance according to 'Principle e'. Courtesy of AMI (2014).

d. No Product Or Liquid Collection

Equipment should be self-draining to assure that liquid, which can harbour and promote the growth of bacteria, does not accumulate, pool or condense on the equipment (total 100 points).

1. All surfaces should be designed to eliminate water pooling and to be self-draining (10 points).
2. Round framework is used for horizontal members where possible (20 points).
3. Where square or rectangular bases are used, the flat surface is turned 45 degrees to horizontal where possible (10 points).
4. All open surfaces are made of sufficient strength to prevent warping and subsequent pooling of water (10 points).
5. Moisture does not drip, drain or draw into product zones (15 points).
6. Belt tension is adequate throughout operations to prevent water from pooling on the belts (15 points).
7. Dead spaces are eliminated (15 points).
8. Materials used in the construction are non-absorbent (15 points).

e. Hollow Areas Should Be Hermetically Sealed

Hollow areas of equipment, such as frames and rollers must be eliminated whenever possible or permanently sealed. Bolts, studs, mounting plates, brackets, junction boxes, nameplates, end caps, sleeves, and other such items should be continuously welded to the surface, not attached via drilled and tapped holes (150 points total).

1. All rotating members, such as drive sprockets or belt pulleys, are to be solid or filled with dye and fully sealed with continuous welds (30 points).
2. All stationary hollow tube construction, such as frame members or blade spacers, are fully sealed with continuous welds to prevent interior contamination (30 points).
3. There are no fastener penetrations into hollow tube construction (30 points).
4. Threaded leg adjustments are internal and do not penetrate the tube frame members (30 points).
5. Name plates and tags are minimized. When attached, plates and tags are continuously welded. Rivet- or screw-attached plates (often sealed with caulk) are absent (30 points).

f. No Niches

Equipment parts should be free of niches such as pits, cracks, corrosion, recesses, open seams, gaps, lap seams, protruding ledges, inside threads, bolt rivets and dead ends (150 points total).

1. Surface texture of a product contact surface shall not exceed 32 microns, except as described in NSF/ANSI/3A 14159-1 (10 points).
2. Surface texture on a non-product contact surface shall not exceed 125 microns (10 points).
3. Internal corners and angles shall have a smooth and continuous radius of at least 3 mm (angles < 35 degrees) (10 points).
4. No lap joints (10 points).
5. Hermetically sealed spacers are used to allow for space between two adjoining pieces to permit mechanical action during cleaning (10 points).
6. Caulking is not used (10 points).
7. All joints and welds are flush and free of pits, cracks, and corrosion (10 points).
8. All welds are continuous, smooth and polished (10 points).
9. Sleeved assemblies (bushings, sprockets, and bearings) are no longer than 1.5 inches or are disassembled for cleaning (10 points).
10. Press and shrink fits are not used (10 points).
11. Fasteners are not used in or above product zone (10 points).
12. Fasteners that are product contact surfaces must utilize the ACME 60-degree stub thread (10 points).
13. If fasteners are necessary, they do not have exposed threads and have a positive locking method to prevent falling or vibrating off the machine (10 points).
14. Belt scrapers do not have lap joints and are removed without tools (10 points).
15. Belt supports are constructed from single pieces of material (10 points).

g. Sanitary Operational Performance

During normal operations, the equipment must perform so it does not contribute to unsanitary conditions or the harbourage and growth of bacteria (100 points total).

1. Buttons on control panels are easily cleaned and sanitized during operations (15 points).
2. All compressed air used for blowing on the product or contact surfaces is filtered to a minimum of a 0.3 micron level and dried to prevent the formation of moisture in the piping system (15 points).

3. No bearings are present in the product contact zone areas (15 points).
4. A separation exists between the product contact and non-product contact areas to prevent cross-contamination during operation (15 points).
5. All surfaces near the product contact zone areas are designated as if they were product contact zone areas (15 points).
6. Product contact surfaces are made to prevent accumulation of product residue during operation (15 points).
7. Shafts passing through a product zone shall have an air gap to prevent product contamination (10 points).

h. Hygienic Design Of Maintenance Enclosures

Maintenance enclosures and human machine interfaces such as push buttons, valve handles, switches, and touch screens, must be designed to ensure food product, water or product liquid does not penetrate or accumulate in or on the enclosure or interface. Also, physical design of the enclosures should be sloped or pitched to avoid use as storage area (50 points total).

1. Drives, chain guards, electrical control boxes, and bearings are not located over open product zones (10 points).
2. Control and junction boxes are fastened to the frame in a manner consistent with the sanitary design principles (10 points).
3. Utility supply lines and pipes are separated to prevent catch points and allow for cleaning (5 points).
4. Utility lines are 31 cm above the floor and cleanable (5 points).
5. Conduit and supply lines are not routed above product contact areas (10 points).
6. Maintenance enclosures in direct wash-down areas must be able to be exposed to water and chemicals used in cleaning and sanitation (10 points).

i. Hygienic Compatibility With Other Plant Systems

Equipment design should ensure hygienic compatibility with other equipment and systems, such as electrical, hydraulics, steam, air and water (50 points total).

1. Exhaust systems have welded seams with adequate access for cleaning and inspection (10 points).
2. Vertical duct sections have a drain to prevent drainage from flowing back into the equipment (10 points).
3. Separate exhausts are supplied for raw and ready-to-eat product zones (10 points).

4. CIP systems are designed, installed, and validated using a recognized third-party in sections of duct work that are not easily cleaned through access openings (10 points).
5. Equipment is designed to meet criteria of waste water infrastructure capability to assure no backups of drainage lines result under normal operation (10 points).

j. Validate Cleaning And Sanitation Protocols

Procedures for cleaning and sanitation must be clearly written, designed and proven effective and efficient. Chemicals recommended for cleaning and sanitation must be compatible with the equipment and the manufacturing environment (50 points total).

1. Cleaning and sanitizing are considered in the design process (10 points).
2. Cleaning protocols must be safe, practical, effective, and efficient (10 points).
3. Cleaning and sanitation protocols are developed by the manufacturer, validated by a third-party, and provided in a training manual that is easy to read and understood by cleaning and sanitation employees (10 points).
4. Equipment design and materials are capable of withstanding standard cleanup procedures. Equipment materials have been reviewed with Materials Safety Data Sheets for the cleaning and sanitizing chemicals to assure compatibility (10 points).
5. All belts should withstand heating to 71°C for up to 30 minutes (10 points).

Design emphasis is placed not only on efficiency and safety, but also on hygiene. The latter has become a non-competitive issue (AMI, 2003, 2014) and information is shared among equipment manufacturers and processors.

In conclusion, it is important to understand that meat is a perishable food item because it contains all nutrients required for microbial growth and its pH (5.5-6.5) is not inhibitory to most spoilage and pathogenic microorganisms. The extensive fabrication, handling (ground meat can be handled 10-12 times before it gets to the consumer), and distribution of meat can increase exposure to microbial contamination. Living, healthy muscle is essentially free of microorganisms but after slaughter the natural defense mechanisms no longer function. During slaughter, the blades that cut through the skin can transfer microorganisms into the bloodstream. Because blood circulation is not immediately stopped, this can distribute microorganisms throughout the carcass. It is important to realize

that 1 g of soil (dirt or manure) attached to the skin or feathers can contain 1 billion microorganisms. Evisceration or removal of the digestive tract is another significant potential point of contamination. The digestive tract harbours high numbers of microorganisms (e.g., 100 million microorganisms/g) and if it is ruptured and its contents spilled on the carcass, high contamination levels are expected. Other potential contamination sources can come from people handling the meat, air coming into the plant (or moved from the primary to the secondary processing area), water used to rinse the carcasses/equipment, and insects getting into the plant. All surfaces in contact with the meat should be periodically cleaned and disinfected (e.g., a common practice for a manual cutting operation is dipping knives in a > 80°C water bath) and employee hygiene should be enforced at all times. This includes measures such as hair nets (mandatory in most food processing plants), clean gloves, aprons and coats, removal of jewelry, and mandatory hand washing before starting work. In some specialized operations, such as packaging of cooked products, employees might be required to cover their nose and mouth with a mask to minimize the spread of microorganisms. This can be another important measure to reduce the risk of pathogens and also increase the shelf life of the product. In such an operation, air filters for incoming air are usually installed as well as keeping a positive air pressure within the room in order to prevent suction of air from other areas of the plant. Today there is also more emphasis on consumer education where cooking instruction labels and raw meat handling stickers appear on meat packages. All of these measures are integral in achieving the larger goal of supplying the customer wholesome and safe food.

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16

EVALUATING TEXTURE AND SENSORY ATTRIBUTES

16.1 Introduction

Texture evaluation of raw meat and fully prepared products is very important to the industry as it helps control product quality, design and optimize processes (e.g., deboning time), and select ingredients to achieve certain textural characteristics (e.g., breading on nuggets). Industry and academia use different tests to measure the properties of meat and meat products. In the industry tests such as shear, tension, and torsion can help optimize formulations and predict the sensory characteristics (e.g., hardness, chewiness) that will be perceived by the consumer. More rigorous sensory evaluations, on the other hand, are more time consuming and expensive to complete but provide more precise information and can also be used to evaluate flavour, aroma, and overall acceptability of the product. Numerous sensory evaluation procedures (e.g., triangle test, descriptive test) will be discussed in this chapter alongside examples of meat products. As in other parts of the book, automation and computer use to facilitate testing will be highlighted.

The goal of this chapter is to review the major texture and sensory methods used to evaluate meat products. However, it is not within the scope of this chapter to cover all material published about such methods as an electronic literature search will yield over a thousand articles in which key words such as meat, texture, and sensory have been used. It is hoped that this chapter will improve the uniformity of methods used by industry and academia, which would increase study consistency and permit direct comparisons between results from different laboratories. In this chapter, an example of using the same test with different operating parameters will be used to illustrate the challenges in comparing currently published results.

16.2 Texture Evaluations

16.2.1 General

Evaluating the textural parameters of a meat product is important in quality control operations and in optimizing ingredient use/processing conditions to consistently produce an acceptable product. A product that is either too tough or too soft (e.g., turkey/pig roast made from PSE meat) will be unacceptable to the consumer. Texture evaluations are done by several tests including shear, penetration, compression, tension (pulling) and torsion (Fig. 16.2.1.1). Another test, dynamic scanning rigidity monitoring, is more commonly used for research purposes and employs a very small non-destructive stress/strain during phase transitions. Such a test is often used to monitor meat gelation during cooking and to evaluate the interactions among different meat and non-meat components.

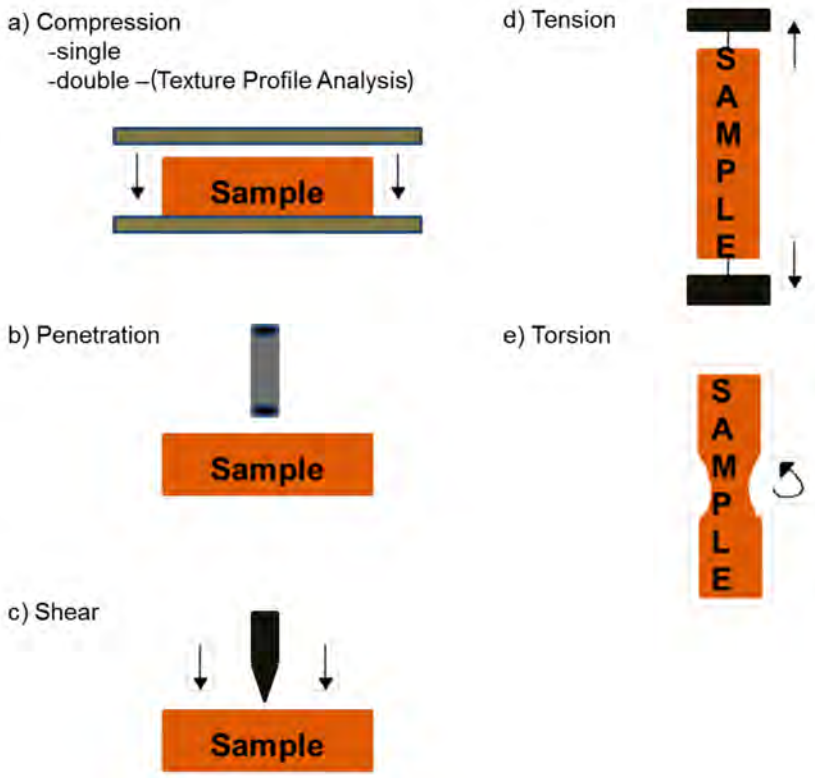


Figure 16.2.1.1 Common methods used for texture analysis such as shear, penetration, compression, tension and torsion. See text for details.

16.2.2 Penetration and Shear Tests

These types of tests are commonly used to evaluate the toughness of a whole muscle product or a gel made with various meat proteins. Shear tests use a blade/knife to cut the sample, whereas penetration tests use a flat/round probe (Fig. 16.2.2.1). The values obtained are usually correlated with sensory analysis (e.g., bite value). A tougher cut of meat will show a higher shear/penetration value. One of the most common tests in this area is the Warner Bratzler shear (WB), named after the person who developed it in 1949. The test employs a single blade to shear a core meat sample and provides values for peak force (i.e., the force required to shear the sample; Fig. 16.2.2.2), work (i.e., the area under the force x distance curve), and Young's Modulus (i.e., the slope of the force deformation curve). Shear determination is usually evaluated on intact pieces or core samples large enough to ensure a representative sample. Bratzler (1949) indicated that sample size, location within the muscle, orientation of the fiber to the shearing blade, and presence or absence of connective tissue are all critical to ensure reliable results with the shear device. Another development, the Allo-Kramer shear device (AK), was introduced in the 1950s and has been adapted for meat texture. It is routinely used by researchers and quality control personnel and the same considerations regarding the size, muscle, fiber orientation, etc., have been noted for the AK as for the WB. The AK employs a cell consisting of 10 to 13 blades that is guided into a square box to shear a large sample.

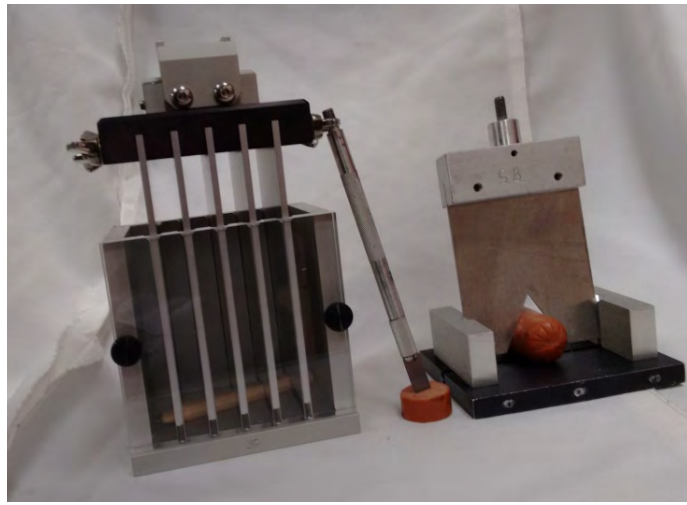




Figure 16.2.2.1 Probes used for shear testing of food products. Showing the Allo Kramer shear cell (first photo on the left), Warner Bratzler shear blade (on the right), and a 9 mm shear blade (center). Second photo shows different probes used for the penetration test. See text for further explanation.
Photos by S. Barbut.

Lyon and Lyon (1996) showed the effect of broiler breast meat deboning time on meat toughness by using the WB and AK shear methods and correlated the results with a sensory panel (Table 16.2.2.1). For the WB, 1.9 cm wide strips of intact, cooked meat were evaluated. For the AK, 20 g meat portions of diced, 1 cm^2 pieces were evaluated. The sensory characteristics were evaluated by an untrained panel via category scales and by a trained panel via descriptive analysis.

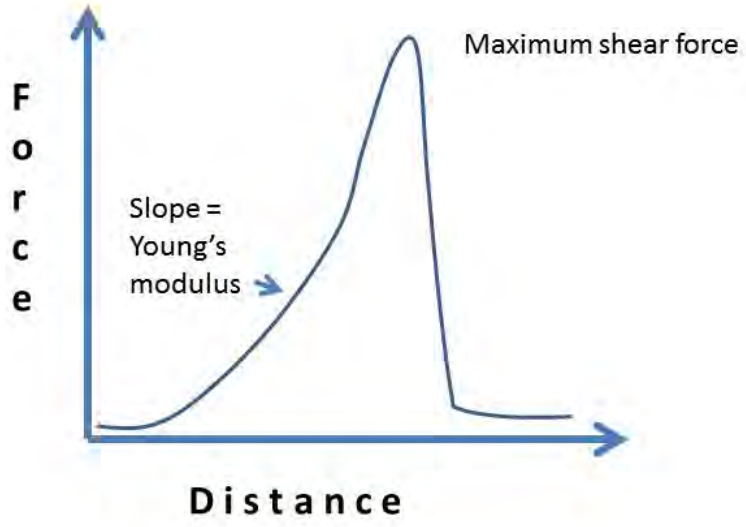


Figure 16.2.2.2 Shear force curve showing force increases as the blade goes down into the sample. When the blade cuts the sample there is a sharp decline in the force needed to drive the blade down. The maximum force is expressed as the shear force value. The work to shear is the area under the curve and is calculated as the force X distance. The Young's modulus is the linear part of the slope of the curve. See text for further explanation.

Deboning time had a significant effect on the shear values for both the intact (WB) and diced (AK) samples (Table 16.2.2.1) and both shearing procedures were sensitive enough to discriminate between the three deboning times (as was also reported by other researchers). The sensory panel showed similar results and tenderness was highly correlated with both shear measurement methods. While juiciness was not significantly affected by deboning time, texture acceptability was and there was a high correlation between values obtained from both shear measurement methods. It is now accepted by the industry that WB values of $\leq$ 4.5 kg are considered good and are preferred for deboned chicken breast meat sold to the consumer.

More recently, the so called razor blade shear test was introduced (Cavitt et al, 2005). Sample preparation is usually easier for this test as there is no need to cut strips from the raw or cooked product before the 9 mm blade is used to shear the sample. This test was found to yield similar texture results to both the Warner Bratzler and Allo Kramer shear tests.

Table 16.2.2.1 Warner-Bratzler and Allo-Kramer shear values for intact and dices cooked (80°C) samples of broiler breasts deboned at three postmortem (PM) times and sensory values (category scale-untrained panel) of cooked diced chicken. Adapted from Lyon and Lyon (1996).

	Texture		Sensory		
Deboning time	**Warner-Bratzler[1] (intact)**	**Allo-Kramer[2] (20-g diced)**	**Juiciness[3]**	**Tenderness[3]**	**Acceptability[4]**
(h PM)	(kg)	(kg/g)			
2	9.5 + 3.9[a]	5.2 + 1.0[a]	3.5 + 1.3	2.5 + 1.3[c]	2.0 + 0.9[c]
6	4.7 + 1.6[b]	3.4 + 0.8[b]	3.4 + 1.2	3.8 + 1.2[b]	2.6 + 0.9[b]
24	3.2 + 0.9[c]	2.2 + 0.2[c]	3.5 + 1.3	5.1 + 0.8[a]	3.0 + 0.9[a]
Correlations (r values)					
With Warner-Bratzler			0.06	-0.90	-0.92
With Allo-Kramer			0.00	-0.99	-0.93

[a-c] Values (× + SE) within a column with no common superscript differ significantly ($P < 0.05$). For texture, mean values are averages of 66 observations (22 birds × 3 replications) for each deboning time. For sensory, 22 panelists × 3 replications

[1] Bench Top Warner-Bratzler device was used to shear a 1.9 cm-wide intact strip

[2] Multiple bladed Allo-Kramer attached to an Instron was used to shear 20 g of diced sample

[3] Category scales: 1 = very dry, tough to 6 = very juicy, tender

[4] Category scales: 1 = poor to 5 = excellent

Penetration tests are commonly used for restructured products, i.e., those made from small, ground or flaked pieces of meat, and some emulsified meat products (e.g., frankfurters; see Chapter 13). Usually, a small diameter probe descends into the product at a constant rate (Fig. 16.2.1.1). Different probes have been used, including flat, pointed, and rounded tips with different diameters. The resistance to puncture of the ground or comminuted product is determined while obtaining a force deformation curve and the results are usually used to compare relative toughness. This test is easy to perform and some companies use it on a routine basis as a rapid quality control test. The gelatin industry, for example, uses the test to standardize gelatin strength (cold 3-8% gelatin samples), also known as the "bloom" test/value. This test can also be useful in monitoring changes to meat batters during cooking as the texture changes from pasty to stiff. Results obtained for a poultry meat batter prepared with either salt (2.5%) or low salt (1.5%) and phosphate (0.42%) are presented in Table 16.2.2.2. Using a 9 mm diameter flat tip probe, the raw meat batter showed low penetration values that could not be determined by a shear test because of the flow characteristics of the sample. Change from a viscous to an elastic sample was visible around 50 to 55°C, the point where myofibrillar proteins start to gel (see Chapter 13). The effect of lowering the NaCl level and using tripolyphosphates can also be seen; textural changes were similar up to 55°C, but later increased at a slower rate when

phosphates were present. The amount of extractable protein (Table 16.2.2.2) was used to evaluate the quantity of proteins used to build the gel. As temperature increased, the protein concentration decreased at about the same rate in both the 2.5 and 1.5% salt treatments. However, differences in penetration force values suggest that the extent of protein-protein interactions differed between the high and low salt treatments. The changes were also monitored by microscopy. The micrographs in Figure 16.2.2.3 show a progressive change in the low salt (1.5% NaCl + 0.42% tri poly phosphate) meat batter's microstructure during cooking (20 to 70°C). As has been previously reported, it is interesting to note that, even at room temperature, the batter showed an organized gel structure. At 40°C, the protein strands became thicker while pore size stayed the same. A further increase to 55°C resulted in both a further thickening of the protein strands and an increase in the number of connections between them. Some thin protein strands were also visible among the thick strands. Overall, these changes corresponded to the large increase in gel strength observed at this temperature and reported in Table 16.2.2.2. Heating to 70°C resulted in a denser protein matrix with the formation of more protein strands concurrent with a reduction in pore size. Wang and Smith (1992) also observed a salt-soluble protein solution (30 mg/mL, at pH 6.5) heated to 55°C formed protein aggregates composed of globular structures connected by strands. When the temperature was increased to 65°C, the strands thickened (125 vs. 300 nm; observed by scanning electron microscopy). Additional heating to 80°C caused a reduction in strand thickness, but the structure remained ordered. As the authors only monitored microstructure starting at 55°C, a comparison of the structure at a pre-denaturation temperature (20°C) was not possible.

Table 16.2.2.2 Effect of salts and heating temperature on gel strength, measured by a penetration probe, and amount of extractable protein. From Barbut et al. (1996).

Treatment temperature (°C)	Penetration (N)		Extractable proteins (mg/mL)	
	2.5% NaCl	1.5% NaCl + 0.42% TPP[a]	2.5% NaCl	1.5% NaCl + 0.42% TPP[a]
20	30.8^{f}	25.3^{f}	1.62^{ab}	1.72^{a}
40	43.3^{ef}	40.1^{ef}	1.58^{b}	1.60^{b}
50	60.0^{e}	60.5^{e}	1.38^{c}	1.50^{b}
55	189.0^{d}	194.1^{d}	1.18^{de}	1.21^{d}
60	356.6^{b}	287.5^{c}	1.07^{e}	1.08^{e}
70	475.8^{a}	373.3^{b}	0.37^{f}	0.40^{f}

[a] Both the 2.5% NaCl and 1.5% NaCl + 0.42% phosphate treatments were formulated with the same ionic strength (IS = 0.42).
[b-f] Means followed by the same superscript letter, within each test category, are not significantly different at 95% level.

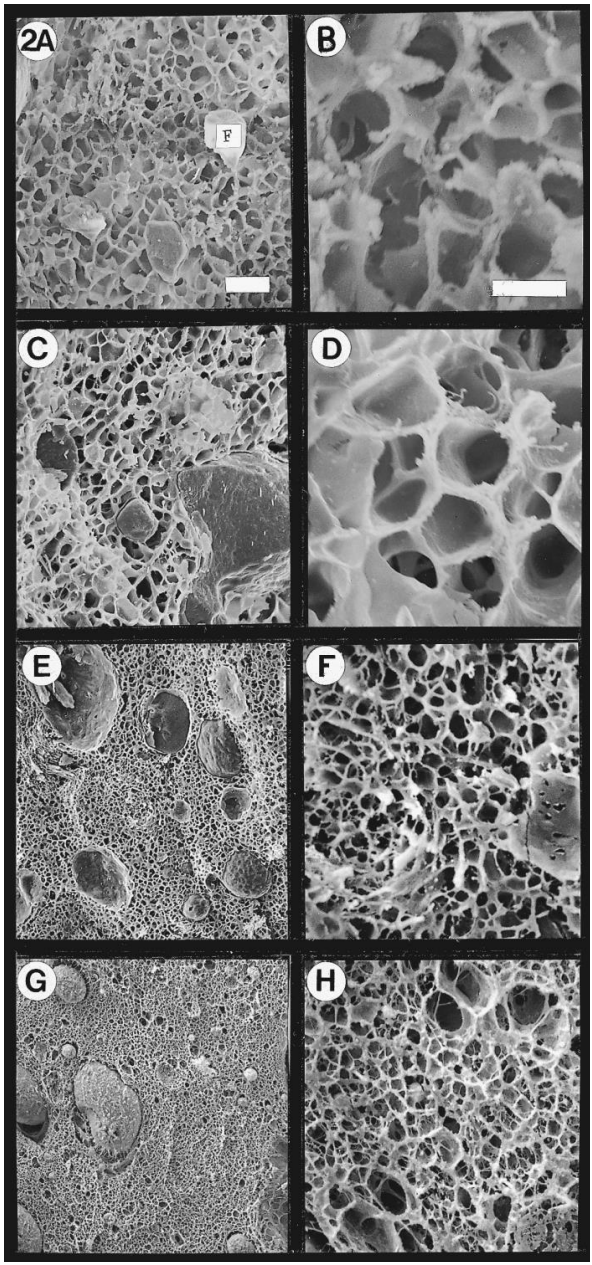


Figure 16.2.2.3 Scanning electron microscopy of meat batters containing low salt level of 1.5% NaCl + 0.42% tri poly phosphate, heated to (2A,B) 20°C; (C,D) 40°C; (E,F) 55°C; and (G,H) 70°C. Micrographs on the left are at low magnification (bar = 15 μm), on the right at higher magnification (bar = 3 μm). F = fat globules surrounded by a honeycomb protein matrix. From Barbut et al. (1996). With permission.

16.2.3 Texture Profile Analyses (TPA) and Other Compression Tests

TPA test is one of the most popular test methods for a variety of food products (e.g., meat, baked goods, dairy, and hydrocolloid gels) and was developed by a group of scientists at General Foods in the early 1960s. It is based on a two-cycle compression where a cylindrical sample is compressed twice to a predetermined deformation point (Bourne, 1978). The General Foods group established some parameters that correlate well with sensory data (Fig. 16.2.3.1). A test setup is shown in Figure 16.2.3.2. Over the years different test parameters have been introduced, which makes it difficult to compare results from different laboratories. Mittal et al. (1992) reviewed the test parameters used to evaluate meat samples.

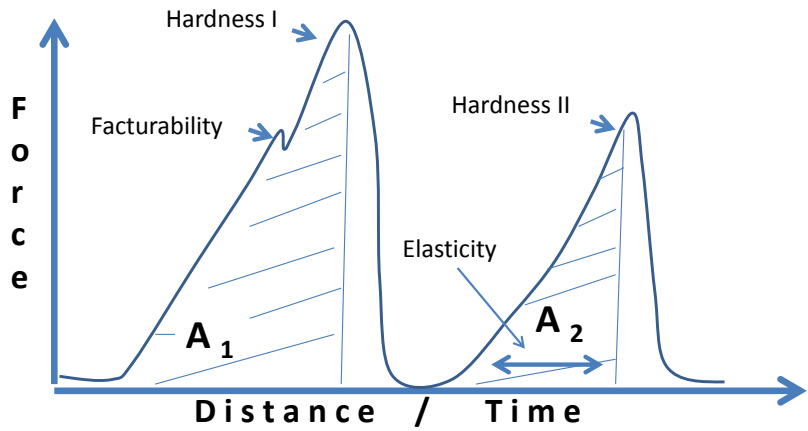


Figure 16.2.3.1 Parameters, derived from a two-cycle compression cycle, used to describe sensory attributes. Cohesiveness = A2 /A1. Gumminess = Hardness I x Cohesiveness. Chewiness = Gumminess x Springiness. Based on Bourne (1978).

The authors showed variations in specimen length or height (L) from 10 to 20 mm, diameter (D) from 13 to 73 mm, and D/L ratio from 1 to 4. Additionally, the compression ratio varied from 50 to 85% and compression speed from 5 to 200 mm/min. The effects of varying D/L, speed, and compression rate on beef wieners (55.9% water, 28.5% fat, 12.6% protein, and 2.9% ash) are shown in Table 16.2.3.1. A decrease in D/L resulted in a decrease of hardness 1(H1), hardness 2 (H2), cohesiveness, and gumminess, and an increase in springiness and chewiness.

Increasing the compression rate resulted in decreasing springiness, cohesiveness, gumminess, and chewiness. According to Peleg (1977), at the same deformation rate, a shorter specimen is actually deformed at a higher strain rate and, therefore, should exhibit higher stress than a longer specimen under the same strain. Thus, TPA parameters are comparable when the tests are performed by a standard procedure. The values reported in Table 16.2.3.1 as well as the values obtained for a ground salami meat product and a whole muscle corned beef product resulted in recommending the following test parameters: D/L = 1.5, compression ratio = 75%, and compression rate = 1-2 cm/min. Employing these standard conditions will allow direct comparison of data from different laboratories/institutions and reduce confusion and mistakes that result from choosing inappropriate parameters.

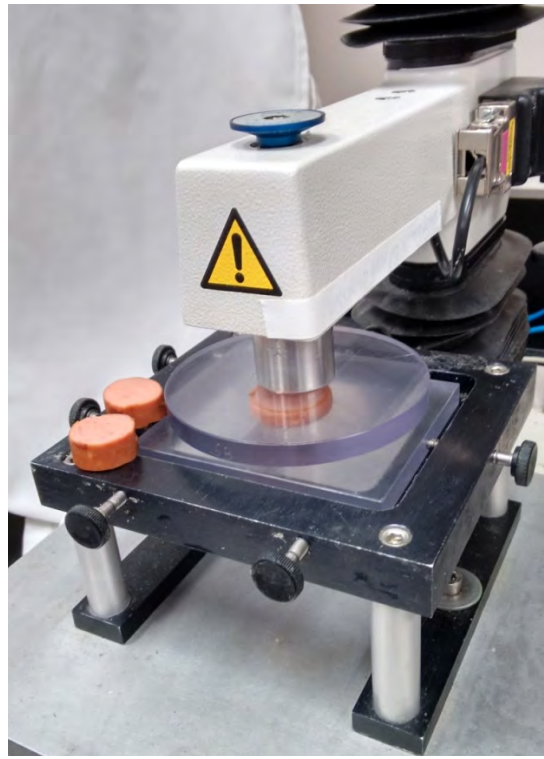


Figure 16.2.3.2 Showing the setup for the double compression Texture Profile Analysis (TPA) test. Photo by S. Barbut.

Single axial compression between two flat plates is a simpler test. The test can be done to failure, where the sample is compressed until it totally breaks or shatters, or to a pre-fracture point where the deformation is measured. Two products that exhibit the two extremes are hard candy and a marshmallow. When force is applied to hard candy, the sample deforms very little but at a certain point it will shatter. A marshmallow, on the other hand, is quickly deformed when force is applied, but can easily recover (i.e., the sample is highly elastic). Meat samples fall in between these two extremes, as they possess moderate elasticity. A single compression test can also be used to measure the fracture force of a food product (hard candy, meat loaf, Jell-O), which can help formulate the product with various ingredients.

Table 16.2.3.1 Duncan's test results for different Texture Profile Analysis parameters of wieners. Adapted from Mittal et al. (1992).

	Mean values					
	H1 (N/cm^2)	**H2 (N/cm^2)**	**E (m/cm^2)**	**COH**	**GUM (N/cm^2)**	**CHEW (J/cm^4)**
D/L						
2.0	30.11^a	23.47^a	0.024^c	0.405^a	11.76^a	0.33^c
1.5	27.39^b	20.40^b	0.047^b	0.388^a	10.25^b	0.56^b
1.0	24.14^c	14.52^c	0.084^a	0.338^b	7.69^c	0.77^a
Speed (cm/min)						
2.0	29.51^a	20.64^a	0.053^a	0.369^a	10.41^a	0.58^a
1.0	26.81^b	20.16^a	0.052^a	0.369^a	10.27^a	0.57^a
0.5	25.32^c	17.59^b	0.051^a	0.366^a	9.02^b	0.50^a
Compression (%)						
25	22.72^c	20.52^a	0.070^a	0.686^a	15.58^a	1.05^a
50	34.41^a	18.51^b	0.055^b	0.299^b	10.54b	0.50^b
75	24.50^b	19.36^{ab}	0.031^c	0.147^c	3.59c	0.11^c
	Correlation coefficients					
D/L	0.38**	0.63**	-0.78**	0.11	0.29**	-0.37**
Speed	0.27	0.19	0.02	-0.01	0.09	0.06
Comp.	0.11	-0.08	-0.52**	-0.92**	-0.85**	-0.78**

D/L = diameter to length ration; ** = $p < 0.0001$; H1 = harness-1; H2 = hardness-2; E = springiness; COH = cohesiveness; GUM = gumminess; CHEW = chewiness.

[a-c] Data with the same superscript letter in a column, within a category, are not significantly different at $p > 0.05$ level.

16.2.4 Torsion Tests

While not currently as popular in meat testing, torsion tests do have the advantage of allowing the calculation of true shear strain and stress values from the force required to break a dumbbell shaped sample (Fig. 16.2.1.1) through twisting. The controlled rotation can be done with a viscometer after the sample ends have been glued to plastic disks. Volume changes are minimized and squeezing out of water and fat prior to the breakpoint (typically occurring in a compression test) are avoided. The test has revealed differences in meat protein functionality (Hamann, 1988) in the ability of salt soluble proteins to form heat-induced cohesive gels under different protein concentrations, different thermal processing conditions, and in the presence of non-meat additives. It was shown that shear stress relates to sensory hardness and shear strain to sensory cohesiveness. The authors reported that it was more difficult to modify sensory cohesiveness by addition of non-meat ingredients than it was to modify sensory hardness of meat gels. Montejano et al. (1985), compared torsion and TPA results with sensory results for eight protein gels made from low-fat beef, pork, turkey and egg whites. Shear strains at rupture ranged from 1.2 to 2.8 N/m^2. TPA cohesiveness correlated strongly with six of the sensory notes: springiness, hardness, cohesiveness, denseness, chewiness, gel persistence. Furthermore, these two instrumental parameters (shear strain and stress) correlated strongly with each other ($R = 0.83$), as did the six sensory notes. Stress and TPA hardness were also strongly correlated ($R = 0.94$) but did not correlate as strongly with the sensory notes as did the parameters based on deformation to failure. Overall, the torsion test has the potential to obtain some fundamental data about gel structure without strongly deforming the structure.

16.2.5 Tension/Extension Tests

Tension/extension tests are commonly used to evaluate the binding strength of meat slices (e.g., deli meat slices) as well as gelled protein systems. The test is performed by pulling the sample apart (Fig. 16.2.5.1).

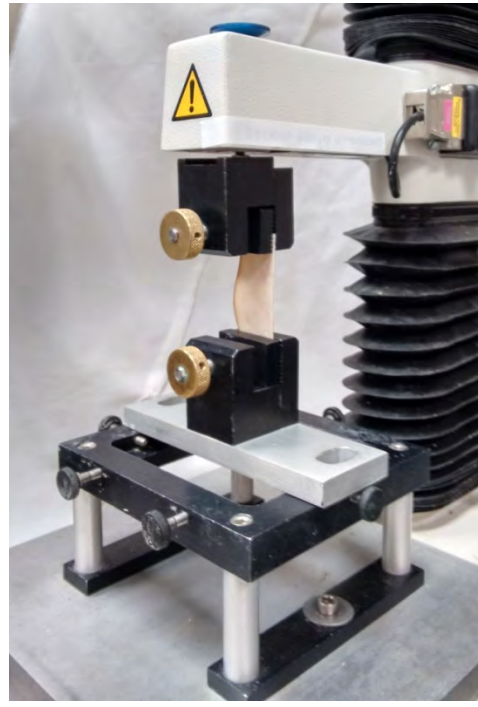


Figure 16.2.5.1 Showing the tension test. Commonly used to measure the integrity of sliced meat (e.g., effect of connective tissue, non-meat additives). Photo by S. Barbut.

In such a test, muscle fiber orientation is very important since muscle fibers pulled 90° to their longitudinal axis will require a lower pulling force than fibers pulled along their longitudinal axis. To illustrate what can be expected, the results of a small scale trial of commercial whole muscle, turkey breast meat products showing good slice integrity (i.e., not falling apart during cutting) and poor slice integrity (i.e., often falling apart during slicing and breaking when folded 120°) are discussed. First, the cooked product was sliced into 3 mm thick pieces and

later 20 x 150 mm strips were prepared. The average pulling force for the good binding products was 3.0 Newtons while the poor binding slices had a value of 1.4 Newtons. A microscopic evaluation of the weak slices revealed poor connective tissue structure among muscle fibers in certain areas.

16.2.6 Scanning Rigidity Monitoring

The previously described tests are considered destructive because a new sample is required each time. Conversely, scanning rigidity monitoring is a non-destructive test that is used to continuously monitor a process such as meat protein gelation during heating. The equipment is designed to operate at very low strain or stress. Measurement from a continuous scanning rigidity example are provided in Figure 16.2.6.1, where the changes in rigidity provide information on the changes taking place during the structure building phase of gelation in samples with different levels of salt and phosphate. The changes are related to protein unfolding, protein-protein interactions, and interactions with other non-meat components. Overall, the test provides basic information on transition temperatures, protein interactions, etc. However, several studies have shown that the results do not correlate well with sensory texture or rupture strength. Nevertheless, the information is very valuable for optimizing processing conditions, ingredient substitution, and studying the effects of factors such as salt concentration and pH (Hamann, 1988).

One of the first laboratory devices used was a glass microscope coverslip that was moved up and down a short distance at an extremely slow rate in a protein solution while it was heated. The resistance to movement was recorded and plotted against temperature (see figure by Yasui et al. 1980 in Chapter 13) and showed the effects of heating different concentrations of actin and myosin. The data revealed gelation temperatures, the effect of the myosin:actin ratio on gel structure formation, and the magnitude of the protein-protein interactions. Today, more sophisticated stress/strain rheometers are available where operation is controlled by high speed computers that provide precise movement and temperature control and facilitate calculations. The two most common types of measuring probes are the parallel plates configuration and the bob and cup (Fig. 16.2.6.2). If the meat batter is slippery, serrated plates can also be used. As an example, results obtained by a commercial rheometer that show the effect of phosphate addition to low salt (slippery) poultry meat batter are shown in Fig. 16.2.6.1.

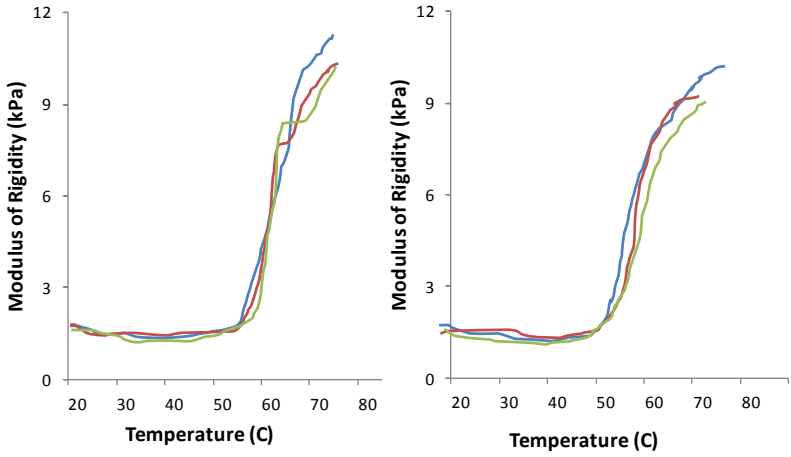


Figure 16.2.6.1 Modulus of rigidity profiles of poultry meat batters containing 2.5% NaCl (left) and 1.5% NaCl (right) stored at 1 C for various times prior to cooking. Green line = 0 days; red line = 1 day; blue line = 4 days. Redrawn from Barbut and Mittal (1991).



Figure 16.2.6.2 Two of the most common configurations for rheological testing. On the left showing parallel plates (note: there is also a serrated plate that can be used when a slippery meat batter is evaluated). On the right is a bob and cup configuration. See text for more details. Photo by S. Barbut.

16.3 Flavour of Meat

Flavour is one of the most important factors in determining the acceptability of food. A significant amount of meat flavour develops during cooking via complex reactions between natural compounds present in raw meat (Aliani and Farmer, 2005; Calkins and Hodgen, 2007). This is evidenced by the aroma that cooked meat, which is completely different than that of raw meat. Many of the compounds produced during cooking (a few hundreds) have relatively high odour thresholds and present little contribution to the overall aroma and flavour. New developments in analytical equipment (e.g., gas chromatography – mass spectrometry) have allowed scientists to more precisely identify major compounds of importance and the lower concentration compounds with which they interact. Overall, flavour is a combination of taste and smell, which are perceived by the taste buds and olfactory receptors in the nose, respectively (Farmer, 1999). Flavour and taste perception mechanisms are complex and are still not fully understood. It is known, however, that they are affected by numerous factors such as the quantity and ratio of different flavour compounds, fat content, and temperature. Taste is perceived by sensors on the tongue that are capable of detecting four major tastes: salty, sweet, sour/acid, and bitter. Other sensations such as "umami" (a Japanese term meaning deliciousness), astringency, metallic, and pain ("hot" and "cold") are also known. A number of textbooks and reviews have been written on the subject of meat flavour (Calkins and Hodgen, 2007). The following discussion highlights some of the major findings in the area of chemical contribution to the taste and smell sensation as well as the effect of certain processing practices on meat flavour and aroma.

Cooking meat generates hundreds of volatile compounds; e.g., Farmer (1999) indicated about 500 in chicken meat. The precursors may include amino acids, reducing and phosphorylated sugars, lipids, and thiamine. Most volatile compounds are present in concentrations below their taste threshold, which suggests that synergistic effects are important in taste perception.

To identify the contribution of different volatile compounds, researchers use diluted aroma extracts that are obtained by gas chromatography and a subjective human odour assessment. Diluted compounds that can be detected by humans are considered important. In this way, the thresholds of many individual compounds have been established and evaluated. Discrepancies in the reported compounds of importance underline the complexity of sensory perception and the effect of different methods used for extraction, sample preparation, and assessment. To evaluate the effect of some of the major compounds one can also remove them from the food entirely or supplement the food with more of an individual

compound. These approaches have been employed by Fujimura et al. (1996) and Aliani and Farmer (2005), and are discussed below.

Fujimura et al. (1996) analyzed water soluble compounds in a cooked chicken extract and later combined some of the amino acids, ATP metabolites, and inorganic ions to try and simulate the sensory properties of the extract. The major compounds were glutamic acid, inosine monophosphate, and potassium ions. The glutamic acid and inosine monophosphate conferred "umami" and salty tastes, while the inosine also produced some sweetness. The potassium ions were responsible for salty, bitter and some sweet sensations. During cooking, a change in the concentration of reducing sugars, free amino acids, and nucleotides was observed. These changes affect the taste and aroma of the poultry meat, as many of the substances are precursors for chemical reactions that are responsible for odour formation during cooking, roasting or frying.

Aliani and Farmer (2005) assessed volatile odour compounds by gas chromatography – odour assessment and gas chromatography – mass spectrometry to examine the contribution of the following potential flavour precursors: thiamine, inosine 5'-monophosphate, ribose, ribose-5-phosphate, glucose, and glucose-6-phosphate at elevated concentrations (2-4 fold). They indicated that ribose appeared to be most important in increasing an aroma described as "roasted" and "chicken". They also mentioned that the change in odour was probably also caused by elevated concentrations of compounds such as 2-furanmethanethiol, 2-methyl-3 furanthiol, and 3-methylthiopropanol.

In her 1999 review, Farmer produced a summary list of the most important compounds in cooked poultry meat and later Calkins and Hodgen (2007) produced a table concerning flavours in beef. Key compounds for poultry are shown in Table 16.3.1 and are grouped into furanthiols and disulfides, sulphur containing compounds, aldehydes, ketones and lactones, heterocyclic compounds (containing sulphur, oxygen, nitrogen), and others. Individually, these compounds can be responsible for one major aroma note such as meaty, mushroomy, fruity, sulphurous, or toasted, but together they combine to provide the typical aroma of a cooked chicken. The important compounds for cooked chicken aroma differ from those for cooked beef in that 2-methyl-3-furyl disulphide, methional, and phenylacetaldehyde are less important and certain lipid oxidation byproducts such as trans-2,4-decadienal and trans-undecenal are more important (Gasser and Grosch, 1990). Gasser and Grosch suggested that this difference may be related to the higher concentrations of linoleic acid in chicken than beef. It should also be mentioned that cooking methods have a strong effect on flavour and aroma (e.g., fried meat has a different aroma than boiled).

Table 16.3.1 List of some of the major compounds contributing to odour of cooked poultry meat. Adapted from Farmer (1999).

Compound	Odour Character	Compound	Odour Character
Furanthiols and Disulfides		2-undecenal	Tallowy, sweet
Bis (2-methyl-3-furyl) disulphide	Meaty, roasted	γ-decalactone	Peach-like
2-methyl-3-furanthiol	Meaty, sweet	γ-dodecalactone	Tallowy, fruity
2,5-dimethyl-3-furanthiol	Meaty	**Other Heterocyclic Compounds**	
2-furanmethanethiol	Roasty	2-formyl-5-methyl thiophene	Sulphurous
2-methyl-3-(methylthio) furan	Meaty, sweet	Trimethylthiazole	Earthy
2-methyl-3-(ethylthio) furan	Meaty	2-acetyl-2-thiazoline	Roasty
2-methyl-3-methyldithiofuran	Meaty, sweet	2,5(6)-dimethyl-pyrazine	Coffee, roasted
Sulphur Containing		2,3-dimethyl-pyrazine	Meaty, roasted
3-mercapto-2-pentanone	Sulfurous	2-ethyl-3,5-dimethyl-pyrazine	Roasty
Dimethyltrisulfide	Gassy, metallic	3,5(2)-diethyl-2(6)-methyl-pyrazine	Sweet, roasted
Hydrogen sulfide	Sulfurous, eggy	2-acetyl-pyrroline	Popcorn
Methional	Cooked potatoes	**Other**	
Aldehydes, Ketones and Lactones		2,3-butanedione	Caramel
1-octen-3-one	Mushrooms	β-ionone	Violets
trans-2-nonenal	Tallowy, fatty	14-methyl-pentadecanal	Fatty, tallowy, train-oil
Nonanal	Tallowy, green	14-methyl-hexadecanal	Fatty, tallowy, orange-like
trans, *trans*-2,4-nonadienal	Fatty	15-methyl-hexadecanal	Fatty, tallowy
Decanal	Green, aldehyde	4-methylphenol	Phenolic
trans, *trans*-2,4-decadienal (& an isomer)	Fatty, tallowy		

The chemical reactions important for flavour and aroma production can be categorized into three main groups: (a) Maillard reactions, (b) lipid oxidation, and (c) degradation of thiamine (vitamin B1).

a. Maillard reactions are a fairly complex sequence of chemical reactions in which one or more amino acids react with reducing sugar(s). Different pathways yield a variety of products; some are responsible for flavour and some for surface browning. These reactions can result in over a hundred volatile products. All of the first 19 compounds listed in Table 16.3.1 can be formed by the Maillard reaction.

For example, hydrogen sulphide is produced by a reaction between the amino acid cysteine and dicarbonyl as part of the Strecker degradation reaction, which is part of the overall Maillard reaction. This specific reaction contributes to the overall aroma and also produces a key sulphur-containing intermediate for other reactions. A comprehensive review of the nine most common classes of aromatic compounds that result from the Maillard reaction was written by Manley and Choudhury (1999).

b. Lipid oxidation contributes to desirable flavours and aroma, but can also cause potential problems with rancidity development. Cooking results in thermal oxidation, which is responsible for generating flavour notes. However, oxidation occurring at ambient temperature, usually by endogenous enzymes, can result in the production of negative flavour and aroma notes, described as rancid or cardboard-like. The information in Table 16.3.1 shows ten compounds that result from thermal oxidation (under the Aldehydes, Ketones, and Lactones subheading). They include 1-Octen-3-one, trans-2-nonenal, trans trans-2,4-nonadienal, and trans trans-2,4-decadienal. All are from thermal oxidation of n-6 fatty acids and all are believed to contribute positive flavour notes to cooked chicken. The most reactive lipids are the polyunsaturated fats, followed by monounsaturated and saturated lipids. Some are also known to contribute to the unpleasant odour of reheated cooked poultry described as the warmed-over-flavour (WOF). Diet can affect fatty acid composition in the muscle and later influence the flavour of the meat as will be discussed below.

c. Thiamine degradation can produce different sulphur and nitrogen containing end products that result from the breakdown of the vitamin's bicyclic structure. Some of the compounds have a potent aroma such as the 2-methyl-3-furanthiol, which is responsible for a "meaty" aroma and flavour in chicken/red meat (Gasser and Grosch, 1990; Calkins and Hodgen, 2007). The compound can be formed by thiamine degradation or by a reaction between cysteine and ribose. 2-furanmethanethiol can also be formed by thiamine degradation, and provides a "roasted" aroma in meat.

As indicated above, the overall flavour and aroma of meat is influenced by the concentration of various precursors, temperature, pH, and the presence of salt and other chemicals in the food. The lack of some precursors can be a limiting factor in aroma development and may explain the bland flavour of some meats. Temperature is a key factor that can be controlled by the processor/consumer. It affects both the extent of the Maillard reaction and the oxidation of fatty acids. Salama (1993) compared conventional oven cooking and microwave heating and found that conventional heating provides preferable flavour for leg and breast meat.

This may be explained by the fact that microwave heating is rapid (fast changing of water molecule polarity throughout the product), which does not allow enough time for odour and flavour development. The author also showed that Maillard browning reactions were substantially reduced due to the absence of hot air circulating around the product for a sufficient amount of time. Adding phosphate or sodium chloride, prior to cooking, was reported to increase flavour rating under both conventional and microwave heating. Ang and Liu (1996) demonstrated that the amounts of volatiles produced increases as cooking temperature is raised from 60° to 80°C. Higher temperatures can increase the rate of the chemical reactions as well as the release of free amino acids and other precursors. Quantities of lipid oxidation byproducts, namely nonanal and heptanone, increased as temperature was raised from 60° to 70°C and later plateaued. On the other hand, the amounts of 2-, 3-butanedione and dimethyl disulphide increased at an almost constant rate between 60° and 80°C.

Overall, the characteristic flavour of poultry/red meat is derived from the presence and concentration of various water soluble and volatile aroma compounds. The concentrations and interactions between these compounds can be affected by various factors related to the animal such as the breed/genetic stock, sex, age, and diet, as well as by processing factors such as evisceration time, chilling rate, storage and cooking method (see reviews by Land and Hobson-Frohock, 1977; Farmer, 1999; Calkins and Hodgen, 2007). As agreed upon by most researchers, the age of the animal is one of the most important factors. Other factors such as genotype and weight are considered extremely important by some but not by others. Land and Hobson-Frohock (1977) indicated that there is little evidence of statistical significance between different breeds of chicken (e.g., New Hampshire crosses, Barred Plymouth Rock) when compared at a similar age. This is an important observation since comparisons within a single breed at different ages have shown significant differences. Farmer (1999) summarized data related to genotype, where four studies reported that slower growing breeds provided meat with more flavour, but three other reports showed no significant difference.

The effect of age can be attributed to physiological changes that occur during the growing period. As animals/birds reach maturity, there are changes in the amount of fat, protein, and subsequent concentrations of flavour compounds/precursors. An example is the slow growing Label-Rouge free-range chickens that are popular in France. It was shown that flavour intensity in male chickens increased up to 14 weeks, which corresponds with sexual maturity (Touraille et al., 1981). The authors suggested that lipid composition may be the determining factor since they did not find correlations with muscle pH, moisture content, or lipid content. The sex of the bird has been reported by some to affect the flavour, with males

tending to have a stronger flavour (Land and Hobson-Frohock, 1977). Others have indicated that there are no flavour differences between sexes until broilers reach sexual maturity (Touraille et al., 1981).

Diet may affect flavour, but Land and Hobson-Frohock (1977) suggested that large dietary changes are required to produce a small change in flavour. However, a small amount of feed, such as oxidized fish oil, can induce a fishy aroma in meat (and eggs). Various studies have evaluated the effect of feed ingredients/additives on flavour, mainly to ensure no deleterious effects. Supplemental vitamin E, for example, has been shown to enhance the shelf life of stored poultry/red meat by, retarding lipid oxidation and off-flavour formation during prolonged fresh/frozen storage (Sheldon et al., 1997).

Growing conditions (e.g., indoor barn, outside pasture), stocking density, environmental conditions, and husbandry methods can affect meat flavour (Land and Hobson-Frohock, 1977; Farmer et al., 1997; Calkins and Hodgen, 2007), but these variables have little effect in poultry, for example, once the age of the bird is accounted for. A series of studies on Label Rouge broilers (i.e., slow growing chickens with exposure to the outside environment, low stocking densities, and high cereal diets) indicated that birds raised for a minimum of 12 weeks had a more intense odour and flavour than birds raised inside a barn and fed conventional pelleted diet. However, it was suggested that the older marketing age of the Label Rouge birds was responsible for this improvement in flavour (Touraille et al., 1981). A British study of the French Label Rouge system that examined genotype, age, diet, and stocking densities also found age to be the most important factor with the older broilers having more intense flavour (Farmer et al., 1997). Stocking density and diet showed few effects on sensory attributes, but a significant difference between genotypes was detected (e.g., higher overall odour intensity for the Ross than the ISA 657 broiler line). Overall, the authors indicated that their study supports the idea that the improved flavour of the free-range Label chickens is mainly due to their older age.

16.4 Sensory Analysis

16.4.1 General

Sensory analysis is used to study the effects of different ingredients (e.g., dark, light meat, salt, starch), processing parameters (e.g., deboning time), preparation techniques (e.g., frying), and their interactions on the way the consumer perceives the product. The evaluation can include different parameters based on our senses

of taste (salty, sweet, sour, and bitter), smell, touch (e.g., texture, mouth feel, moisture level), sight (colour, shape) and hearing (e.g., crunchy). The field of sensory analysis has matured over the years to become a recognized discipline in food science. Specially trained sensory professionals work in areas such as quality control, product development, texture and flavour research, and ingredient and process modification. From an industry point of view, a good sensory evaluation team can help ensure successful products with desirable sensory attributes reach the market (Lawless and Heymann, 2010).

Overall sensory analysis comprises a set of techniques that measure human responses to a particular food or a consumer product. Sensory evaluation has been defined as "a scientific method used to evoke, measure, analyze and interpret those responses to products, as perceived through the senses of taste, touch, smell, sight and hearing" (Lawless and Heymann, 2010). The term "to evoke" indicates that a given set of guidelines is used in preparing and serving the samples under controlled conditions so that bias is minimized. For this purpose, individual testing booths are used, samples are labeled with blinding codes (pictures provided later in the chapter), products are presented in a different order to each participant, and food is served at a specific temperature and volume. The term "to measure" indicates that sensory evaluation is quantitative science in which numerical data are collected to establish legitimate and specific relationships between product characteristics and human perception. The term "to analyze" indicates that proper evaluation is critical, although data generated from human observers are often highly variable. There can be many sources of variation that cannot be completely controlled during the test (e.g., previous food eaten, physiological sensitivity to sensory stimulation, mood, past history, and familiarity with similar products). Therefore, some screening should take place to eliminate participants with taste and colour vision insensitivity (Nute, 1999).

The next step is the interpretation of the results. As with other experiments, the data and statistical information are only useful when interpreted in the context of hypotheses, background information, and relevance for future actions. Conclusions involve consideration of the method, the limitations of the experiment, the background, and the study's framework. A sensory scientist who is preparing for a career in this area must, therefore, be trained in all four areas mentioned above. The scientist must understand the product, the people, and statistical analyses, and be able to interpret the data within the context of the research objectives (Lawless and Heymann, 2010).

Sensory tests can be generally divided into:

a. Descriptive analysis – investigates how products differ in specific sensory characteristics
b. Difference testing – investigates if products are perceptibly different in any way
c. Affective testing – investigates how well products are liked and which are preferred

The three categories are described below. In most cases, meat/poultry product references are provided for further reading. Detailed information on sensory analyses can be found in books devoted to the subject such as Lawless and Heymann (2010) and the AMSA (2015).



Figure 16.4.1.1 Presentation of samples of food samples (e.g., cooked chicken breast fillet) under red light (to mask any potential colour differences) presented to a taste panel. A tablet computer is used to show the question and automatically process the data collected from the panel. Courtesy of Compusense.

Below is an example of how quality control sensory monitoring can be used to evaluate production in a commercial meat processing line. This example demonstrates how a computerized sensory analysis system can provide real time results and allow a supervisor to quickly check for problems. A quality control panel is trained and calibrated in the sensory evaluation of key attributes of cooked chicken breast meat (e.g., chicken white meat flavour, roasted/grilled flavour,

tenderness, juiciness, and the number of chews before swallowing) for which ideal ranges have been established using consumer research. The panel is trained using computerized feedback to ensure that each member will evaluate attributes the same way. During the actual evaluation, boneless skinless chicken breast meat from the production line is sampled (on different production days) and evaluated by ten assessors using a standardized protocol. The chicken breast meat is water cooked to an internal temperature of 72°C, then cooled to room temperature and cut into portions for evaluation. All samples are identified using three digit blinding codes to minimize bias. The samples are served under red light (Fig. 16.4.1.1) to reduce colour bias, since colour is not a key parameter in this case (but can result in bias by the panel).

The sensory attributes of the sample are scored using a computerized ballot displayed on a computer tablet (Fig. 16.4.1.2). Results are collected, statistically analyzed (Fig. 16.4.1.3), and a pass/fail decision is reported automatically and immediately.



Figure 16.4.1.2 A questionnaire consisting of unstructured line scales (see additional description in text) presented to the panel for the evaluation of the food samples presented in the previous figure. Courtesy of Compusense.

Summary Report

Project: 14-321 BONELESS SKINLESS BREAST

# of Evaluations: 10

Summary Results

Attribute Title/ Standard Deviation	p value	1-519 1 Run 3 male B/S Breast	2-611 2 Run 3 female B/S Breast	3-384 3 Run 7 male B/S Breast	4-425 4 Run 7 female B/S Breast	5-523 5 Line 7 male B/S Breast
Chicken - White Meat Flavor	0.293	23 a	21 a	22 a	22 a	23 a
(Standard Deviation)		(3.8)	(3.8)	(4.4)	(4.8)	(5.1)
Roasted/Grilled Flavor	0.001	11 ab	10 ab	9 ab	13 a	10 ab
(Standard Deviation)		(6.7)	(6.6)	(6.0)	(6.6)	(6.1)
Tenderness - Overall Impression	0.001	50 ab	51 ab	51 ab	46 b	52 ab
(Standard Deviation)		(10.8)	(11.6)	(10.3)	(10.0)	(11.0)
Juiciness	0.000	34 abcd	35 abcd	37 ab	31 cd	38 a
(Standard Deviation)		(7.4)	(5.1)	(8.6)	(7.1)	(8.9)
# Of Chews	0.008	21 ab	19 b	20 ab	21 ab	20 ab
(Standard Deviation)		(6.6)	(5.8)	(6.1)	(6.0)	(8.4)

Multiple comparison tests may appear above. Tukey's HSD controls for maximum experimentwise error rate and can be used without F protection. Standard practice recommends that LSD and Duncan's be considered only if the ANOVA p-value is deemed acceptable to control for experimentwise error rates (under the complete null hypothesis). If Duncan's Multiple Range Test appears, only the largest critical range is reported. See analysis for other critical ranges. If automatic significance is selected, an available significance level is chosen for the multiple comparison test based on the observed p-value.

Figure 16.4.1.3 Screen shot of the statistical analysis results obtained from the test. Analysis can be generated automatically after the last panelist completed the test.

Data can be accumulated over any period of time and can be displayed graphically to reveal trends or potential emerging problems in the production or supply chain (Fig. 16.4.1.4). Because calibrated values are collected, it is easy to draw quantitative conclusions about the quality parameters. Automation of this process delivers reliable results quickly and efficiently and makes the process of training proficient quality control assessors routine.

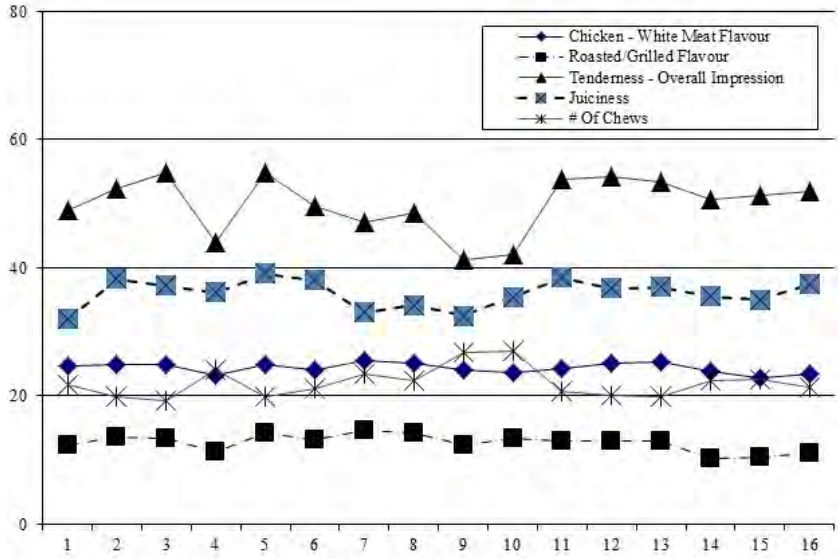


Figure 16.4.1.4 Sensory quality of boneless-skinless chicken breast meat. Five key attributes rated by a trained quality panel over 16 production days. Courtesy of Compusense.

The information provided in the AMSA (2015) Guideline for Cookery of Meat includes recommendations for collecting and preparing appropriate samples for sensory and/or tenderness evaluation for fresh beef, pork, lamb steaks/chops, roasts, and ground patties. It also can be applicable to certain enhanced, cured, or comminuted products. Additional topics covered include product handling, cookery methods, sensory panel methods, instrumental approaches to measuring meat tenderness, and a data analyses overview. The revised reference list provides material from the ASTM (formerly American Society for Testing and Materials) Committee E-18, the Society of Sensory Professionals, and the Institute of Food Technologists related to more publications and annual workshops on sensory evaluation.

16.4.2 Descriptive/Profiling Analysis

Descriptive analysis is used to quantify the perceived intensity of a product's sensory characteristics. After screening for sensory acuity and motivation, panelists are selected and trained by the people performing the analyses (Lawless and Heymann, 2010). This method provides the most sophisticated tool in the arsenal of the sensory scientist. From panelists, researchers can obtain complete sensory descriptions of a product, help underline flavours or a specific ingredient, process variables, and determine which sensory attributes are important to acceptance. Overall, there are several different descriptive analysis methods, which generally reflect different sensory philosophies and approaches. Depending on the specific technique used, the description can be quantitative or qualitative, as well as fairly objective. Descriptive analysis is used when a detailed specification of the sensory attributes of a single product or a comparison among several products is important. Descriptive analysis can indicate exactly how, in the sensory dimension, one product is different from the other (e.g., your product versus a competitor's). These methods are also used in product development to assess how close a new entry is to the target or to assess the suitability of a prototype. One of the most important aspects of descriptive analysis is the language used. During the training phase, there is a major effort to teach/train the panelists to use specific language. Alternatively, panelists can construct their own scientific language for the product category of interest.

The first method that used the descriptive concept was the Flavour Profile introduced by the A.D. Little Consulting group in the 1940s. They needed a tool to analyze unpleasant off flavours in nutritional capsules and therefore had to train panelists extensively to characterize all the flavour notes and their intensities. This was an important step in sensory science development as it relied on feedback from several expert judges and provided a means to characterize individual attributes (Lawless and Heymann, 2010). In the 1960s, General Foods developed and refined the test to quantify food texture. The method is referred to as Texture Profile Analysis or TPA (Szczesniak et al., 1975) and was already mentioned at the beginning of this chapter. Overall, the sensory characteristics have parallels to the physical characteristics of food (e.g., perceived hardness is related to the physical force required to break the sample).

Lyon (1987) developed terms to profile the flavour and aroma of fresh and reheated chicken meat. Initially, panelists developed a free word association list of 45 descriptive terms that included words such as meaty, chickeny, gamey, roasted, boiled, toasted, bouillon-like, brothy, liver-organy, earthy, greasy, cooked vegetable, moldy, nutty, cardboardy, stale, reheated, fatty, oxidized, fishy, metallic,

astringent, and chemical. Afterwards, all panelists evaluated chicken patties (50% light, 50% dark meat) that were freshly cooked and reheated patties that had been stored for 1, 3 and 5 days. The terms were used to obtain intensity data and frequency of use for statistical analyses. The initial list was later reduced to 31 terms and factor analysis was used to group the terms together according to the newly created factors. It was found that eight factors could explain 77% of the variation in the data. Terms were further reduced after discussion with the panelists while applying further factor analyses. In addition, the redundant terms were eliminated by variable cluster analysis and step wise discriminate analysis. This resulted in 12 terms: chicken, meaty, brothy, liver/organy, browned, burned, cardboardy/musty, warmed over, rancid/painty, sweet, bitter, and metallic. This illustrates the many challenges in developing an appropriate sensory flavour questionnaire.

Quantitative Descriptive Analysis (QDA) was developed in the early 1970s (Stone and Sidel, 2004). In contrast to Flavour Profile Analysis, the data are not generated through consensus discussions and panel leaders are not active participants. QDA integrates concepts from traditional behavioural research with experimental designs and statistical procedures (e.g., analysis of variance). Lyon and Lyon (1993) developed an attribute profile to study the effect of deboning time on samples cooked in water or on a belt-grill oven (Table 16.4.2.1). Their factor analysis showed that two primary categories of sensory attributes explained about 84% of the variation. The first, factor I, consisted of the mechanical geometric characteristics (i.e., hardness, chewiness, fibrousness, and particle size and shape), explained 64% of the variation, and separated the treatments based on deboning time. The second, factor II, explained 20% of the variation that was related to moisture characteristics and discriminated the samples based on the cooking method used (water, grill). Later, Lyon and Lyon (1997) used the same profile to investigate the relationship between sensory descriptive profile and shear values of chicken breast meat deboned 2, 6 and 24 hr post mortem and summarized the results as a cobweb presentation (Fig. 16.4.2.1). Sensory descriptive texture attributes were separated by variable cluster analysis into five groups representing mechanical, moisture, chewdown, saliva, and residual characteristics. The authors reported differences in texture between the different deboning times of the chicken breast fillets. The mechanical characteristics in cluster I, excluding breakdown, were highly related to shear force values measured by the Warner-Bratzler and Allo-Kramer shear tests. The overall conclusion was that meat texture is highly complex and instrumental methods can only provide one dimension of texture (i.e., the one involved in mechanical breakdown in this case). Sensory perception of texture involves aspects that, as of yet, cannot be directly related to instrumental methods. Lawless and Heymann (2010) discussed this in greater detail and said that, "in many cases instruments lack the sensitivity of human sensory systems – smell is a good example".

Table 16.4.2.1 Attributes, definitions and terms used to anchor scales developed for the texture profile of broiler breast meat deboned at 2 and 24 hrs post mortem and cooked either in water or grilled. Adapted from Lyon and Lyon (1993).

Attribute	Definition	Anchor terms
Wetness	Degree of moisture on surface	Dry to wet
Springiness	Degree that sample returns to original shape after partial compression	Low to high
Initial cohesiveness	Deformation before rupture	Low to high
Hardness I	Force required to bit through to rupture the sample	Low to high
Initial juiciness	Amount of moisture in the meat	Low, dry to high, wet
Rate of breakdown	Rate that sample mass breaks down to individual components	Slow to fast
Hardness II	Force necessary to continue biting through sample	Low to high
Chewiness	Amount of WORK to chew sample (Hardness x Cohesiveness x Chewiness)	Low to high
Persistence of moisture release	Degree that moisture release persists or continues during chewing	Low to high
Cohesiveness of mass	How sample holds together during chewing (LOW = fibers break easily, wad dissipates to HIGH = wad grows in size, resists breakdown)	Low to high
Saliva produced	Amount of saliva produced in the mouth during sample manipulation to mix with sample to ready it for swallowing	None to much
Particle size and shape	Description of size-shape of particles as sample breakdown continues on chewing	Fine, small to coarse, large
Fibrousness	Degree of fibrousness or stringiness	None to very much
Chew count	NUMBER of chews to get sample ready to swallow	Small to large
Bolus size	Size of wad at point of swallowing	Dry to wet
Bolus wetness	Amount of or feel of moisture in wad at the point ready for swallowing	Easy to hard
Ease of swallow	EASY to HARD	None to many
Residual loose particles	Amount of loose particles left in mouth after swallowing	None to much
Toothpack	Amount of sample packed in or around teeth	Low to high
Mouthcoating	Amount of moisture-fat coating the oral cavity after swallowing	Low to high

Overall, the descriptive methods are very useful in examining individual components contributing to flavour, texture, etc. However, it is very important to include a precise description of the terms used for evaluation to allow other researchers to compare results.

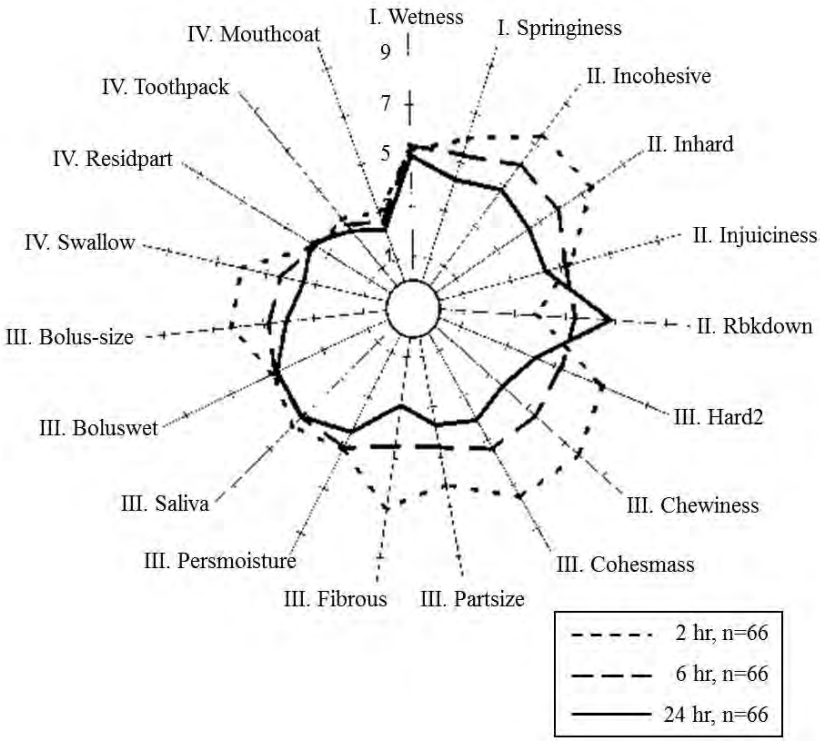


Figure 16.4.2.1 Sensory descriptive profile of texture attributes of broiler breast samples deboned at postmortem times of 2, 6 and 24 hr. Each ray, originating at the center polygon (0 point) and extending out to the attribute label, represents the 0 to 15 linear response scale, truncated to 10 points. Each ray is labeled with the attribute abbreviation and phase of evaluation. Mean values (n = 66) for each attribute for a PM treatment are connected to depict the sensory texture profile. Ray labels: Phase I - wetness and springiness were evaluated during the initial compression with molars; Phase II - incohesive (initial cohesiveness), inhard (initial hardness), injuiciness (initial juiciness), and rbkdown (rate of breakdown) were evaluated during the initial compression with molar teeth; Phase III - hard 2 (hardness after 15 chews), chewiness, cohesmass (cohesiveness of mass), partsize (particle size/shape), fibrous, persmoisture (persistence of moisture release), saliva, boluswet (bolus wetness) and bolus-size were evaluated after 15-25 chews; and Phase IV - swallow, residpart (residual particles), toothpack and mouthcoat were evaluated at the point of swallowing [- - - 2 hr; - - - 6 hr; ---- 24 hr]. From Lyon and Lyon (1997). With permission.

16.4.3 Difference Tests

Difference tests are easier to conduct than descriptive analysis. In this type of test, the panelist is presented with samples and asked to identify the odd sample, match the sample to a reference, or classify the samples into two groups (Nute, 1999; Stone and Sidel, 2004). Careful thought is required in their execution as panelists may regard the idea of selecting the odd sample as a game of chance. Therefore, any differences, except the one studied, should be eliminated (e.g., if flavour is evaluated, colour and appearance must be uniform). The most common difference tests include the (a) triangle, (b) paired comparison, (c) duo trio, and (d) the two out of five test.

a. Triangle test – was initially used in the 1940s by Carlsberg breweries for two beers from one batch and one from another. The panelists were asked to identify the odd sample and their ability to discriminate differences was used to screen for judges for beer evaluation. In the test, three samples are presented simultaneously and there are six possible order combinations (112, 121, 122, 211, 212, 221). It is important to randomize the sample sets so the statistical analyses are valid. The probability of a panelist selecting the correct odd sample by chance is 33%. To analyze the test results, the number of correct replies is compared to a reference probability table to determine if the numbers are significantly different.

An example of evaluating meat products has been provided by Dickens et al. (1994), who looked at the sensory effect of using an acetic acid (vinegar) dip to reduce microbial counts on poultry meat. The authors used three replications of 40 carcasses each (20 control and 20 dipped in acid). The samples were either cooked in water, a bag, or an oven. The panelists were oriented to the test objectives and the computerized system used for data entry. There were three sessions (one for each replication) for each cooking method (i.e., six sensory testing) with ten panelists. The results revealed no significant effect of the acetic acid (vinegar) or the cooking method. In this example, the total number of responses by cooking method and replication was 20. For a significant difference ($P < 0.05$), thirteen correct responses out of 20 were needed; none of the replications met this criterion.

b. Paired comparison – two samples are served and panelists are asked to choose the sample with the stronger or more intense attribute. The differences may be directional or non-directional. Directional tests are one-sided, meaning that they are tailed tests with a question such as: which sample is tougher? more juicy? more salty? A non-directional test is a two-tailed test that indicates the panelist's preference, asking which sample he/she prefers.

As an example, the test was used to study the effect of lactic acid as a broiler meat decontaminant on sensory quality (Van der Marel et al., 1989). Broiler leg meat was used as a control and treated samples were dipped in 1% lactic acid for 15 s. Products were grilled for 30 min and divided into 48 thigh and drumstick portions, each. Twelve trained panelists received four pairs of covered, hot samples and were asked to indicate preference and provide the reason. Each panelist evaluated one pair of drumsticks and one pair of thigh meat in each of two sessions. Panelists' preferences for the control showed that one preferred the control four times, five three times, three twice, two once and one never. This distribution does not differ from that expected by chance alone. The reasons (and their frequency) for preferring the treated samples were stronger taste (nine times), metallic taste (twice), fatty taste (once) and fishy (once). For the untreated samples the reasons were stronger taste (11 times), fatty taste (once) and fishy (once). Overall, the treated samples were preferred 22 times and the controls 26 times. This meant no significant difference between the treated and control samples as a minimum of 32 choices in one category were required for a significant difference ($P < 0.05$).

c. Duo-trio test – asks the panelist to match a reference sample to a test sample. This test is an intermediate between the triangle and paired comparison test and is statistically more powerful than the triangle test. Special tables, interpreted in the context of the number of panelists, are used to determine the number of correct samples required to show a significant difference. An example for poultry meat is the study of a standard method for the duo-trio test published by the British Standards Institute (BSI, 1992) and the American Society of Testing Materials (ASTM, 1992). Janky and Salman (1986) used the test to evaluate the effect of water versus brine chilling. After chilling, the products were battered, breaded, deep fat fried, and bite-size samples were assessed by 25 panelists. Training involved selection of panelists who were sensitive to texture variations and also experienced in assessing chicken meat. In at least half of the taste panels, held with light or dark meat which was obtained from either water-chilled or brined-chilled carcasses, panelists were able to distinguish a significant tenderness difference between the two chilling treatments. The results paralleled those observed for instrumental shear force tenderness.

d. Two out of five test – panelists get five samples and are asked to sort them into two groups. The groups contain either two of sample A and three of sample B, or three of sample A and two of sample B. Overall, there are 20 different possible order combinations for this test. Statistically, it is more powerful than the paired comparison test (i.e., chance of correctly guessing the answer is 50%) and the triangle test (33% chance). However, a disadvantage might be sensory fatigue.

Overall, the panelists have to make a number of repeat evaluations that could be extremely fatiguing when they have to taste and smell the samples numerous times.

16.4.4 Affective Testing

Affective tests quantify the degree to which a product is liked or disliked. A historic landmark in this class of tests was the hedonic scale developed at the U.S. Army Food Container Institute in the 1940s (Lawless and Heymann, 2010). The balanced, nine point scale had a central, neutral category and attempted to produce scale point labels with adverbs representing psychologically equal steps in hedonic tone: like extremely, like very much, like moderately, like slightly, neither like nor dislike, dislike slightly, dislike moderately, dislike very much, dislike extremely. Panelists can be screened for the products to be tasted or can be consumers who are regular users of the product (usually 75-150 consumers). The development of the nine point hedonic scale serves as a good example of the benefits that can be realized by the cooperation of food scientists and experimental psychologists. It is through the process of numerification that sensory evaluation becomes a quantitative science that is subject to statistical analysis, modeling, prediction, and hard theory. In these tests, the numbers can be assigned by a panelist in a variety of ways: categorization, ranking, or in ways that attempt to reflect the intensity of sensory attributes. Currently, the most common methods include (a) category scales, (b) line scales, and (c) magnitude estimation (see description below).

These methods differ along two dimensions. The first dimension is the degree of freedom provided to the panelist. An open-ended scale allows the freedom to choose any numeric response that seems appropriate. However, such responses are difficult to calibrate across panelists. Simple category ratings are usually easier to assign with fixed intensity anchors or reference standards. Later, this facilitates calibration of panelists, data coding, and analysis. The second dimension is the degree of differentiation allowed to the panelists. Panelists can be given the freedom to use as many intermediate points along the scale as necessary, or be limited to discrete options (5 – 10 boxes are provided). Usually, there appears to be a rule of diminishing returns to the number of allowable scale points. A category scale of nine or more points behaves much like the more finely graded methods of magnitude estimation and line scaling, at least when product differences are not large (Lawless and Heymann, 2010). Overall, the affective tests are relatively easy to use and can usually cover a number of attributes (e.g., texture, flavour) and samples in a single session.

a. Category scales – one of the oldest scaling methods. They involve the choice of discrete response alternatives to signify increasing/decreasing sensation intensity or degree of preference. The number of alternative responses is usually between 5 and 15, depending on the application and number of graduations that the panelists can perceptually distinguish in the products. Usually, as panel training increases, perceptual discrimination of intensity improves.

Berge et al. (1997) used the test to evaluate differences in emu muscle (*M. iliotibialis cranialis*) from different age groups (10, 14, 17 and > 20 months old) on tenderness, juiciness, and flavour. Twelve trained panelists were served plates of three meat samples arranged at random and given a 10-point scale (zero indicating lowest intensity and 10 indicating highest intensity). The authors found tenderness significantly decreased with age, but juiciness and flavour were not affected.

b. Line scales – are also referred to as graphic rating scales and visual analog scales. The panelists are asked to make a mark on a line that indicates the intensity or amount of some sensory characteristic (see Fig. 16.4.1.2). Anchors may be used to help avoid end-effects associated with the reluctance of panelists to use the ends of the scale. Other intermediate points may also be labeled. In some cases, a central reference point representing the value of a standard or baseline product is marked on the scale and test products are scaled relative to the reference. Line scales have become fairly popular since the advent of digitizing equipment and the widespread application of on-line computerized data entry programs (see introduction to this section).

As an example, Oltrogge and Prusa (1987) examined the effect of microwave power settings on the eating quality of chicken meat (meatiness, tenderness, juiciness, chicken flavour). Each line scale was a 15 cm unstructured horizontal line. Samples of chicken breast were cooked to an internal temperature of 82°C at 40, 60, 80 or 100% power in a 600 W microwave oven. The authors reported that cooking at 60% power resulted in the most tender samples (also correlated with instrumental texture evaluation), but there were no significant differences in the other three attributes investigated.

Caron et al. (1990) used the same test in three lines of Japanese quails. They employed a 15 cm line scale with anchor points at 1.5 cm from each end and looked at selection response to body weight and carcass composition after 18 generations. They reported a significant line effect for tenderness and juiciness but not flavour.

c. Magnitude estimation – used for unrestricted application of numbers to represent sensation ratios. The panelist is allowed to use any positive number and is instructed to assign values so that the ratios between them reflect the ratios of sensation magnitudes experienced. For example, if an oven roasted turkey breast is given a value of 8 for saltiness intensity, and the next sample tastes twice as salty, it will be given a magnitude estimate of 16. Unlike the category and line marking scales, the test does not depend on the visual appearance of the ballot. Rather, the critical points in applying the method are the instructions given to the panelist and the data analysis techniques. Overall, there are two variations of the test. The first employs a standard stimulus that is given to the panelist as a reference or anchor point and it is usually assigned a fixed numeric value. The second provides no standard and the panelist is free to assign any number to the first sample, to which all following samples are compared. Below is an example of the instructions for such a test.

> "Please taste the first sample and note its hardness. This is a reference sample that is assigned the value of -10-. Please rate all other samples relative to this reference, applying numbers to the samples to represent the ratio of hardness intensity among samples. For example, if the next sample were twice as hard, you would assign it a value of -20-. You may use any positive number including fractions and decimals".

In summary, texture and sensory analyses are extensively used by both industry and academia to formulate new products, reformulate existing products (with new/different ingredients), check interactions between different components, and evaluate preparation methods (deboning, chilling, cooking). Using the right test under the appropriate conditions is very important in getting accurate results.

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17

EVALUATING WATER/FAT BINDING AND COLOUR

17.1 Introduction

Consumers look for food products with an appealing appearance, texture, and flavour. Meeting consumers' expectations is a critical factor, especially when a large selection of products is available on the market. There are obviously other factors that influence the buying decision (e.g., price, brand recognition), but if, for example, the colour of the product is off or there is free liquid in the package, then the consumer will most likely not buy it. The fact that many products are prepacked puts more emphasis on presentation. Fresh meat cuts and processed products rely on their proteins (i.e., salt-soluble proteins; see Chapter 3) to assist in holding water/fat and water-soluble colour pigments. Therefore, studying and understanding the relationships between protein and water/fat holding and colour are very important. This chapter will discuss the principles and methods used to study and influence water/fat holding and colour. Various methods have been developed in the past, but their standardization would permit the test results, from different laboratories, to be compared more easily. Examples will be provided.

17.2 Water Holding Capacity

17.2.1 Water Holding of Fresh and Cooked Meats

Lean meat contains about 75% water that is held within the muscle structure (muscle fibers and their associated components). This large amount of water is held both by chemical bonds (e.g., hydrogen bonds) and physical forces (e.g., capillary forces). In further processed products moisture usually ranges from 55-80% and protein from 10-18%. In certain countries, such as Canada, a minimum of 11% protein is required; otherwise, words like "imitation" must be included in the product's name. Because proteins are responsible for holding water,

ensuring that they have highly functional properties is extremely important. The water holding capacity (WHC) of proteins is influenced by factors such as muscle type, rigor conditions (e.g., pale, soft exudative meat; see Chapter 16), processing conditions (e.g., storage time and temperature, freezing, tumbling), and additives (e.g., alkaline phosphate, salt). Determining the WHC is important for both fresh meat cuts sold directly to the consumer and products that will be further processed by the industry. In both cases, increased yield is a highly desired outcome.

In the scientific literature there are a variety of terms that describe the phenomenon of WHC such as water binding, water retention, hydration capacity, water absorption, suction potential and swelling. In this chapter, the term WHC will be used. The specific molecular structure and conformation of the protein can have a significant effect on WHC as has been described in various reviews (Mohsenin, 1986; Kinsella et al., 1989; Huff-Lonergan and Lonergan, 2005). Over the years, different methods have been suggested to estimate the water holding capacity of meat and non-meat protein systems (Hamm, 1960; Honikel and Hamm, 1994; Honikel, 1998; Hermansson, 1986; Trout, 1988; Barbut, 1996; Tornberg, 2013).

In this section, the major methods used for meat and meat products will be discussed and some will be highlighted as potential standard methods for specific applications. As indicated in the introduction, the existence of different methods and the use of different test conditions (e.g., centrifugal force, speed, and time) have made it difficult to compare results from different laboratories.

Location of water in meat – Fennema (1985), Kinsella et al. (1989) and Puolanne and Halonen (2010) describe in detail the types of water in a food protein system. They distinguished between six basic categories:

a. Structural water – tightly bound to protein molecules and unavailable for chemical reactions
b. Hydration water – found around the apolar residues of amino acids
c. Monolayer water – first layer of water absorbed to the protein groups; it may be available for some reactions
d. Unfreezable water – does not freeze at the first sharp transition temperature
e. Capillary water – held by surface tension forces
f. Hydrodynamic hydration water – loosely surrounds the proteins

For practical reasons, water held within a protein matrix such as meat can be divided into three major categories:

a. Structural/bound water – includes water directly attached to the protein molecules that is no longer available as a solvent. In muscle food, it usually amounts to 5-10 g water per 100 g of protein. In this case, the polar water molecules bond with the charged amino acid side chains (Fennema, 1985). In practice this represents about 10% of tightly bound water as a monomolecular layer to the thin and thick filament structure (Zayas, 1996).

b. Immobilized water/hydration – represents only a few layers of water molecules that are attached to the bound water (usually by hydrogen bonds). The attachment becomes successively weaker as the distance from the charged protein groups increases. In muscle food, immobilized water usually amounts to 20-60 g water per 100 g protein (Fennema, 1985). In practice this represents about 10-20 % of a second layer outside the first layer (Zayas, 1996).

c. Bulk/free water – is mainly held by surface forces and can be squeezed out of the meat with relative ease. The processor's goal is to keep this water in the product as it is of major importance in meat processing and usually amounts to 50-60 % of the water in the muscle. Overall, Zayas (1996) indicated that only 40-80 g out of the 280-380 g of water/100 g protein is directly bound to protein and the remaining 240-300 g water/100 g protein is found in the thick and thin filament lattice. This points out to the fact that a substantial amount of water is only 'trapped' within the filament structure, and during the conversion of muscle to meat this water can come out as drip loss, purge, etc. Therefore, processors must be very conscientious about conserving as much of the "trapped" water.

Factors affecting binding of water – different aspects influence the amount of water and degree of binding for each water category; e.g., molecular structure and properties of meat proteins, pH, protein type and concentration, number of exposed charged groups, salt concentration, and temperature. The pH is a very important factor influencing the fresh meat, and later during further processing (e.g., adding salt/alkaline phosphate affects the pH and the charges on the amino acid side chains). To a certain extent, the processor can control the pH as will be explained in more detail below (see Fig. 17.2.1.1).

There is no doubt that the basic molecular protein structure as it is related to WHC. Proteins consist of a folded chain of amino acids attached by peptide bonds. The linear order of amino acids represents the primary structure of the protein. The three dimensional folds in the chain represent the secondary and tertiary structures. Finally, quaternary structure refers to the geometric arrangement of various amino acid chains that are bound, most often, by non-covalent bonds (e.g., see the 3D structure of myoglobin in this chapter). The side chains of the individual

amino acids "stick out" from the main strand of the protein molecule and may be positively, negatively, or neutrally charged depending on the amino acid and the pH of the environment. The pH of the living muscle is close to 7.0.

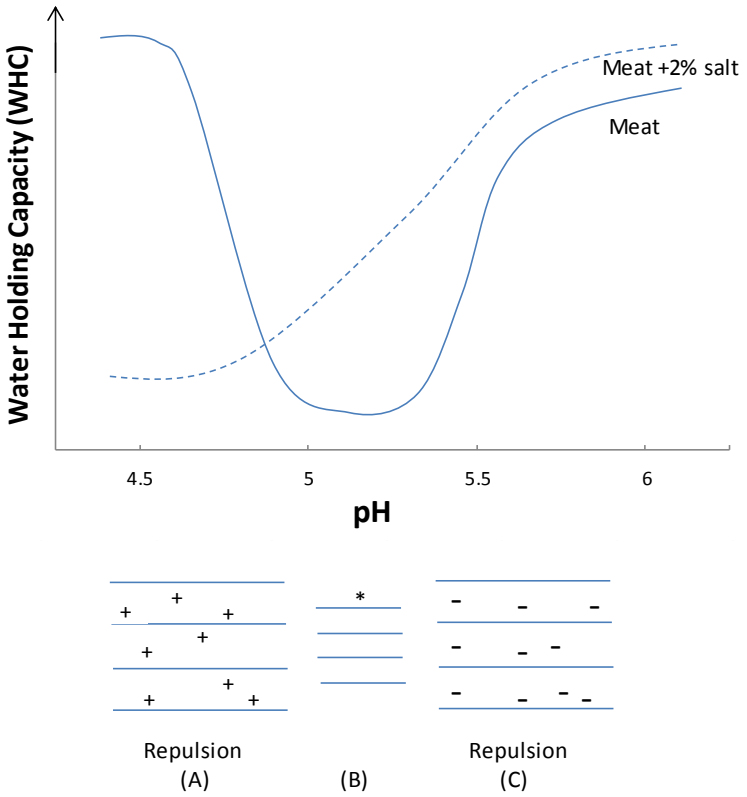


Figure 17.2.1.1 Effect of pH on the amount of immobilized water present in meat. The pH effect is due to its impact on the distribution of charged groups on the myofilaments and the amount of space between them. (A) Excess positive charges on the filaments. (B) Balance of positive and negative charges. (C) Excess negative charges on the filaments.
Adapted from Price and Schweigert (1987).

However, after slaughter, the pH drops due to the accumulation of lactic acid in the muscle (see Chapter 3). This pH decline results in a decrease in the number of reactive, charged groups in the proteins that otherwise would be available for water binding. The shift in pH causes a reduction in WHC (Fig. 17.2.1.1), which can be explained as the result of three main factors (Aberle et al., 2001):

a. Net-charge Effect – refers to the number of charged amino acid groups that are available for water binding. During the conversion of muscle to meat, lactic acid formation results in a pH reduction that approaches the isoelectric point (pI) of the muscle which is about 5.1. Note this is an average value obtained for the major muscle proteins (myosin - pI of 5.4, and actin pI of 4.7; Zayas, 1996). At the pI, the numbers of negatively and positively charged groups are equal and the net charge of the protein is zero. As a result, the side chains have fewer groups available for water attachment; this is known as the net charge effect (also see next section regarding the steric effect. Thus, at the pre rigor muscle pH (around 7.0) more water will be bound to the muscle proteins than at the post rigor pH of about 5.4 (see also Huff-Lonergan and Lonergan, 2005).

b. Steric Effect – most of the water inside living muscle cells is located within the myofibrils (i.e., up to 85%). Much of this water is held by capillary forces that arise from the unique layout of the thick and thin filaments (see Chapter 3). As the muscle goes into rigor, cross bridges between the thick and thin filaments are formed, which causes a reduction in the space available for water (Offer and Trinick, 1983). More recent studies using nuclear magnetic resonance (NMR) have improved our understanding of the relationship between cell structure and water distribution (Bertram et al., 2002). It has been suggested that loss of volume in the myofibrillar region combined with pH induced lateral shrinkage of the myofibril could lead to water expulsion from the myofibril into the extra-myofibrillar space (i.e., this can be used to explain drip loss of muscle going into rigor). The steric effect refers to the repulsion of similarly charged side chains (i.e., like charges repel). Understanding the charge repulsion spacing of proteins can be beneficial to the processor, who can later add ingredients such as an alkaline phosphate to shift the pH, add charges, and hence increase WHC. By doing this, larger spaces are created for water molecules to reside. This can take place on both sides of the isoelectric point, where a high proportion of negatively or positively charged groups will result in more repulsion.

c. Ion exchange – takes place during the meat aging process (after rigor mortis has been completed). Enzymatic degradation of the cellular structure results in a redistribution of ions and as divalent ions (e.g., calcium) are replaced with monovalent ions (e.g., sodium), charged amino acid side groups are freed and hence WHC increases. The calcium ion is mentioned here because it is released during the post mortem process and is capable of attaching to and thereby neutralizing two negatively charged side groups. Once calcium is replaced by monovalent ions, the proteins can bind more water.

When meat is further processed, sodium chloride is the most common ingredient used. One of the major reasons for this is to enhance WHC (Fig. 17.2.1.1; see the WHC curve shift to the left) as myofibrillar proteins are solubilized (also so-called salt soluble fraction of the muscle proteins; see Chapter 3) and negative chloride ions are added to the system. There is, however, a maximum salt level that can be used to increase WHC. Increasing salt concentration from 0 to 5% dramatically increases the WHC, but at salt concentrations above 5% the reverse is seen. This is due to the "salting-out" effect where proteins will aggregate in such a way that their amino acid side groups are not available for water binding water.

17.2.2 Measuring Water Holding Capacity (WHC)

It is important that the food/meat industry be able to measure WHC and predict food/meat behavior in specific applications (e.g., storage, cooking). As a matter of fact, several of the least cost formulation programs (i.e., computer programs used for calculating ingredients; see Chapter 13) have a value assigned for water binding. Over the years, various methods to measure WHC have been developed and used by industry personnel and university scientists. The methods can be basically divided into:

a. Monitoring meat sample behavior
b. Pressure application
c. Microstructure evaluation
d. Optical sensors
e. Studying water molecule behavior – NMR and DSC

a. Meat sample behavior – a simple and inexpensive way to evaluate how fresh meat will behave in terms of WHC. To evaluate WHC during storage, a small sample (e.g., 10-100 g) is usually placed in a closed plastic bag where drip loss is collected (e.g., tissue hung on a hook and placed inside a plastic bag; note that sample geometry and the direction of the cut applied relative to the orientation of the myofibers are also important). A possible disadvantage of this method is that the analytical data are extremely affected by meat quality and storage time, thus the results will not predict the behavior of the batch on hand unless all the data collection is at standardized times. That said, this is a very popular test and drip loss values are reported in numerous research papers. For evaluating WHC during cooking, the raw meat/meat batter is placed in a closed jar/test tube and heated to the desired temperature at a specified rate while cooking loss is monitored (e.g., during heating or after cooling the sample).

b. Pressure application – this is one of the most popular approaches for quickly obtaining a WHC estimate. An external force, low to high, is applied by a press or centrifuge to extract a certain volume of water. However, it should be noted that when different conditions are used, it is difficult to compare results among different research groups. An example of the effect of employing different test conditions for the centrifugation test can be seen in Table 17.2.2.1 (note: a recommendation for a standard test will be presented at the end of this section).

Table 17.2.2.1 Centrifugal method - effect of g force, time, temperature and salt level on water holding capacity (WHC) results of lean meat. From Zhang et al. (1995).

Test conditions	Mean value of WHC			
	Overall	Centrifugal force (g)		
		959	8,630	34,500
Test time (min)				
7.5	4.0[a]	23.7[a]	4.1[a]	-15.7[a]
15.0	1.1[b]	25.0[ab]	-3.7[b]	-17.9[b]
22.5	1.2[b]	27.0[b]	-4.9[b]	-18.5[b]
Test temperature (°C)				
2	6.5[a]	28.3[a]	6.0[a]	-14.9[a]
10	1.8[b]	26.6[a]	-3.3[b]	-18.0[b]
20	-1.9[c]	20.7[b]	-7.1[c]	-19.2[c]
Salt concentration (M)				
0.0	-2.2[c]	19.3[c]	-4.7[c]	-21.3[c]
0.3	1.9[b]	25.3[b]	-1.9[b]	-17.6[b]
0.6	6.6[a]	31.0[a]	2.1[a]	-13.2[a]
Centrifugal force (g)				
959	25.2[a]	–	–	–
8,630	-1.5[b]	–	–	–
34,500	-17.4[c]	–	–	–

Mean values (n = 5) followed by the same superscript letter in a column are not significantly different at the 95% level

Centrifugal force (low to high) is applied by placing a meat sample in a test tube. Various test conditions (g-force, time, temperature) have been reported for different foods and also for the same food. Meat sample sizes have ranged from 1.5 to 20 g (a 13 fold variation) and forces of 1,500 to 190,000 g (a 127 fold variation) have been reported. These variations allow relative comparisons of treatment parameters but

not a proper comparison of the results between different laboratories. Zhang et al. (1995) set up an experiment to illustrate the difference in results obtained using low, medium, and high g-forces at three different times, temperatures, and salt levels. Their test was based on a fairly common test procedure (Wardlaw et al., 1973) that is used by meat scientists around the world. According to this test, 16 ml of a salt solution (0.6 M) is added to a 10 g meat sample and incubated for 30 min at refrigeration temperature prior to centrifugation. The WHC is expressed as the percent of added water retained (positive value) or the amount of the original water expelled (negative value) by the sample after centrifugation. The salt solution is added to solubilize the major meat proteins (myosin, actin) and also to evaluate the potential ability of the meat to hold added moisture during further processing (i.e., salt is the most common additive used by the industry to enhance water retention). At a high g-force, water was expelled from the sample (Table 17.2.2.1), but at low g-force some of the added brine was retained. Based on a statistical analysis, the following conditions were suggested for analyzing a fresh meat sample: 8,630 g for 7.5 min at 20°C at all the salt concentrations tested (0 - 0.6 M). Their study and other research showed that an increase in g-force does not cause a linear increase in the WHC values obtained.

The press method has also been used, for a long time, to evaluate the amount of "squeezable water" in a product. In this test, the meat sample (fresh/cooked) is compressed between two parallel plates; force is applied by putting a certain weight on top of the upper plate or by using a hydraulic press/texture analyzer. The released moisture is commonly collected on a pre-weighed, dehumidified filter paper (Trout, 1988; Zhang et al., 1993). Depending on the pressure, the sample is compressed into a thin layer from which most or all of the free water has been squeezed out. Various test conditions have been reported in the literature for evaluating meat samples. They range from a force of 0.01 to 44 kN, a sample size of 0.3 to 1.5 g, a temperature of 4 to 23°C, a compression time of 1 to 20 min, and different filter paper types. Zhang et al. (1993) evaluated test conditions such as applied force, sample size, compression time, and salt in common ground beef meat samples. After analyzing the data, they proposed the following conditions: sample size of 1 g, compression force of 20 kN, compression time of 2 min. The authors showed that these conditions can also be used to study processing parameters such as salt addition (i.e., 0-2% salt level commonly used by the meat industry).

A note of caution is that the units of expression can be confusing as confirmed by differences of expression used in reported literature. Depending on what is used for the numerator and denominator and other parts of the calculations, it is possible that "high" WHC values actually indicate a low WHC and vice versa. Choose

your formulas for calculating WHC considering how the data will be used and what relationships you want to show.

When it comes to evaluating the WHC of cooked meat protein gels, one should be careful not to destroy the gel structure during the test (e.g., high compressive pressure or g force will cause the sample to break/collapse). It is also important to prevent water reabsorption at the end of the test (i.e., while waiting for the centrifuge to slow down and stop). Hermansson and Lucisano (1982) studied the effect of g force on heat induced gelled plasma proteins (5%, at pH 9.0, heated to 82°C). They measured the amount of exudate from 1, 2, and 5 g samples centrifuged at 5,100, 9,750, and 30,000 g. Higher force resulted in the higher moisture loss. For example, the 2 g sample lost 3.8, 6.6 and 38.3% moisture when centrifuged at 5,100, 9,750 and 30,000 g, respectively. Low g forces (465, 790, 1045 and 1290 g) were also examined, but in a set up that included a net to hold the sample above the bottom of the test tube; i.e., preventing water reabsorption at the end of the test. This was called the net (or basket) test. These samples showed a water loss of 20-22% at all four g forces. The state of the sample after applying a high centrifugation force was also investigated by Hermansson and Lucisano (1982) and later by Kocher and Foegeding (1993). They showed that a permanent sample deformation indicates structural breakdown. Therefore, the two groups recommended using a low g force net test so there would be no damage to the gel structure. Overall, low speed centrifugation that will not cause permanent deformation to protein samples refers to a force of 100 - 1,000 g (Wierbicki et al., 1957; Hermansson and Lucisano, 1982; Barbut, 1996). As outlined above, the main advantages are that sample deformation is minimal and no or minimal structural damage occurs. In this current and commonly used test, a small sample is centrifuged while placed on a net at about 750 g for 10 min (Kocher and Foegeding, 1993).

c. Microstructure evaluation is an indirect measure of WHC that provides a more basic understanding of the science of WHC, but it is not as good as other methods for predicting WHC. Studies using low resolution light microscopy (Oroszvári et al., 2006) or by high resolution scanning/transmission electron microscopy (see Chapter 16; SEM of meat gels) can reveal relationships between structure and functionality that will help provide food scientists with a better understanding of the factors that affect water holding during structure forming (e.g., gelation), pressure application (e.g., compression, freezing), use of different protein concentration, pH, ionic strength, and temperature. In general, protein can form two distinct categories of gels. The first is a fine-stranded gel made up of small-diameter molecules forming an order network. The second is an aggregate gel comprised of relatively large particles bound to one another to form a network (Hermannson, 1986; Barbut, 1996). In between these two categories there are

mixed gels and/or gels showing different degrees of small and large aggregates. It should be mentioned that the same protein can form both types of gels. For example, egg white proteins can form the typical white large aggregated gel, but also a transparent gel with thin strands at a low pH.

Information obtained by microscopy can be used to show how microstructure affects WHC. Increasing pore size above 0.5 μm seems to have the greatest effect on WHC. Capillary forces exhibit a significant holding force at a small pore diameter. Hermansson (1986) provided a table showing the calculated height of a water column drawn by capillary forces: a 0.1 μm radius capillary draws water up to 150 m, a 1.0 μm radius up to 15 m, a 10 μm radius up to 1.5 m, and a 100 μm radius up to 0.15 m. The corresponding water activities have been calculated as 0.90, 0.99, 0.999, and 0.9999, respectively.

Changing the pH or salt level in a meat batter can also result in the formation of a finer stranded protein structure. Wang and Smith (1992) showed that salt soluble proteins (0.6 M NaCl) formed a finer structure at pH 6.5 and 7.5 than at pH 4.5; the latter showed a large aggregate structure. Such a change also affects the WHC. In finely comminuted meat batters, Gordon and Barbut (1992) showed that adding urea caused a reduction in pore size as compared to a control (2.5% salt) and resulted in a much higher WHC (0.4 vs 4.8%, respectively). Overall, studying the relationship between protein gel structure and WHC is an active research area where more work would help develop better modeling of food systems.

d. Optical sensors – an indirect method to assess water binding in different meats. For example, meats that are categorized as pale, soft, and exudative (PSE), or dark, firm, and dry (DFD) are known to have very poor and very good WHC, respectively. The distinction of pale and dark indicates that humans can detect a visual difference even without the use of an instrument. PSE has been reported by many researchers to affect poultry, turkey, pork, beef, lamb, bison, deer and African game animal meat. Overall, the relationship between colour and WHC in meat is very complex and not fully understood. However, for practical application, it has been established that the lightness value can be used to predict PSE (Bendall and Swatland, 1988) and meat reflectance, used to predict WHC, correlates well with the violet and red spectrum (Swatland, 1995). Numerous researchers have use d the International Commission on Illumination (CIE) system, but the results have not been impressive. This may be because the CIE system puts much more emphasis on green light, which is the region of the spectrum where the human eye is most sensitive (CIE, 1976). In addition, some misuse of the CIE data, by disregarding inherent differences in L*a*b* values between illuminants.

When developing probes it is also important to understand the relationships between the different meat components. Bendall and Swatland (1989) discussed the effect of measuring water from myofibrial spaces compared to water from inter-fibre and inter-fisiculae spaces, and the relationship between WHC and pH. Depending on the "type" of water, the curve can either be linear (increasing from pH 5 to 7), or step-wise with a change at around pH 6. In order to compare results, they summarized data from various studies and showed that the physical location of the water determines the apparent behavior of the curve. Therefore, when optical measurement is developed/used, one should be careful to understand the origin of the water as water within myofibrial spaces is highly pH-dependent, while inter-fibrillar water is more dependent on capillary forces.

The use of near-infrared (NIR) birefringence was later shown to correlate well with WHC of raw turkey breast meat samples ($r = 0.85$, $P < 0.0005$), and with fluid losses during cooking ($r = -0.82$, $P < 0.005$; Swatland and Barbut, 1995). This was the basis for developing a NIR birefringence probe, which was almost as useful as a pH probe and more accurate than a visible colourimeter paleness measurement (L* value) at predicting WHC and cooking losses of the turkey meat samples. Optical probes are also used to monitor specific components of meat products that are important to WHC (Prieto et al., 2009). For example, high levels of collagen can be detrimental to WHC because its conversion to gelatin during cooking can result in excessive cooking losses. Collagen in meat batters can be assessed using a quartz probe to evaluate fluorescence intensity and comparing that to a characteristic fluorescence pattern. Assessing collagen content this way has been used to successfully predict the cooking losses ($r = 0.99$, $P < 0.005$) and WHC of meat batters (Swatland and Barbut, 1991). When compared to a common centrifugation method (i.e., raw meat mixed with salt and centrifuged at 7,000 g; Wardlaw et al., 1973; described earlier in the chapter), a good correlation was obtained ($r = -0.92$, $P < 0.005$). Overall, the NIR fiber optic probe measurement was much faster and easier. Today, there are many more opportunities for developing optical sensors with quick response times in the food industry. Such fast reacting probes help optimize production and product quality while increasing automation and reducing production cost.

e. Studying water molecule behaviour - instruments such as nuclear magnetic resonance (NMR) and differential scanning calorimetry (DSC) can be used to indirectly measure the WHC in various foods. These instruments provide information on water molecule relaxation time (e.g., NMR) and the degree of hydration (Bertram et al., 2002; 2006) and/or amount of freezable water in a protein system (e.g., DSC). Fundamental information on the relationship between proteins and WHC can be provided, as well as basic information about chemical

bonding, etc. However, the equipment is more complex and expensive than the previously described methods and therefore trained employees are required.

NMR spectroscopy measures water binding indirectly by scanning a small, homogeneous sample (e.g., 1 to 5 g in a special tube) several hundred times to produce a representative value for the "relaxation times" of the water molecules within the sample (Bertram et al., 2002; Pearce et al., 2011). The relaxation time is the time required for the magnetic nuclei of the water molecules to return to their original energy level after being excited to a higher energy level by high frequency radio waves in the presence of a magnetic field. The three nuclei with magnetic moments that can be used in an NMR study of water are the proton, the deuteron, and oxygen^{-17}; the latter two are most commonly used. After excitation, the nuclei show two relaxation times (T_1 and T_2). These represent the times required for the longitudinal (rotational) and transfer (gyrational) motions of the nuclei to return to normal. Usually the T_2 values are used to determine WHC in food systems such as meat because they show greater changes (Bertram et al., 2002). In pure water, T_2 values are in the order of 1-2 sec. When compounds such as proteins are present, however, the time is reduced by a factor of 10-150. This is because proteins can absorb some of the energy from the water, which results in a faster return to the original low energy state. In a meat system, a large portion of the water is held in pores (e.g., spaces between the muscle filaments); therefore, it has a shorter distance to diffuse to the water-protein interface than in a pure open water system. As a result, the water in the pores shows a much lower T_2 value.

17.3 Fat Holding Capacity

Fat is another major component in many meat products and ranges between 4-40%. It contributes to the texture and mouth feel of the product but, unlike protein (ranges from 10-20%), it does not contribute to water holding capacity. Sometimes high fat products have problems holding water, fat, or both as will be discussed later in this section (note: the importance of fat in providing flavour and juiciness is discussed in Chapter 16).

Fat holding capacity is important in all products (whole muscle, ground meat, and finely comminuted products). Similar to WHC, losing too much fat during processing can result in products with an unacceptable product while also creating a net loss for the processor. In whole muscle and ground products fat is usually trapped within the adipose tissue cells that are in the confines of the connective tissue network, which provide an envelope and hold a considerable amount of the fat. In finely comminuted products the fat is usually extracted from the adipose

tissue cells (i.e. by chopping the meat batter). The ability to retain fat in a finely comminuted product (e.g., a frankfurter that contains 25% fat) is a challenge and of great importance to the meat industry. This is especially important during cooking when animal fat is converted to liquid before the meat proteins coagulate (40-50°C and 50-60°C, respectively). After melting, the liquid fat can flow out of the product if not properly confined. In some whole muscle products partial fat exudation can be desirable (e.g., while roasting a whole chicken or barbequing a steak some of the fat drips out and helps provide unique "roasty" flavours). However, in comminuted products, such as frankfurters and bologna, fat losses would leave voids that are considered defects in the product and adversely affect texture, mouth feel and appearance as exuded fat, commonly referred to as "fatting out", "fat caps", "fat streaking", would accumulate in the casings and later appear as white pools of fat.

Various methods to predict fat holding capacity in processed products have been developed. The fat holding values are often used in least cost formulation programs as mentioned in the WHC section. In such programs, raw materials are assigned numerical values indicating their functional properties such as general binding and fat holding capacity.

The principles of the methods currently used to predict fat holding capacity are fairly similar to WHC methods and involve:

a. Monitoring meat sample behavior
b. Pressure application
c. Microstructure evaluation
d. Emulsion capacity testing
e. Chemical extraction
f. Optical sensors

a. Monitoring meat sample behavior: Numerous methods can be used during processing to access quality issues of the final product. For example, sausage may be monitored while they are cooked in a smoke house. Alternatively, product samples can be processed in small batches (e.g., test tubes) while fat and moisture losses are captured and measured. An example of measuring fat and moisture losses that occur while cooking finely comminuted meat batters formulated with different levels of animal fat and vegetable oil is provided in Chapter 13. The example uses a common test where 34 g samples were stuffed into 50 ml plastic test tubes and cooked in a water bath (Youssef and Barbut, 2011). The closed system allows precise collection of fat and moisture (cooking exudates). The test allows the processor to see if and where problems occur and to specifically

address processing/formulation issues. Another common test in this category is monitoring exudates during cooking of a ground meat product (Fig. 17.3.1; fat loss is plotted against fat content). The figure also provides an example of an emulsion type product. The results show that fat loss increased as fat content was raised from 5 to 35%. In that study the goal was to look at the mechanism(s) of fat holding rather than to optimize the meat formulation (e.g., by adding salt) or processing conditions (e.g., frying temperature). Overall, observing a sample while cooking and monitoring the amount of fat/water loss is a common practice. Such monitoring can reveal the advantages/disadvantages of using certain meats, processes parameters (e.g., slow versus fast heating rate) and different ingredients. The test is easy to perform and does not require sophisticated equipment. However this specific test is not designed to determine the upper limit of fat holding capacity (e.g., needed for Least Cost Formulation programs).

Whiting (1987) monitored meat samples to study the effect of adding a broad spectrum of chemical compounds (salts, alcohols, monoglycerides, nonionic detergents, chelating agents, etc.) on fat holding in a meat protein system. He showed that cations from groups IA and IIA of the periodic table equaled or surpassed the stability obtained of meat batters prepared with sodium chloride, while the inclusion of cations such as zinc greatly reduced fat holding. Nonionic detergents, alcohol, and monoglycerides were detrimental to both fat and water holding. Other compounds such as urea, which stabilizes hydrophobic and peptide groups, improved fat holding. In that study, the cooking test was very beneficial and provided information about the mechanisms associated with fat binding. Olsson and Tornberg (1991) used the cooking test (frying in this case) to study the relationship between fat level and fat retention. In low fat products, fat loss was minimal when regular animal fat was used. However, when rendered fat was used (fat that has been heated to 80°C for 30 min and then filtered to remove cell wall material) fat losses were much higher than when regular fat was used, even at the low fat level. The reason for this was the absence of cell wall structure to hold the fat in place during frying. Understanding this relationship is important to the industry in terms of achieving reasonable yield and product acceptability.

b. Pressure application to evaluate fat holding capacity can be employed by using low/high centrifugation to using a hydraulic press. Olsson and Tornberg (1991) compared results of fat holding capacity in hamburger patties between the cooking test and the net test described in the WHC section. In the frying/cooking test, fat losses were minor in low fat products, and increased linearly with fat content ($r = 0.98$). In the corresponding net test, centrifuged samples also showed a linear increase with raising fat content ($r = 0.88$) but the fat losses were significantly higher than for the frying test. The authors suggested that the higher fat losses were

due to the centrifugal force being applied after cooking. They used a force of 500 g to centrifuge cooked (77°C for 35 min), 10 g samples. The authors also indicated that the longer cooking time in the net test could allow more fat to coalesce and, therefore, separate more easily from the product. The authors indicated that the net test was useful in predicting fat holding in ground hamburgers.

High centrifugation force (18,000 g) was also used to separate some of the fat from raw meat batters prepared with different chloride salts (NaCl, $MgCl_2$, $CaCl_2$; Gordon and Barbut, 1990). This high centrifugation force was required to evaluate raw stable and semi-stable meat products, since low force would not remove any fat from the raw batters. The test showed a significantly higher fat release from raw batters formulated with the two divalent salts ($MgCl_2$, $CaCl_2$) as compared to monovalent salts. There was also a significant difference between the two divalent salts in their influence on fat holding. Later, during cooking, both divalent salts showed a detrimental effect on fat holding capacity that resulted in almost total fat loss (note: this is why calcium-reduced milk powder should be used in emulsion-type meat products instead of regular milk powder). Overall, the high centrifugation force predicted fat stability during cooking. Although such high g forces are not commonly used by the industry to check raw meats, they are useful in studying the mechanisms of fat binding.

c. Microstructure evaluations are often used to study fresh and cooked meats. Understanding the relationship between microstructure and fat/water holding has proven useful. As previously indicated, in ground meat products like hamburger the fat is held within the original fat cell structure. Figure 17.3.1 shows fat loss from the product as a function of fat content. The authors also provided light microscopy pictures (not shown here) that display the distribution of fat clusters within the raw product. To the consumer, these fat clusters appear as white dots in a hamburger or a salami type product. In the cooked product some of the fat stayed in clusters, while other fat came out via fat channels. The authors indicated that when regular fat trimmings were used, intact fat cells were dispersed within the protein matrix. In the micrographs of the rendered fat treatments (stained with Aniline blue), hardly any connective tissue was observed around the fat clusters and this resulted in much higher fat losses compared to using regular fat trimmings. The losses were determined by both a frying test and a hexane extraction test (see additional discussion on chemical extraction, below).

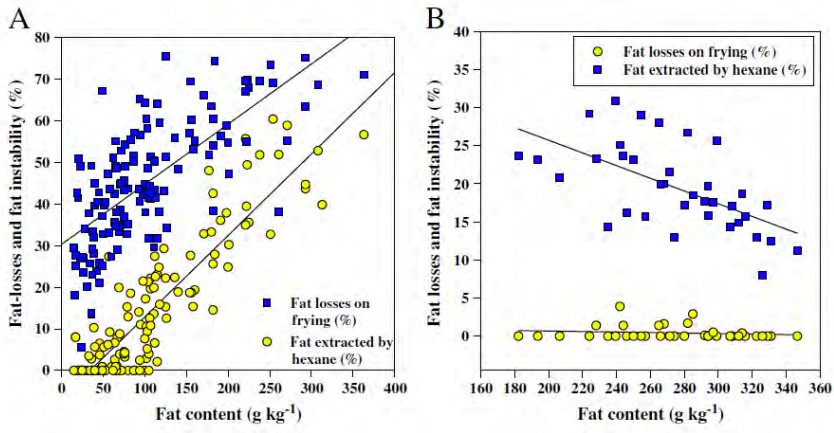


Figure 17.3.1 The amount of fat loss plotted against fat content. Fat instability (percentage of fat extracted by hexane) and fat losses (g fat lost/g fat originally in product) on frying for beef burgers (A) and emulsion sausages (B) of varying fat content (g kg^{-1}).
From Tornberg (2013). With permission

In a finely comminuted meat product (e.g., bologna), fat is removed from cells during the chopping operation. The fat globules are then coated with meat proteins, which help stabilize the fat within the meat protein matrix. Overall, the protein gel matrix has an open structure (Fig. 17.3.2) that has embedded fat globules. The thin protein coat around the fat globule serves as an emulsifying agent that separates the fat and aqueous phases. Assuming that there is enough protein extraction and the surface area of the fat is not too large, this usually provides good fat stabilization. The addition of ingredients such as caseinate and polyphosphates can greatly enhance fat holding as they can increase emulsifying capacity (see Chapter 13). In the examples shown in Figure 17.3.1, fat stabilization was much better in the emulsion type product compared to the ground hamburger sample (note: fat losses reach 80% on the left graph and only 40% on the right). Examining the microstructure provides a better understanding of the mechanisms responsible for fat holding in these two distinct systems. Using microscopy (low/high magnification) has been shown to be very beneficial in studying the interactions between fat and proteins, fat distribution (see also micrographs in Chapter 13), pore size, and the extent of the interfacial protein film.

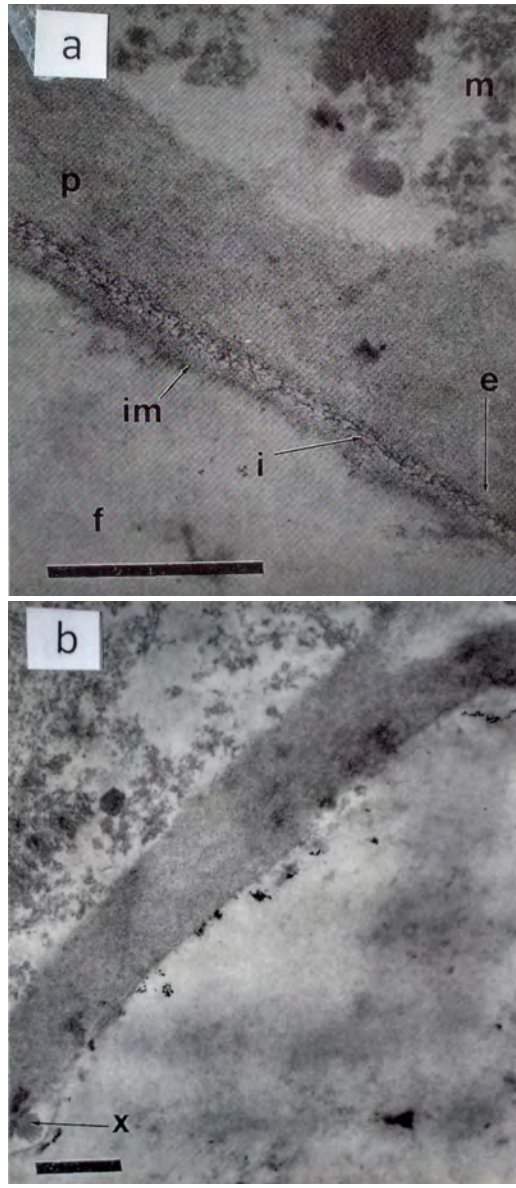


Figure 17.3.2 Transmission electron micrographs of fat globules in a cooked meat batter produced with KCl (ionic strength = 0.43). Showing a high magnification (a) and a lower magnification (b) of the interfacial protein film surrounding the fat globules within the protein matrix of the batter. f = fat; m = matrix; p = thick diffuse protein coat; im = internal membrane; i = interconnecting diffuse region; x = unidentified particle. Bar = 1 um. From Gordon and Barbut (1990).

d. Emulsion capacity tests are commonly done in model systems by overloading the food/meat system with liquid oil and determining the maximum emulsification point. These tests have been used for many years and the results have helped develop numerical systems for scoring meat using cost and formulating programs, such as the Least Cost Formulation program (previously discussed). The meat/protein sample is placed in a high speed homogenizer that is used to emulsify the oil. The oil (e.g., vegetable oil) is slowly added to the sample at a constant rate and is gradually emulsified until the system is overloaded and reaches a "breakdown" point where the oil and protein phases separate. This separation is observable by an abrupt change in viscosity, a change in the sound of the mixer, or changes in the electrical conductivity of the product. The latter basically shows the transformation to a continuous fat phase, which has a much higher resistance to electrical conductivity than before. Maurer et al. (1969) used the test to characterize salt soluble proteins from chicken breast muscle and showed that emulsifying capacity decreased when salt was removed by dialysis or even removed and then added back. Common test parameters reported in the literature include the slow addition (1 ml/sec) of room temperature vegetable oil (cotton seed oil) to a high speed blender (Maurer et al., 1996).

e. Chemical extraction is used to estimate fat holding by removing fat that is not well held within the product and can escape during conventional processing (e.g., cooking). This fat is known as the unbound fat portion. In whole muscle and ground products this is usually the fat that is not surrounded by a cellular membrane structure. In finely comminuted products it is fat that is not properly surrounded by an interfacial protein film. Andersson et al. (2000) used hexane to extract unbound fat from hamburgers and emulsion sausages formulated with increasing fat levels: 10 to 35% and 18 to 35%, respectively (Fig. 17.3.1). The results were compared to fat losses achieved from frying the products and showed that the hamburgers lost more fat than the sausages. In the hamburgers, fat losses were related to fat content. In the sausages, however, fat loss was independent of fat content and the hexane extraction test values actually decreased with increasing fat content (Andersson et al., 2000). The authors also noted that fat instability in the sausages was related to water loss (results not shown here), which also reflected the properties of the protein matrix. They concluded that the physical entrapment of fat within the protein matrix was more important in the emulsion type sausages than in the ground hamburger product (see also discussion of the emulsion theory in Chapter 13).

f. Optical sensors and spectrophotometry are not often used to assess fat binding in food products but are commonly used to assess fat content via infrared spectroscopy (Prieto et al., 2009). However, the need to develop rapid/online methods to monitor food processing conditions has sparked interest in looking for optical methods including fiber optic sensors. An example is the development of a fiber optic probe to predict lipid content and processing losses from finely comminuted meat batters (Swatland and Barbut, 1990). A bifurcated light guide was produced to measure reflectance of different mixtures of lean beef and fat. The authors looked at a range of 400-1,000 nm and found that reflectance at 1,000 nm correlated best with lipid content of the meat/fat mixtures ($r = 0.99$, $P < 0.005$). At 930 nm, fluid loss, which was determined by centrifugation, was significantly correlated with fat content ($r = 0.77$, $P < 0.005$). Such a probe could be calibrated against the spectrum of an ideal reference meat batter and provide the processor with a rapid response to control meat batter composition on a sausage manufacturing line (i.e., feed forward control). Later, a fiber optic probe to determine the optimal time for meat batter chopping was developed (Barbut, 1998a). This probe measures light reflectance as fat globule size first decreases and then increases again due to coalescence. At this point the chopping process should be stopped, because too much coalescence will cause a meat batter breakdown. The probe can be calibrated to indicate when the desired fat globule size has been reached. Data for calibrating the probe is initially obtained from cooking test results. Later a few other researchers worked on this concept and improved the prediction value of the probe.

These examples illustrate the way optical sensors can be developed to obtain measures to optimize processing parameters. The meat batter/emulsion probe can be used to determine the chopping time endpoint when no visible signs are available to operators. Most people in the industry rely on temperature to determine the chopping endpoint but it cannot be used to truly optimize the process. Other very experienced operators use stickiness and/or viscosity changes but these are not always accurate and this skill cannot be easily transferred to a new employee. Despite published papers about such probes, so far there has not been a large scale adoption of fiber optic probes to monitor sausage production. As described in the WHC section, the advantage of a light measuring device/probe is its fast response, convenient use for online measurements, durability in a processing plant (e.g., fiber optics inside a stainless steel sleeve), and its relatively simple operation at the plant level.

17.4 Colour

17.4.1 Colour – Introduction

Vision is an important sense for our survival as it helps us make choices (about food/other items) and communicate with others. The way we see and interpret colour is complex and beyond the scope of this book. However, a few basic explanations and references are provided, below. Briefly, humans can detect different wavelengths and translate them into either black and white or colour images. The visible spectrum for humans is presented in Figure 17.4.1.1.

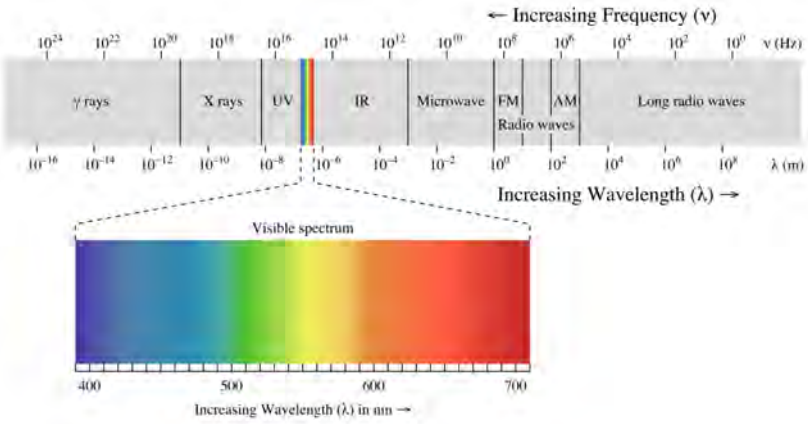


Figure 17.4.1.1 Use of a prism to separate the white sunlight into its components. Note that by using a second prism, one can combine the colours to reproduce the white light. From Wikipedia.

Healthy humans can sense electromagnetic waves in the wavelength range of 400 to 700 nm whereas insects, such as bees, can sense shorter wavelengths in the ultraviolet (UV) range (e.g., cameras with special UV sensitivity show unique patterns on flowers that are not visible to humans). In the animal kingdom, colour also plays an important role in both warning other animals and/or attracting animals from the same species. For example, a male peacock tail feather shows an impressive colour presentation (Fig. 17.4.1.2) that actually requires a lot of energy to grow and maintain.

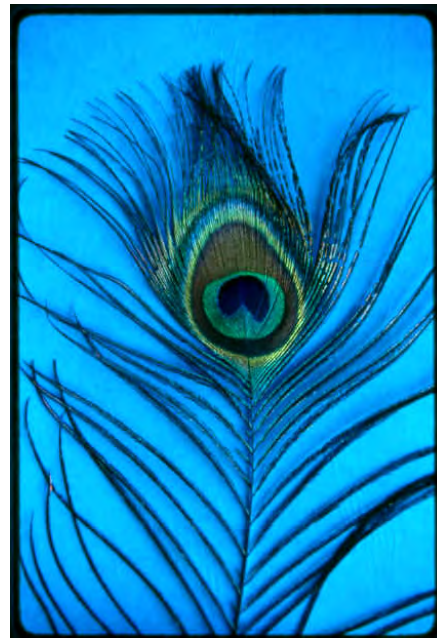


Figure 17.4.1.2 Male peacock feather – colour presentation.
Photo by S. Barbut

When it comes to acceptance or rejection of food by humans, colour plays an important role. Adding purple food colouring to a scrambled egg mix, for example, will make the product unacceptable to consumers even though there are no deviations in flavour, texture, odour, and safety. This can be verified by presenting the purple eggs under red light, which masks the colour differences (see Chapter 16). It is also important to note that we use colour to make strong assumptions about the flavour of a product. For example, when the colour of an ice cream is switched from red to yellow, people are easily tricked into believing that the flavour has also changed.

The colour of meat primarily arises from the red myoglobin molecules present in the tissue. However, it should be emphasized that meat colour is also affected by factors such as the breed, nutrition and feed/forage antioxidants, animal age, muscle type, post mortem changes (e.g., see later discussion on PSE meat), processing methods (e.g., cooking, frying), use of additives (e.g., nitrite), lighting conditions, and packaging. Interactions between these factors can make evaluating a specific meat product's colour fairly complicated.

17.4.2 Vision and Colour Perception

Light is a key component in our ability to see. A simple example is entering dark room where we cannot perceive the items inside. As the light level is slowly increased, one will first start to see the outline of the items but without colour. Then, as the light intensity is increased further, colours will gradually start to appear, indicating that a minimum level of light is required to see colour. The colours we see are the result of light reflected from different objects, which will also absorb and scatter some light. Light is a form of radiant energy produced by a hot object such as a candle, lightbulb, or the sun. Light waves radiate in all directions from their originating source and vibration occurs at right angles to the direction of the wave's travel (Fig. 17.4.2.1). The high points of a light wave are called crests and the low points, troughs. The distance from crest to crest is called wavelength and the number of vibrations, or cycles per second is called frequency. When the wavelength (λ) is multiplied by the frequency (v), the result is the speed of light (c):

$$c = \lambda v$$

This relationship indicates that as wavelength increases, frequency decreases, since the speed of light is constant. This can be used to show why blue light (see Fig. 17.4.2.2; $\lambda = 400 - 425$ nm; $v = 75 \times 10^7$ cycles/sec) has a shorter wavelength and is more penetrating than red light ($\lambda = 650 - 700$ nm; $v = 40 \times 10^7$ cycles/sec). The higher penetration of blue light makes it potentially more damaging to our skin (i.e., closer to the UV zone), and explains why it can cause more problems with meat colour and fading (see later discussion on storage). White sunlight can be split into its components naturally by water droplets (as seen in rainbows) or by using a prism (Fig. 17.4.1.1). The Gage Dictionary definition of colour is, "the sensation produced by the different effects of waves of light striking the retina of the eye. Different colours are produced by rays of light having different wavelengths".

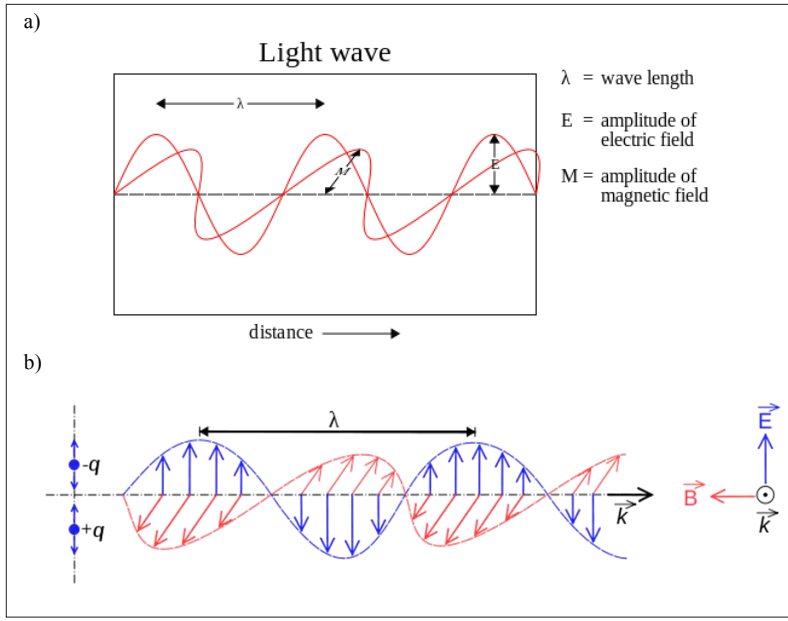


Figure 17.4.2.1 Wavelength is the distance from one crest to the next and frequency is the number of wavelengths per second as shown in (a). Section (b) shows that light is a three dimensional electromagnetic wave, vibrating at right angles to its direction of travel.
From Wikipedia http://en.wikipedia.org/wiki/Light.

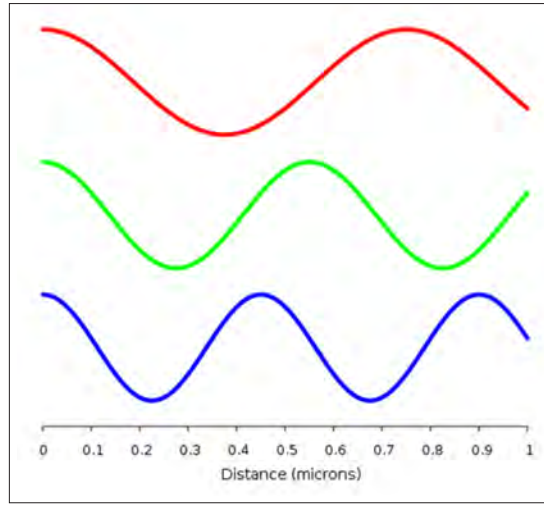


Figure 17.4.2.2 Wavelength of blue vs green vs red light – relationship between λ and frequency

Figure 17.4.2.3 shows the light reflected from meat. It absorbs all/most of the blue and green light and reflects back small amounts of yellow, moderate amounts of orange, and a large amount of red light. Therefore, the overall colour of meat appears red. Light sources with an excess or deficiency of certain wavelengths of light (e.g., fluorescent light is deficient in red), will result in the meat appearing in a different colour.

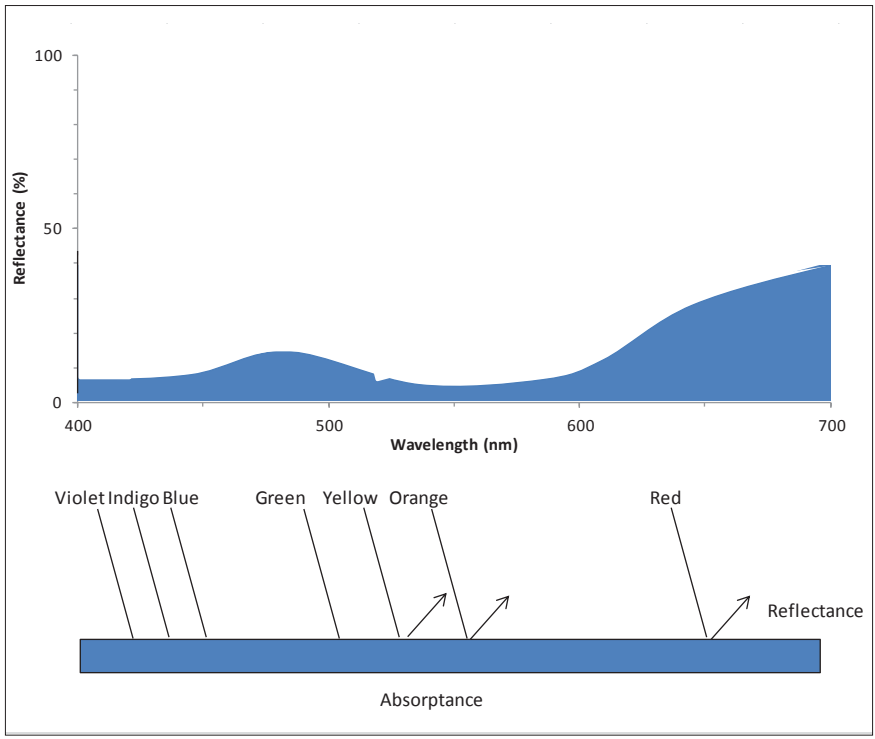


Figure 17.4.2.3 Spectral reflectance for chicken thigh meat.

17.4.3 Method for Colour Evaluations

Determining colour and expressing it in a simple way is not easy. In our daily life, we use a variety of descriptive terms for colour; e.g., the colour green can range from dark to light, bright to dull, glossy to matte, and modifiers such as grass, hunter, etc.

Colour can be evaluated and reported in different ways. Colour scales have been developed to compare the product's colour to a reference. These colour scales are popular, for example, in home hardware stores where customers are interested in matching/selecting colours for their homes. An example of a colour fan used by the poultry industry to evaluate and report egg yolk colour and/or chicken skin is shown in Figure 17.4.3.1. Similar colour fans have been produced for meat (e.g., the Japanese pork meat colour chart). Producing chicken/pork/beef with a consistent meat/skin colour is important to consumers who have certain expectations for a wholesome product. Deviation from such a colour will raise questions and might prevent the customer from buying the product. It is also interesting to note that expectations differ regionally; in the USA light coloured chicken skin is desirable whereas in Japan darker yellow skin is praised (Note: preferences can also differ within the same country). Growers can affect skin and egg yolk colour through diet by providing feed rich in carotenoids or synthetic xanthophylls which will enhance the yellow colour.



Figure 17.4.3.1 Example of a colour fan used by the poultry industry to check for egg yolk colour and/or chicken skin

Fletcher (1999a) provided a historical review of the various methods used by the poultry/meat industry to measure and express colour. The methods can be basically divided into three categories:

a. visual
b. chemical-spectral photometric (e.g., direct pigment analyses)
c. reflectance colourimetry

a. Visual descriptions were developed in the early 1900s when colour chip standards were introduced to score colour of poultry skin and egg yolks. Originally, a series of colour standards (fairly linear scale) were created and assigned numbers. One of the most common colour standards was the Hoffman-LaRoche yolk colour fan (Fig. 17.4.3.1), which was also used for broiler skin colour evaluation. The colour fan has been used for many decades and is still used today in certain parts of the world. This applies a less subjective scoring system to evaluate skin colour and also serves as a quality control measurement. This and the Japanese pork meat chart are still used today.

b. Chemical-spectral photometric methods are based on spectrophotometric characterization of extraction of meat pigments. Pigments can range from the carotenoids found in feed material (e.g., corn) that are deposited in the skin and fat to the heme pigment found in meat. Several procedures for poultry are based on the extraction of skin pigments from the shank area using acetone, followed by a colourimeter evaluation. Meat pigments, including heme and cytochrome C, are also extracted and quantified (AMSA, 2012; to be further discussed below).

Several of the problems encountered with the visual and chemical methods were due to the incorrect assumption that the results were linearly related to the product's final colour. For example, the Hoffman-LaRoche colour fan employs a linear scale to describe non-linear colour values. This problem becomes apparent when colour values do increase in a linear fashion in response to the amount of carotenoids fed in the diet. The problem can also be seen when examining the relationship between the heme content and meat colour, since the colour is often more affected by the chemical state of the heme pigment rather than its concentration in the tissue (Fletcher, 1999a). It should be mentioned that one of the major disadvantages of pigment extraction, from meat, is that the processing steps can change the chemical redox form of the pigments. Thus, extractions are best for quantification of pigments and determine spectral peaks and valleys.

c. Reflectance colourimetry is the most popular method used today in meat/food science colour research. It can overcome some of the previously described problems and eliminate the inherent problem of variation among panelists. It also

eliminates problems associated with changes of pigment forms when extracted and from differences due to lighting type and intensity, differences in light viewing angles of colour by panelists, and background effects (i.e., items placed on different coloured backgrounds can appear different to people). The major advantages of reflectance colourimetry, when done correctly, include its accuracy, objectivity, and reproducibility. Some of the limitations include the dependency on more expensive equipment, potential operating errors, and improper use. Overall, the three components involved in the way we perceive colour include the illumination source, the object/surface viewed, and the observer (human or instrument). When discussing instrumental colour measurements it is important to first explain the concepts of hue, lightness, and saturation (Swatland, 1989).

Hue describes a primary colour such as red, green, or blue.

Lightness or luminosity describes the brightness of the colour.

Saturation describes how vivid or dull the colour is.

As an illustration of the relationship between the three terms, consider the slow mixing of green paint into dull white paint. The colour will gradually change from the original dull white to pale green to dark green, but the hue (green in this case) remains unchanged. What changes is the saturation; the colour progressively changes from dull green to a more vivid, saturated green. The lightness or luminosity can be changed by using bright white paint instead of dull white, so the paint would be brighter.

Figure 17.4.3.2 shows a graphic description of hue, lightness, and saturation. In the example provided above, adding more green paint moves along the saturation axis toward the outside of the sphere. Using a brighter white paint (as the starting ingredient) moves upwards along the lightness line.

With scientific advancements, different numerical systems have been developed to measure colour. Established in 1931, the CIE (Commission Internationale de l'Eclairage) incorporated the spectral aspect of illumination with the three primary colours into the so-called tri-stimulus values, also known today as the X, Y, Z. The CIE X, Y, Z system defines a colour by the additive mixture of the three primary light colours, X (red), Y (green) and Z (blue) that would be required to match the colour of a mixture as viewed by a "standard observer" (human) under defined illumination and viewing conditions. This is based on the theory that the human eye possesses receptors only for these three primary colours, and that all other colours seen are a mixture of the three. Note: the system is useful for defining colours but the results are not always easily visualized.

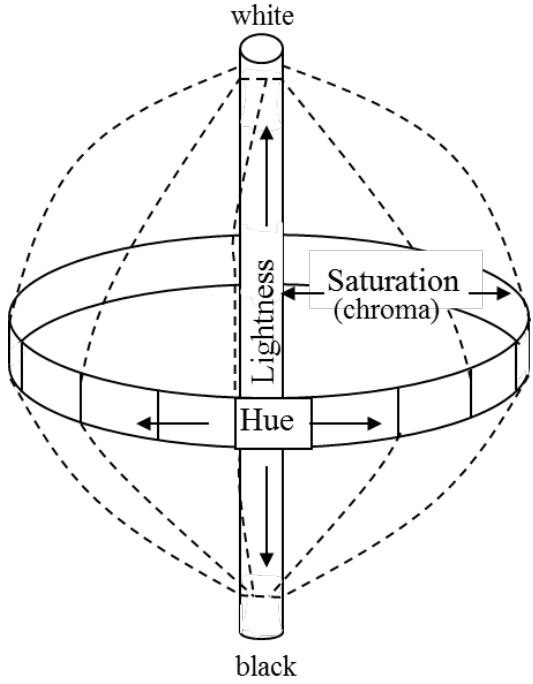


Figure 17.4.3.2 The relationship between hue, lightness and saturation presented in a 3 dimensional space. Derived from the tristimulus values of the CIE (1976). Note: in the CIE, saturation is termed chroma. Redrawn from Anonymous (1989).

Richard Hunter used the CIE data and established a Hunter Lab system (Mancini and Hunt, 2005). The original formulas for calculation L, a, and b, were modified in 1976 to minimize the problem that equal distances on a chromaticity diagram do not correspond to equal differences in colour perception (CIE, 1976). This system is one of the most popular systems currently used by the meat industry and is known as the CIE L*, a*, and b*, (note that the asterisk is now used to indicate the 1976 modifications).

The CIE L*, a*, and b* colour space system is presented in Figure 17.4.3.3. The L* value is an expression of the lightness of the surface ranging from 0 (black) to 100 (white). The a* spans from -60 (green) to +60 (red), and b* from -60 (blue) to +60 (yellow). Another frequently used method for food applications is the Hunter L, a, b solids scale. The relationship between the CIE and other colour scales has been discussed in the AMSA Guidelines (2012).

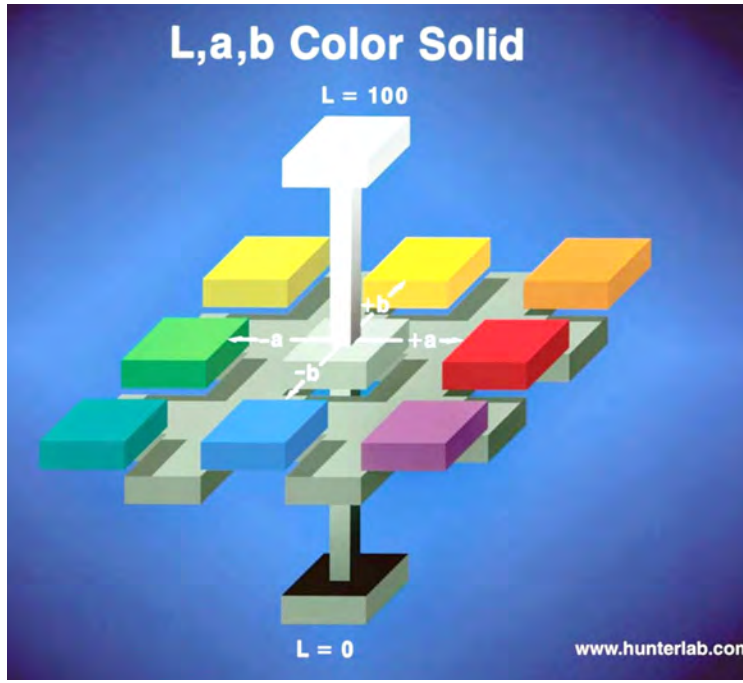


Figure 17.4.3.3 Schematic diagram of the CIE (1976). LAB colour space used to describe colours. Each colour can be expressed by 3 numbers indicating its position in a 3-dimensional spherical space. The vertical axes shows lightness to darkness in a 0 (black) to 100 (white) scale. The a* spans from +60 (red) to -60 (green), and the b* from +60 (yellow) to -60 (blue). Note: the square shown in a midway position can be moved up or down depending on lightness. From http://www.hunterlab.com/images/NEW-Lab-Chart-Web.jpg.

17.4.4 Myoglobin and Meat Colour

Meat colour is affected by various intrinsic and extrinsic factors. The main intrinsic factors include myoglobin content (also called meat pigment content), muscle fiber orientation, spacing among muscle fibers, and pH.

For many years muscle fibers have been described as "dark vs. light", "red vs. white", "slow vs. fast", "aerobic vs. anaerobic", and numerous others nomenclatures, which are based on inherent differences in myoglobin content and muscle biochemistry/physiology. When discussing meat colour, it is important to note that muscles differences in myoglobin content have a great effect on colour and colour stability when comparing different muscles (see Chapter 3 - differences between red and while muscle fibers). White chicken breast meat is predominantly

composed of white fibers, which have low myoglobin content and a light gray colour (see *Pectoralis* in Table 17.4.4.1; the table shows differences in total hemoglobin, and myoglobin content).

Table 17.4.4.1 Myoglobin and hemoglobin content in chicken muscles[1]. From Kranen et al. (1999).

Muscle	Hemoglogin	Myoglobin
	(mg/g)	
Heart	2.67 ± 0.65^{a}	1.08 ± 0.41^{a}
Adductor	0.83 ± 0.21^{b}	0.56 ± 0.17^{b}
Pectineus	0.09 ± 0.04^{d}	0.01 ± 0.00^{e}
Sartorius	0.67 ± 0.11^{b}	0.12 ± 0.02^{d}
Pectoralis	0.24 ± 0.04^{c}	ND

[a-e] Per parameter, means within a column with no common superscript differ significantly as analyzed by t test ($P < 0.05$).
[1] Values are means ± SD. ND = not detectable

The heart muscle, which has the darkest colour and more anaerobic chemistry, has the highest heme content followed by the *Adductor* muscle. Thigh meat is mainly composed of red fibers and appears dark. Kranen et al. (1999) used different methods to determine hemoglobin and myoglobin content including spectral photometric, size exclusion chromatography, and immunological methods. They compared their results to about half a dozen other groups and found fairly comparable data. Different poultry also vary in the inherited amount of pigment in their muscles (e.g., chicken vs. duck). Differences can also be related to muscle activity where domestic chicken breast muscle is lighter than active breast muscle of a migratory duck. The muscles' colour is influenced by the amount of hemoglobin and myoglobin found in them. Hemoglobin is found in red blood cells and is composed of four myoglobin units (both are used to deliver oxygen to the muscle and hence can bind and release oxygen fairly easily; e.g., depending on partial pressure of the gas, pH). The structure of the heme complex is shown in Figure 17.4.4.1. Myoglobin is a complex molecule consisting of two major parts: the protein portion called globin and the non-protein portion called the heme ring. The protein component consists of a globular protein and the heme ring has an iron molecule in its center which is responsible for binding molecules such as oxygen and water. The oxidation state of the iron molecule and the compounds attached to the ring determine the shade of red colour.

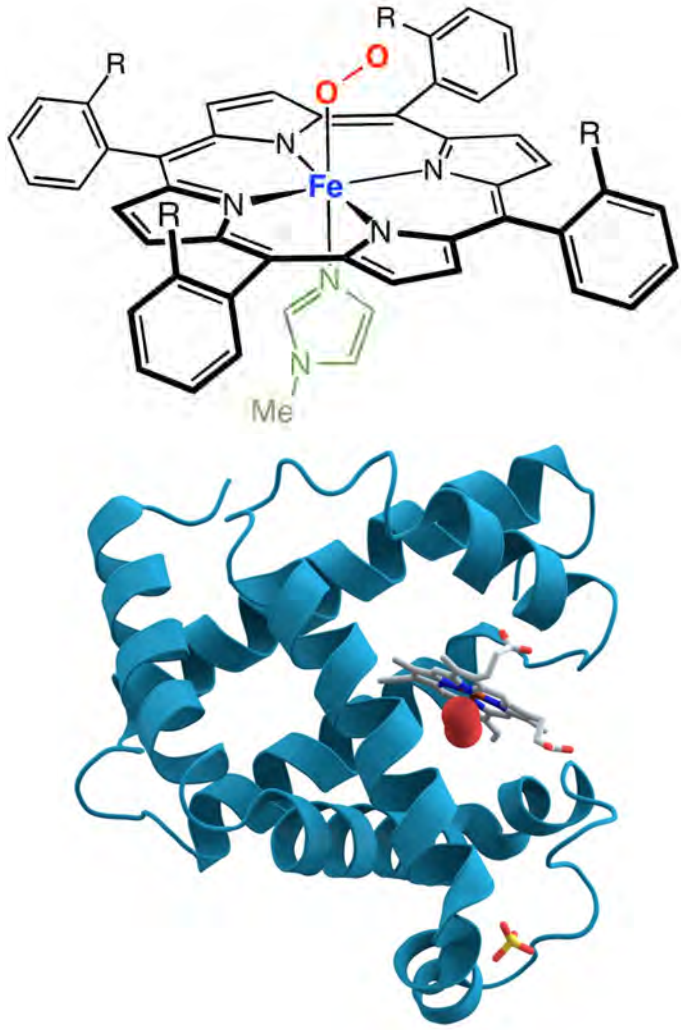


Figure 17.4.4.1 Schematic structure of the myoglobin molecule. First image showing a picket-fence porphyrin complex of Fe, with axial coordination sites occupied by methylimidazole (in green) and dioxygen; the R groups flank the O2-binding site. Second image showing a 3D model of helical domains in myoglobin. From Wikipedia.

In terms of extrinsic factors, myoglobin has a bright-red colour when exposed to oxygen (Fig. 17.4.4.2) and the iron molecule is in its reduced ferrous (Fe^{2+}) state.

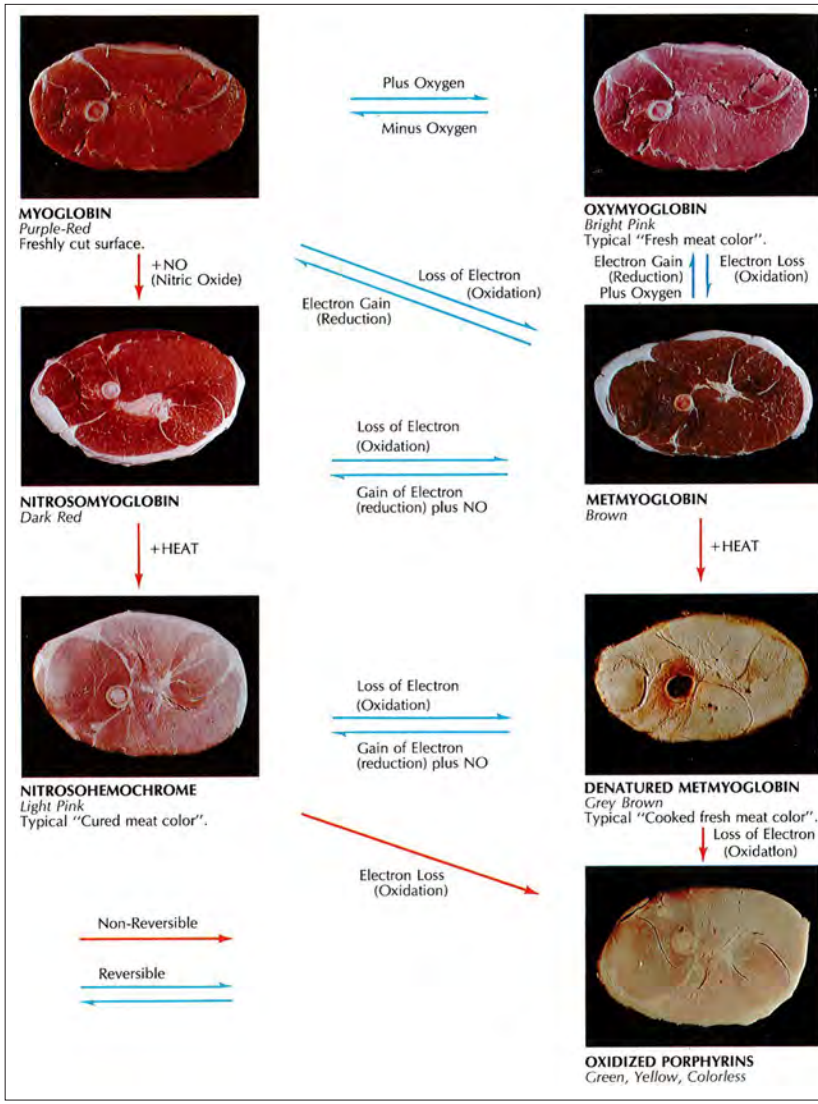


Figure 17.4.4.2 The different states of myoglobin and colours of meat. From: Meat Curing Principles and Modern Practice (1972). With Permission - Koch Supplies Inc.

Consumers associate this bright red colour (called oxymyoglobin) with fresh, high quality meat. This colour is sometimes also referred to as "bloom". When

there is no oxygen, the iron molecule is in its ferric, Fe^{3+}, state and the pigment (called metmyoglobin) gives the meat a brown colour. This can be reversed when the meat is exposed to oxygen (i.e., the metmyoglobin first has to be converted deoxymyoglobin and this form can be converted back to oxymyoglobin; Suman et al., 2014), provided microbial count is not too high. Consumers associate brown meat with old meat because meat tends to be brown when it has been stored for long periods, and a large number of microorganisms that consume oxygen are present.

Extrinsic factors such as vacuum packaging can also result in the conversion of the myoglobin pigment into the brown colour form (Fig. 17.4.4.3). Vacuum packaging is often used to extend the shelf life of the fresh meat product (see also Chapter 11). To overcome this, a master package can be used for the small fresh meat trays. The master package is then either vacuum packed or flushed with CO_2. At the store, the master package is removed and time is allowed (15-30 min) for the "bloom" to develop; i.e., the packaging material of the individual tray is oxygen permeable.

Cooking results in denaturation of the meat pigment and appearance of a typical greyish/dull brown colour (Fig. 17.4.4.2). Heat usually denatures the globin portion of myoglobin and the heme ring is usually separated from myoglobin and adds to the "non-heme" pool in meat. The denaturation temperature depends on the interaction between meat pH and redox status of the myoglobin. As muscle pH increases the myoglobin is more thermally stable resulting is more pink/red colours. Thus, pH effects combined with the redox forms will have a highly significant effect on cooked colour. The relative resistance of the major redox forms to heat induced denaturation is: carboxymyoglobin > deoxymyoglobin > oxymyoglobin > metmyoglobin (AMSA, 2012).

When meat pigments are heated sufficiently, the fully denatured myoglobin becomes the "cooked pigment", or the so-called denatured metmyoglobin. This denaturation results in the meat changing to a more opaque structure (i.e., more translucent in the raw state), and reflecting more light (i.e., appearing lighter). In the case of cooked chicken thigh meat, an almost 50% increase in both the L* (e.g., 45 to 65) and b* (e.g., 6.2 to 16.7) values and a slight decrease in a* are commonly observed. In the case of chicken breast meat, which has a much lower myoglobin content (Table 17.4.4.1), the L* value usually increases by about 60% (e.g., 52 to 82) due to cooking. During cooking, breast meat colour also becomes yellower (e.g., 6 to 14). The a* does not change much and overall the consumer sees a very light product at the end of the cooking process.

There are some other potential colour problems that can be associated with the so called premature browning (meat appears cooked before it reaches a temperature of 65°C) and the persistent pink phenomena (meat still looks uncooked even when a temperature of 72°C has been reached). These colour problems have been investigated over the years (Seyfert et al., 2004; AMSA, 2012) and the processor should be aware of the causes and potential solutions.

During slow roasting, the surface of the meat and/or skin also develops a typical brown colour as a result of the Maillard reaction between amino acids and reducing sugars that causes brown pigment formation. Enhancing the development of the brown colour can be achieved by adding sugars such as honey to the basting media (see Chapter 13). During smoking an extra brownish/golden colour develops on the surface due to the presence of carbonyls in the smoke that also participate in the Maillard reaction (see Chapter 13). Higher than normal pH of meat (such as DFD meat) will usually decrease Maillard surface browning.

When nitrite is added to cured meat products (see Chapter 13, ham recipe), a typical pinkish-red colour will initially develop in the raw meat. Later, upon heating, it will change to the stable light pink pigment called nitrosohemochrome (Fig. 17.4.4.2). The difference between nitrite and nitrite-free meat products can easily be seen when ham or turkey leg meat is prepared at home; without nitrite cooked products have a typical brown colour whereas cured products have a pink colour. Additional discussion on unintentional nitrite contamination of fresh meat (low levels are needed) can be found at the end of the chapter.



Figure 17.4.4.3 Example of beef meat just vacuum packed (right) and same meat after 12 hr (left), showing the transformation of myoglobin to metmyoglobin. Photo by S. Barbut.

17.4.5 Animal Skin Colour

In meat producing animals sold with the skin on (e.g., broilers, turkeys, ducks, pigs), skin colour and shade are important marketing factors. In poultry, skin colour can range from light beige to yellow to even totally black. Skin pigmentation is the result of two major factors that include melanin deposition and carotenoids/ xanthophyll obtained from the diet (Fletcher, 1999a). The first factor is related to the genetic ability of the bird to produce and deposit melanin in the dermal or epidermal layer of the skin (see Chapter 3). The second factor is the broiler's ability to absorb and deposit carotenoid pigments from plant material. Studies have shown that consumers usually prefer the colour that was traditionally available in their region. For example, in the eastern US deeply pigmented poultry are most desirable, whereas in the northwestern US pale skin colour is preferred.

a. White skin colour results from little or no melanin or xanthophyll deposition in either the dermis or epidermis (Fletcher, 1999a).
b. Black skin (found in some Chinese breeds) is the result of melanin deposition in both the dermis and epidermis.
c. Yellow skin results from xanthophyll deposition in the epidermis. Breeds that have the ability to absorb and deposit carotenoids must receive this pigment in their diet.
d. Green skin is the result of the deposition of xanthophyll in the epidermis and melanin in the dermis. Greenish and bluish skin colours can be seen in some South American breeds.

In most commercial breeds, the ability to deposit melanin has been eliminated through genetic selection. Sometimes, however, consumers still return poultry showing dark spots in certain areas. The processor can quickly verify the presence of typical melanin-bodies in the skin cells by using microscope analysis and then assure the consumer that the problem is not related to microbial spoilage or a food hazard.

Various studies have been conducted to evaluate skin pigmentation in relation to natural and synthetic sources of carotenoids, and to establish the dietary levels of carotenoids required to achieve a certain colouration. Carotenoids are deposited in the epidermis. Therefore, if a yellow skin colour is to be maintained, a mild scalding procedure should be used (i.e., one that does not remove the outer skin layer during scalding and plucking. See Chapter 5).

17.4.6 Product Presentation and Light Sources

Colour is the result of light reflected back from an object. As mentioned earlier, the light source used for illumination and its intensity can affect colour. Therefore, if an unbalanced light source is used the colour will be distorted. This is mentioned because fluorescent light, which is deficient in certain wavelengths (e.g., red), is commonly used in refrigerated display cases. It should also be remembered that there are significant differences in how people perceive colours (e.g., a person who is colour blind or cannot distinguish between shades of red will have a different colour perception compared to a person with a perfect vision (AMSA, 2012).

When consumers look at a meat product in the store it is usually displayed under artificial light. The most common artificial lights include incandescent (INC), fluorescent (FL), metal halide (MH) and light emitting diodes (LED). As will be demonstrated below, these sources have different spectra (resulting from the different lighting colour temperature and colour rendering index; i.e., two terms that can be found today in the specification of light bulbs). The decision to install one over another depends on factors such as cost of the light bulb, life expectancy, energy efficiency, and heat output. For example, FL bulbs do not produce a full spectrum but radiate about 20% of the heat produced by INC bulbs of the same light output. Therefore FL bulbs are usually installed in commercial display coolers. Metal halide is the most efficient light bulb to illuminate large areas, but also does not produce a full spectrum (e.g., strong in the yellow/orange range). Barbut (2001) examined the effects of different light sources on the colours perceived by the customer and their degree of liking of certain products (whole chicken with skin on, skinless thigh meat, and breast meat). In most studies the actual colour coordinates (e.g., CIA L*, a*, and b* values) are determined using a commercial spectrophotometer. Such colour meters are equipped with a stable light source (e.g., xenon) to illuminate the surface after the instrument has been calibrated with a white plate. L*, a*, and b* colour coordinates are important in studying the effect of various test parameters (e.g., storage time, additives) but they do not reveal the actual colour the consumer will see at the store when different light sources are used. Therefore, in that particular study scanning equipment capable of utilizing the actual light source used in the store was employed.

Consumer preferences to buy the product under different light sources are shown in Table 17.4.6.1. Consumers liked the whole chicken product with skin presented under the INC (150 W, 120 V). The panelists also indicated a strong preference to buy the product when presented under INC light (data not presented here), as opposed to no specific preference when presented under FL and a significant objection when presented under MH.

Table 17.4.6.1 Preference of fresh chicken cuts under different light sources. All products presented under 70 foot candle. From Barbut (2001).

Product	Incandescent	Fluorescent	Metal halide
Whole chicken (skin on)	7.01[a]	4.55[b]	3.57[b]
Thigh meat	6.08[a]	3.65[b]	4.45[b]
Breast meat	5.76[ab]	6.81[a]	5.55[b]

[a,b] Means, within each row, followed by a different superscript are significantly different ($P < 0.05$) from each other. Twelve panelists evaluating the product on 2 successive days; 1 = dislike, 10 = like.

The reason for that can be explained by examining the luminance data (Fig. 17.4.6.1). The INC light source produces a full spectrum (balanced distribution of the different wavelengths) and imparts a full natural colour to the product (i.e., the luminance data obtained for the products under the INC source are fairly similar to data obtained by a Minolta/Hunter commercial spectrophotometer). The main descriptor colour used by 66% of the panelists to describe the whole chicken with skin on under INC light was yellow, while in the other light sources it was described as cream or white (see below). In general, observed colour is described in one to two words that indicate its main colour and shade. This is the result of our mind summarizing all the reflected wavelength data and expressing it as one colour. Since we do not have the ability to "see" the individual peaks (as measured by photo diode array equipment; Fig. 17.4.6.1), we express our overall impression.

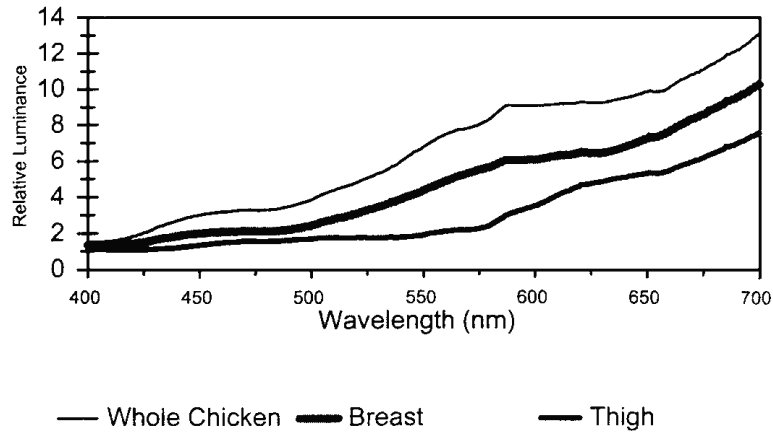


Figure 17.4.6.1 Luminance data of whole chicken (skin on), skinless thigh meat and breast meat presented under incandescent light (70 foot candle). From Barbut (2001). With permission.

When a MH luminance light source was used, the data showed a narrow peak in the yellow region (Fig. 17.4.6.2), strong peaks in the blue and green regions, and a low red peak. The luminance data obtained and the position of the peaks were similar to published data of other commercial MH sources. The use of MH resulted in a low panel preference score (Table 17.4.6.1) and 75% of the panel to describe the colour of the whole chicken with skin on as cream white. The panelists overwhelmingly said that they would not buy the product presented under MH because of its unnatural colour.

Presenting the whole chicken under FL light produced a peak in the yellow zone and two additional, strong peaks in the blue (430 nm) and green (530 nm) regions (Fig. 17.4.6.3). The reflection curve obtained here is similar to published data for other commercial FL light bulbs that show typical strong peaks in the blue (430 nm), green (530 nm), and yellow (570 nm) regions. Seventy-five percent of panelists described the whole chicken with skin on as pale white. The reason for that was the lack of a broad enough yellow peak and the minimal red colour in this light source.

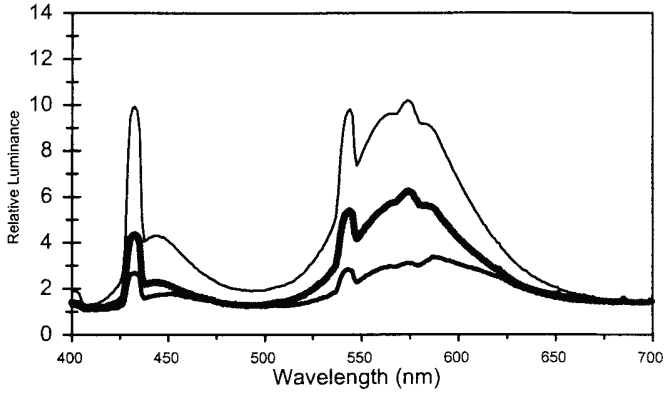


Figure 17.4.6.2 Luminance data of whole chicken (skin on), skinless thigh meat and breast meat presented under metal halide light (70 foot candle). From Barbut (2001). With permission.

The skinless thigh meat with its typical dark poultry meat colour was also most preferred under INC light (Table 17.4.6.1). In this case, the expression of red colour could only be achieved with an adequate source of red light. The luminance curve is fairly similar to data published by Swatland (1989) for poultry leg meat measured using a fiber optic spectrophotometer. The presence of adequate red

light output in the INC source resulted in a high buying preference as opposed to a significantly lower buying preference under FL and no preference under MH. Under INC light, the leg meat was described by most panelists as pink/red, but was described as brown under FL light and brown/purple under MH light.

The skinless breast meat was liked similarly by the panel under both INC and FL light (Table 17.4.6.1). Since the colour of this raw product is actually light beige, the red and yellow components were not as important as in the other two products. The main colour used to describe the product under INC light was tan/pink. Under FL, it was described as brown/beige and beige/tan under MH. Comparing the FL and MH source showed that the product was more liked under FL light. In terms of the buying decision, there was actually a preference to buy the product under FL light ($P < 0.01$). Overall, skinless chicken breast meat has a neutral colour that is not much affected by the lack of red in FL light or the relatively strong blue and green peaks in the FL and MH sources (i.e., this can be related to the colour temperature of the light source, its colour rendering index and light intensity).

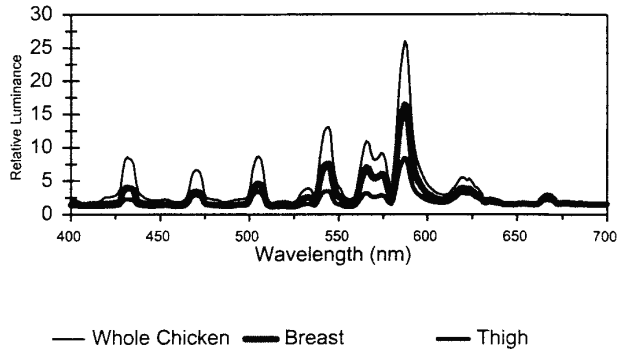


Figure 17.4.6.3 Luminance data of whole chicken (skin on), skinless thigh meat and breast meat presented under fluorescent light (70 foot candle). From Barbut (2001). With permission.

17.4.7 Other factors Influencing Meat Colour (PSE, DFD, White Striation)

The colour and appearance of meat are also affected by the structure and spacing of the sarcomeres (muscle building units). The physical structure of the sarcomeres (see Chapter 3) affects the way light is absorbed and reflected from the muscle's

surface. An example is the differences between pale, soft and exudative (PSE) meat and the dark, firm, and dry (DFD) meat. In this case the PSE meat has a more open structure that reflects more light and results in a lighter appearance (Barbut et al., 2008; Swatland, 2008).

Figure 17.4.7.1 shows the lighter PSE poultry meat that is considered lower quality meat because of its poor water holding capacity (note: pork, beef, and turkey meat is also known to show PSE; see discussion below). This is important to processors as lean muscle contains about 75% water. When PSE breast muscle is used for further processing there are usually problems holding the muscle's original water and any injected moisture (i.e., added during further processing). This can be critical when, for example, large individual turkey breast muscles or pork hams are injected, tumbled and then cooked in a bag. If there is free water in the bag it will have to be opened and the free moisture drained. This results in reduced profit and a substantially shorter shelf life.

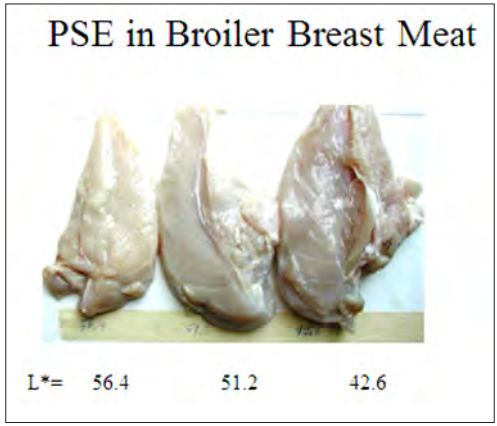


Figure 17.4.7.1 PSE Meat – seen as much lighter than normal meat. Photo by S. Barbut.

When it comes to selling fresh meat, packaging skinless chicken breast fillets/ pork chops in a tray can be a challenge if there are noticeable variations in colour (note: the human eye is very sensitive in detecting colour variations). In a survey of 1,000 packages of skinless breast fillets (four per package) conducted in the USA, Fletcher (1999b) reported an average of 7% that showed noticeable colour variation (i.e., presence of at least one fillet that was lighter or darker than the rest). Samples were evaluated at 16 different stores where packages from six brands

were marketed. It was interesting to note that the occurrence of colour variation varied among companies (0.9, 3.5, 6.1, 8.4, 12.6 and 16.9% showing one or more discoloured fillets). This clearly indicates that some companies sort their meat.

Industry and academic reports have indicated varying degrees of PSE in different species (Barbut et al., 2008). The magnitude and colour distribution (L* value – lightness) of turkey breast meat can be seen in Figure 17.4.7.2 where the occurrence of PSE meat was evaluated over one year in Ontario, Canada (4,000 samples from 40 flocks). Similar results were later published by Owens et el. (2000a) for turkey breast meat sampled in Texas. Seasonal effects can be seen in Figure 17.4.7.3 for the Ontario data, indicating that the hot summer months resulted in higher incidences of PSE meat, likely due to heat stress. Overall the mean L* value of flocks processed in the summer was significantly higher than in the spring, autumn, and winter. The occurrence of PSE in poultry meat has led various researchers to suggest that the problem is associated with genetically inherited stress susceptibility in some broilers/turkeys.

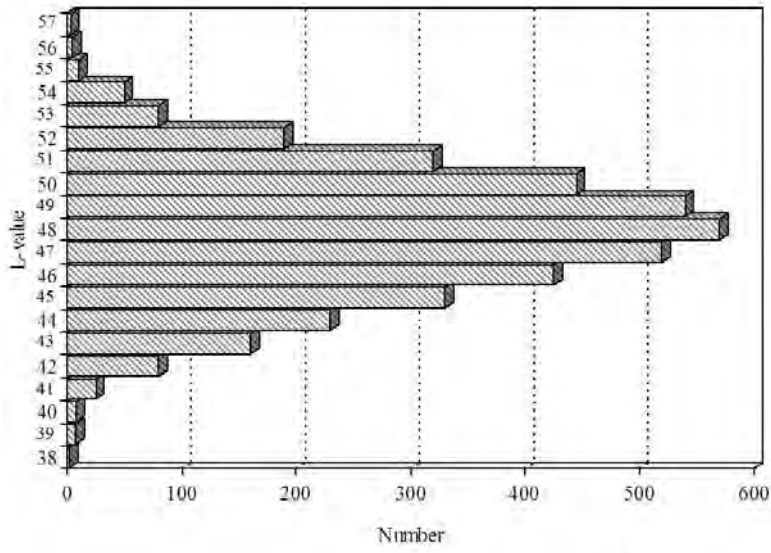


Figure 17.4.7.2 Turkey breast meat lightness (L*) distribution; n = 4,000. From Barbut (1998). With permission.

Strasburg and Chiang (2009) indicated that the mechanisms underlying the development of PSE poultry meat are poorly understood; however, it is widely

accepted that PSE meat results from postmortem hypermetabolism of skeletal muscle. Porcine stress syndrome (PSS) has historically served as the model of hypermetabolism by pigs in response to stress. Upon exposure to heat, transportation, or mating, stress-susceptible pigs can often develop malignant hyperthermia (MH). This syndrome is characterized by excessive heat and lactic acid production coupled with augmented glycogenolysis and anaerobic glycolysis, all of which are coupled with severe muscle contracture. Porcine stress syndrome-malignant hyperthermia can even result in death before slaughter whereas stress-susceptible pigs that go through the slaughter process yield a higher incidence of PSE meat than non-stress-susceptible animals (Offer, 1991). The combination of high carcass temperatures and acidic muscle pH during the early stages of postmortem conversion of muscle to meat leads to denaturation of some of the myofibrillar proteins. Malignant hyperthermia has also been recognized in humans and other animals as an inherited skeletal muscle disorder triggered by response to administration of certain anesthetics such as halothane (Gronert, 1980).

Pork breeders were able to identify two main mutations associated with the PSE condition. The mutations are related to a defect in the regulation of calcium channels (called the ryanodine receptor) a few decades ago. Later, the industry introduced a fairly successful program to remove stress susceptible animals from the herd. However, such an exact gene mutation has not yet been identified in poultry.

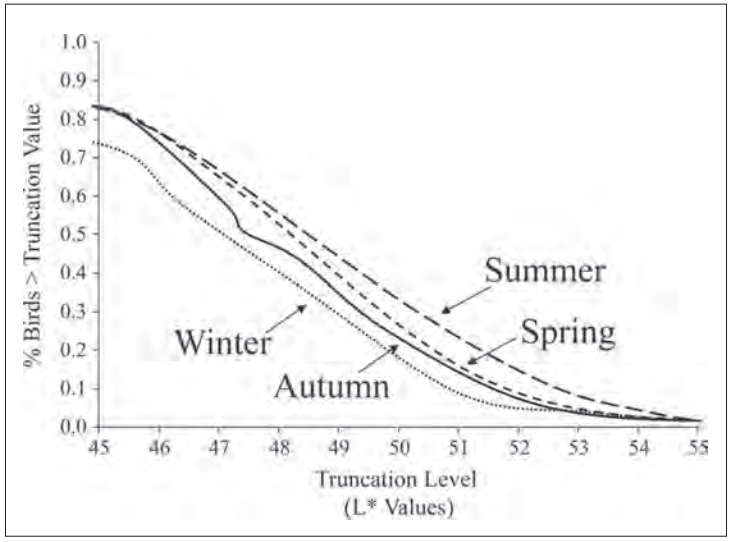


Figure 17.4.7.3 Truncation values of L* measurements obtained for young turkey tom breast meat samples showing seasonal effects. From McCurdy et al. (1996).

Although there is not a comparable malignant hyperthermia phenotype in poultry, there is ample evidence that postmortem hypermetabolism of skeletal muscle underlies the development of PSE turkey meat (Strasburg and Chiang, 2009). Pietrzak et al. (1997) observed that turkey breast muscles, segregated into groups based on high (pH > 6.2) or low (pH < 5.8) 20-min postmortem pH, displayed markedly different biochemical and meat quality characteristics. Breast muscles from the latter group displayed lower mean adenosine triphosphate concentrations, higher lactate levels, lower water-holding capacity, lower cook yield, and lighter colour. These results are consistent with the biochemical description of PSE pork and are suggestive of rapid postmortem glycolytic metabolism.

Owens et al. (2000b) showed that some live turkeys are sensitive to halothane gas, a test used to identify susceptible pigs. The turkeys were exposed to 3% of the halothane for 5 min, which caused leg muscle rigidity in 3.5% of the 4 week old turkeys. However, the susceptible turkeys did not end up with a significantly higher incidence of PSE at slaughter time, as compared to a control group. At that time the authors suggested that either the halothane response is only a limited predictor of PSE meat in turkeys or is not an appropriate stressor to induce the PSE condition in poultry. Strasburg and Chiang (2009) suggested that the ryanodine receptors play a central role in regulation of avian sarcoplasmic Ca^{2+} and changes in receptor activity may have important implications for the development of PSE meat. The authors mentioned that although numerous advances have been made in our understanding of avian ryanodine receptors, particularly with respect to the discovery of alternative splice variants, it will be important to determine whether these transcripts are translated into protein and the functional differences of these variants. As of yet, our understanding of the causes of PSE in poultry is still insufficient to start a massive selection program as the one used in pigs. More research should be conducted with a long-term goal of reducing the problem in poultry. For now, poultry processors can only monitor the problem and try to reduce stress during catching, transport, and unloading and to modify some of the processing conditions (Barbut, 2009).

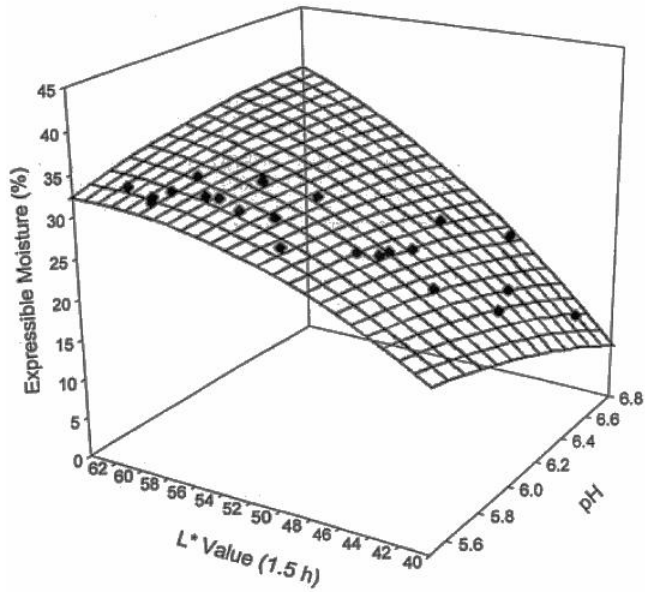


Figure 17.4.7.4 The relationship between expressible moisture (EM), pH, and L* value (1.5 h) of turkey breast fillets (EM = 14.8935 - 0.0236 * colour * colour - 2.5438 * pH * pH + 0.5435 * colour * pH; R2 = 0.3714; P = 0.0001). Each point represents average pH and EM for every one increment of L* value. The surface plot represents predicted values based on raw data. From Owens et al. (2000a). With permission.

As indicated above, incidences of PSE in poultry have been reported to range from 5 to 40% (Barbut, 1998b; Petracci et al., 2009; Owens et al., 2000a) depending on the season, age, and cut point used to classify PSE meat. McCurdy et al. (1996) suggested a cutoff value of L* > 50 for young turkey breast meat based on its lower water holding capacity above this point. Owens et al. (2000a) suggested L* > 53 based on the relationships they identified between colour (L* value), pH, and expressible moisture (Fig. 17.4.7.4). A cut off point of L* > 52/53 was suggested for mature turkey hens, which are known to have overall lighter breast meat colour (Barbut, 1998b). An L* > 49/50 was suggested for broiler chickens based on data shown in Figure 17.4.7.5 and the corresponding WHC plus cooking loss data for these samples. Figure 17.4.7.5 shows that the lightness of broiler breast fillets can range from L* = 41 to 56, which represents a fairly wide colour range.

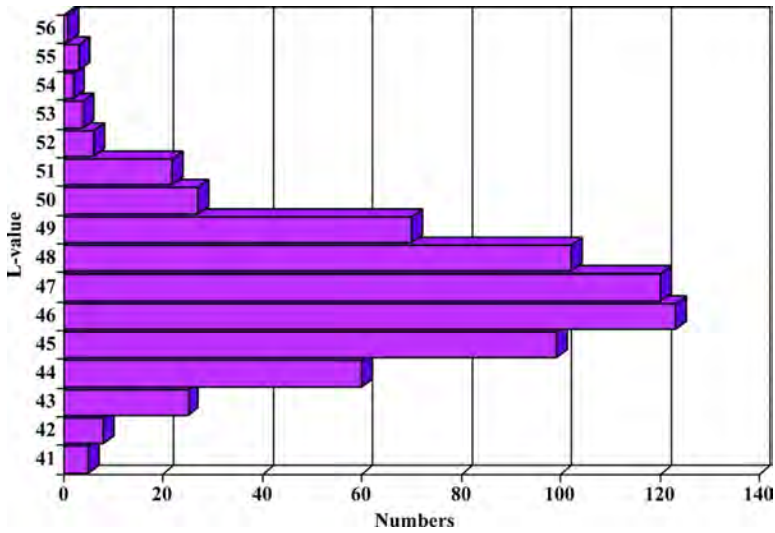


Figure 17.4.7.5 A histogram of L value distributions of breast meat colour in 700 chicken broilers. From Barbut (1998b). With permission.

When it comes to further processing, dealing with a high percentage of PSE meat can be a challenge. Some processors use unsorted meat in large batches (combos) to produce certain products. In the case of a product made out of small pieces (ground/chopped) this would not be a large problem so long as the proportion of PSE meat is low (e.g., < 20%). Mixing is actually one of the solutions to mask the effects of PSE meat (i.e., diluted effect). However, in a product made from large whole muscle pieces (e.g., oven roasted turkey breast injected with brine; see recipe in Chapter 13), the inclusion of PSE meat will result in excessive water release during cooking. In this case, presorting can be a solution. To sort, one needs to establish cutoffs suitable for specific production needs (e.g., requirements for water holding, texture). McCurdy et al. (1996) demonstrated how this could be done. They published a table with L* cutoff values for achieving WHC of 17, 20 and 23%. The corresponding L* values for the spring season were 52.0, 50.9 and 51.3 respectively. Values were also reported for meat obtained during the other three seasons (see Fig. 17.4.7.3) as well as to achieve certain textural characteristics (i.e., maximum compression force of cylindrical cooked meat samples). The important point is that such cutoffs can be established by meat processors to accommodate for their raw meat selection criteria, product formulation, and/or specific preparation method (e.g., injection rate, tumbling time). Overall, employing a grading system based on meat quality rather than the current one that is mainly based on aesthetic

factors (e.g., skin discolouration, bruises, missing parts, confirmation) would be a useful tool to grade meat according to functional properties (e.g., water holding capacity, texture).

White striation is another phenomena that can also be seen today in young broiler's breast meat fillets (i.e., in the past it was associated with older laying hens or mature turkeys). The consumer will see striation on the anterior part of the skinless fillet, and their intensity can vary among individual samples. The problem is related to necrosis of muscle fibers, possibly due to fast growing rate and poor blood supply to the peripheral areas, and filling the spaces with fat and connective tissue (Kuttappan et al., 2013)

17.4.8 Colour Defects and Other Issues Related to Poultry and Red Meat

Looking at a food product is the first step in the consumer decision making process. If at this initial stage customers decide that they do not like the product, there is little that can be done to change their mind. The meat industry faces several challenges when it comes to the colour of fresh meat and processed products. In fresh meat, challenges include the meat being too light (PSE; discussed before), too dark (DFD meat), blood splashes, and discolouration (e.g., greening) of the muscle due to microbial activity. In addition, uneven colouring of meat pieces/fillets placed on the same tray can be considered a problem by the consumer. In cooked products, colour problems can range from nitrate burns to pinkness in traditionally white products (e.g., poultry breast meat). Other problems can develop over storage time; for example, colours can fade or off colours can be produced by microorganisms breaking the heme ring in myoglobin and/or producing certain pigments. Several examples are presented in the section below followed by an explanation of the cause and a potential solution.

a. Hemorrhages and blood splashes – occur due to a blood vessel rupture and are related to muscle injury (e.g., bruising, bone dislocation). Large bruises are usually trimmed/removed at the processing plant. Injury can happen at different stages of the animal's life. During the growing period, animals housed in barns can be bruised/injured by sharp objects, fighting, or even sitting down for a long period (which can create blisters). During catching and transportation there is an even greater risk of injury, including when the animals are loaded and unloaded (see Chapter 4). Susceptibility to hemorrhaging can be increased by moldy feed that contains mycotoxins at a level as low as 5 ppm (Froning, 1995), which cause a weakening of blood vessels. Determining the time of injury is not always an easy task. In general, red bruises indicate recent injuries and brownish grey

discolourations, on the surface, can indicate older bruises. However, in order to precisely determine the cause of the bruise, a histological study is needed. This process involves looking at the distribution of red and white blood cells around the bruise (see discussion in Chapter 4, including staining methods). Determining the time of the injury will help with identify and correct the problem. During injury, cellular components are released into the tissue and cause a physiological or pathological response by triggering an inflammatory response and/or a blood clot. During the process, coagulation factors (e.g., thromboplastin) can cause localized or vascular coagulation and the breakdown of cell membranes releases enzymes such as of proteases and lipases that destabilize other cells.

The hemoglobin content in muscle showing different types of hemorrhaging was reported by Kranen et al. (1999). *Adductor* muscles with ecchymosis (a blood spot of several square mm) contained a hemoglobin concentration between 6.5 to 9.9 mg/g of tissue. Table 17.4.4.1 indicates that the average hemoglobin level is 0.83 mg/g (i.e., tenfold lower than injured tissue). In the *pectineus*, blood stains (described by the authors as a small straightened hemorrhage) contained hemoglobin levels of 0.12 mg/g as compared to hemorrhage-free muscle with 0.09 mg/g hemoglobin (Table 17.4.4.1). In the *Sartorius*, levels of 0.75 to 4.61 mg/g of hemoglobin were seen in bruised muscle as compared to 0.67 mg/g in hemorrhage-free muscles.

Processing conditions such as electrical stunning at high voltage can also increase the rate of hemorrhages as was discussed in Chapter 8. This can be due to severe muscle contraction and physical rupture of blood vessels that later result in blood splashes or what is called a "gunshoot" pattern. Problems, such as blood splashes, that are seen in fresh meat will be exaggerated in the cooked product (e.g., dark spots in a white oven roasted chicken breast).

b. Bone darkening – sometimes seen in young animals after cooking, this phenomenon can be induced by freezing the meat. After thawing, the muscle around the bone may have a dark/bloody appearance because some bone marrow was squeezed out from the porous bone structure. Later, during cooking, the hemoglobin component of the marrow is denatured (see Fig. 17.4.4.2) and forms a dark discolouration. The problem is more commonly seen around bone ends in the knee, wing, and leg joint areas. The problem is aesthetically unpleasing but does not present a health risk.

c. Discolouring due to microbial activity (e.g., greening, yellowing) – Discolouring due to microbial activity (e.g., greening, yellowing) – can be the result of microorganisms breaking the porphyrin (heme) ring of myoglobin or

producing water soluble pigments. This problem in non cured products usually develops over storage time. An example is the growth of *Streptococcus faecium* subspecies *casseliflavus* in vacuum packed meat, which initially appears as little yellow dots (areas of developing colonies) but later can cover the whole surface of the meat and have the appearance of a layer of mustard (Fig. 17.4.8.1).

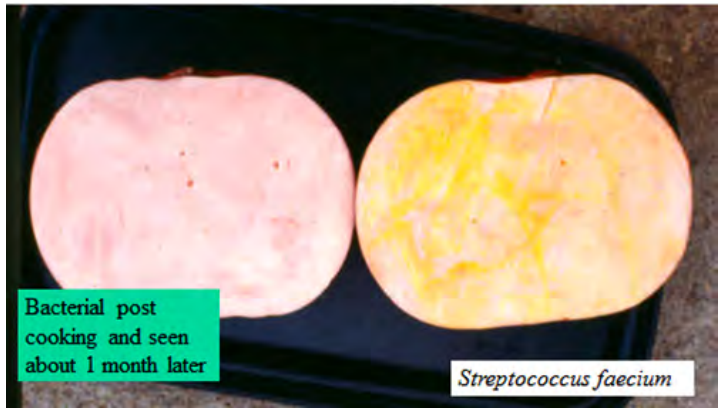


Figure 17.4.8.1 Yellow pigment formation on meat due to microorganisms. Photo by S. Barbut.

Such a discolouration makes the product unappealing and potentially dangerous to consume. In the case of the *Streptococci*, the contamination usually takes place after cooking because the microorganism is fairly heat sensitive and is destroyed by normal cooking procedures (Whiteley and D'Sousa, 1989). Cross-contamination by slicing equipment, handling of the meat, and/or contaminated air can spread the microorganism to different packages. At refrigerated temperature it takes a few weeks for the bacteria to develop. Note that such post cooking contamination can also represent a big safety issue when a pathogen such as *Listeria monocytogenes* is involved as was the case of a big outbreak in the USA in the 1990s.

Green colour has been reported when microorganisms such as *Pseudomonas fluorescence* grow and produce a shiny, transparent, greenish exudate, mainly due to myoglobin breakdown. This is not a common problem, but is more common than the yellow colour described above. The greenish appearance is sometimes mistaken as an iridescence problem (Swatland, 1984). It can be distinguished from an iridescence problem by rotating the product 90°; if the greenish colour does not disappear, then the problem is likely microbial. If the colour does disappear, the problem is likely related to iridescence (see discussion below).

In cooked products the appearance of a so-called "green ring" can indicate an improper cooking procedure. A green core in the middle of a sausage indicates that the target internal cooking temperature was not reached and spoilage microorganisms capable of breaking down the heme pigment are still active. This kind of discolouration is irreversible (see Fig. 17.4.4.2). The appearance of a green colour on the peripheral part of a cooked sausage might indicate the use of meat with a high microbial load. In such a case, the microorganisms might have degraded the heme pigment even before the cooking operation started.

d. Green discolouration of fresh meat seen during the deboning process – also called "green muscle disease", this problem is sometimes seen in the interior of chicken/turkey breast meat. The scientific name is deep pectoral myopathy and results from the necrosis or death of muscle fibers in the interior part of the muscle in the live animals (Sosnicki and Wilson, 1992). In the past it was more commonly seen in heavy turkeys, however, today the problem is also seen in young broilers (Petracci et al., 2009). It might be that some breeds are more susceptible to it, and that certain growing conditions (e.g., thinning towards the end of the growing period) result in higher incidences (Kijowski et al., 2014). Some researchers suggest that selection for increased body/muscle size may have altered blood flow to the deep pectoral muscle. On the processing line, affected birds usually show a sunken area on one side of the breast that, upon cutting, reveals an initial pinkish discolouration which later (in a few days) will change to greenish discolouration. In certain areas the necrotic zone hardens after being filled with fat and connective tissue, a condition referred to as "wooden breast" syndrome.

e. White spots on a fresh meat cut – can appear after a few days of refrigerated storage as a result of microbial growth on the surface and is sometimes associated with a bad smell. Since the problem arises from bacteria and yeast growth, using a microscope to look at the microflora can be a quick way to identify the microorganism. This can be done by aseptically removing a colony and spreading it on a glass slide. If the organisms show budding they are most likely yeast cells. If they are small and rod shaped, they are most likely *Lactobacilli*. A follow up Gram stain can further help in the identification (Russell, 2006). Again, good sanitation during the process is a key factor in eliminating the problem. As well, identifying where the contamination occurred will help to solve the problem.

f. Iridescence – usually appears as green-orangey colour on the surfaces of meat (Figure 17.4.8.2). It can be seen in fresh or cooked meat slices and is the result of white light spitting to its components. The exact mechanism is not fully understood, but it is known that certain muscle structures can cause more optical diffraction than others (Swatland, 1984; Lawrence et al., 2002).

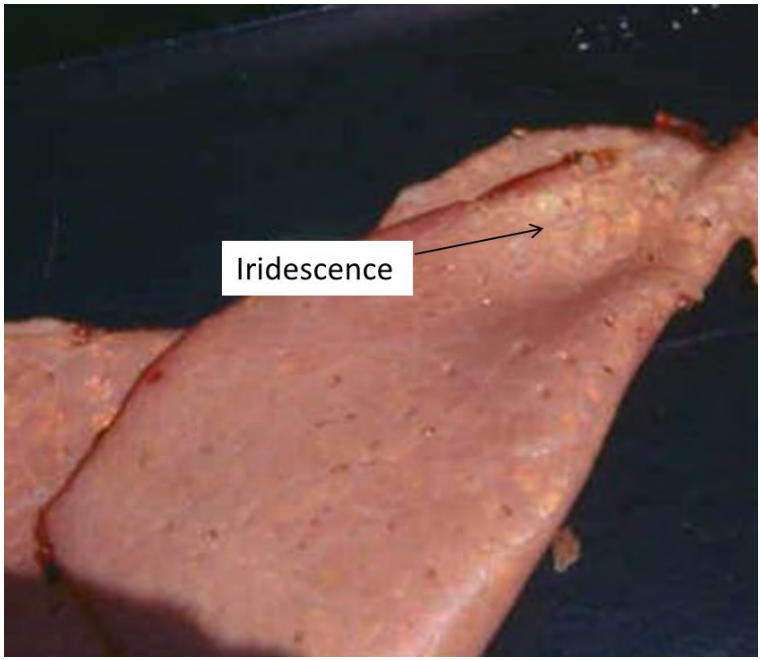


Figure 17.4.8.2 Iridescence on the surface of sliced cured meat. Photo by S. Barbut.

The processor can reduce or even eliminate the problem by using a dull knife instead of a sharp knife. However, using a sharp blade is recommended to maintain high product quality and to avoid tearing the product. The fact that using a dull knife can "eliminate" the problem indicates that a smooth surface structure must be present to cause iridescence. Some reports suggest that the use of high phosphate levels can exaggerate the problem (Wang, 1991). One can use scientific tools to evaluate the spectral emissions of iridescent samples where the greenness has an almost monochromatic purity of colour. Conversely, greening due to microbial activity will show broader spectra typical of heme pigment degradation (Swatland, 1984). As indicated above, distinguishing between green discolouration caused by microorganisms and by physical structure can also be performed by rotating the product 90° and observing if the colour disappears. If it disappears, it was caused by the unique physical structure of the cut muscle surface.

g. Nitrite burn – seen as intense pink areas surrounded by light pink areas in a cured meat product. This can be the result of uneven brine injection in a whole muscle product (e.g., blocked needles in the injector or excessive pressure that causes an uneven distribution of brine). This visual defect can be accompanied

by areas that were not cured at all or by poor distribution of nitrite in both whole muscle and ground meat products (e.g., the no/low nitrite areas showing the typical brown denatured myoglobin colour). The appearance of nitrite burn usually also indicates that other ingredients, such as salt and spices, have not been evenly distributed. However, nitrite is the most critical ingredient for even distribution as it is an anti- *C. botulinum* agent.

h. Pinkness of typically white meat products – a phenomenon sometimes seen in cooked poultry breast meat as pink strips/patches or an overall pink colour. The problem can be formed by two different mechanisms. The first was already mentioned and is referred to as persistent pinking (AMSA, 2012) and the second is due to low nitrite contamination. These products are often rejected by consumers, who suspect that the product has not been properly cooked. Maga (1994) indicated that "one of the interesting phenomena associated with this problem is its very sporadic and random occurrence among carcasses processed in apparently the same manner. Thus, by the time the problem is detected and various changes are made in production and/or processing, the problem has usually disappeared, and one is not sure as to which variable was responsible". However, since this problem tends to come in cycles, it is important to find the cause. Holownia et al. (2003) reviewed the topic and described a number of factors that can be involved in the pinking caused by low nitrite levels getting into the product, and result in different manifestations of the problem (e.g., pinkness throughout the product, in the seams among muscle chunks, around the product's perimeter). In most cases one of the most common causes is nitrite contamination. Heaton et al. (2000) reported that the minimum nitrite level required to cause detectable pinking in turkey breast meat roll was 2 ppm, for chicken 1 ppm, for pork 4 ppm, and for beef 14 ppm. The nitrite can come from the water used in the plant, the spice mix, gases discharged from the truck hauling the live birds, and from gas-fired ovens. Nitrite in the water can be a problem in certain agricultural areas (i.e., where nitrogen fertilizers are used). Therefore, it is recommended that processing plants monitor the nitrite levels on a routine basis and, if needed, install special filters to remove nitrite or at least nitrite in water used to process white meat products.

In the case of persistent pinking, an important factor can be the pH of the meat system. Janky and Froning (1973) studied the effect of pH and several additives on turkey myoglobin denaturation in a model system. The type of myoglobin derivative had an effect on the amount of heat denatured pigment in the crude myoglobin extract system. Denaturation increased when the pH was lowered using sodium erythorbate (i.e., commonly used as a curing accelerator; Chapter 13). On the other hand, sodium tripolyphosphate increased the heat stability of myoglobin by increasing the pH of the model system. This was believed to be due

to the increased polarity charge on the iron of the heme group. Ahn and Maurer (1990) studied the heme-complex-forming reactions of myoglobin, hemoglobin, and cytochrome C (molecular weight of around 12,500 Da with a structure similar to myoglobin). They reported that naturally present ligands such as histidine, cysteine, methionine, or their side chains formed solubilized protein complexes with hemoglobin. They also reported that a high pH (> 6.4) was favorable for the heme-complex-forming reactions of myoglobin and hemoglobin with most naturally present ligands (histidine, cysteine, methionine, nicotinamide, and solubilized proteins).

Additives such as salt, phosphate, and non-fat dried milk can also affect pinking. It has been reported that salt added at 2.5% significantly decreased the heat stability of myoglobin and hemoglobin at 68 and 74°C, respectively, while increasing the heat stability of cytochrome C (Slesinski et al., 2000; Ahn and Maurer, 1989). Sodium tripolyphosphate salt (0.5%) added to meat heated to 68, 74, 80 and 85°C, increased the heat stability of myoglobin but decreased the heat stability of cytochrome C due to the pH increase. Dextrose increased the stability of hemoglobin at 68°C and cytochrome C at 85°C, but not myoglobin. Overall, the authors indicated that adding salt and phosphate decreased oxidation-reduction potentials and that these changes could have a strong effect on cooked turkey breast meat pinkness, particularly if the oxidation-reduction potential of the meat is around +90 mV or -50 mV. Dobson and Cornforth (1992) reported that pink discolouration in turkey rolls could be prevented by adding 3% dried milk solids. They indicated that reactive sulfhydryls or other protein side chains in the non-fat dried milk might have raised the oxidation-reduction potential, thereby preventing complexing between heme and the denatured proteins. They also indicated that casein micelles in the non-fat dried milk might mask the meat pigments.

Froning (1995) and later Holownia et al. (2003) indicated that cooking temperature and time can also play a major role in the pinking (determining the amount of undenatured pigment present in cooked meat). Research findings from both poultry and red meat indicate that the undenatured pigment in cooked meat is mainly oxymyoglobin. Cooking turkey rolls to various end-point temperatures using a rotary oven showed that pink colour problems increased when the end-point was below 71°C. Normally, the end-point temperature should exceed 71°C (e.g., the USDA requires a minimum temperature of 71.2°C for all fully cooked poultry meat products to destroy pathogens), but processing temperatures could fall below this target if not closely monitored. Froning (1995) further reported a problem with regenerated pink pigment appearing 2 hr after cooked meat samples had cooled. In that case oxymyoglobin was identified as the cause for the pink problem.

i. Colour fading – results in yellowish, colourless meat and can arise due to strong light exposure that oxidizes the porphyrin ring in meat pigment (see Fig. 17.4.4.2). The problem is usually more pronounced in cooked products packed in a clear package and presented in a display case. Certain light sources have a relatively high proportion of UV light (e.g., fluorescent; see earlier discussion in this chapter) and are known to be more damaging to the colour and cause faster fading than other light sources (e.g., incandescent). Overall, the meat product becomes lighter (higher L* value) and less red due to partial oxidation of the meat pigment.

In order to minimize this problem, retailers can rotate displayed packages, use a specially designed film to block some/all of the UV light, or use opaque packaging material with or without a small window. The latter might not work if the consumer is used to looking at the actual product. Protecting cured meat pigment can also be achieved by removing oxygen from the package and/or using antioxidants. Vitamin E is a common, natural antioxidant, and as such it can be incorporated into the animal's diet without any special labeling. Vitamin E is found in different plant materials where its function is to protect the plant from oxidation. Various researchers have reported the beneficial effects of vitamin E on preserving colour and flavour, and minimizing off-flavour formation by lipid oxidation in meat (Sheldon et al., 1997).

j. Freezer burn – appear as whitish grey areas caused by moisture loss (e.g., freeze drying) from the surface of uncovered/unprotected meat. The dehydration causes protein denaturation and discolouration. The problem can result from the use of an inappropriate wrapping material or holes in the packaging material. Besides discolouration, the meat in this area will be dry, tasteless, and may exhibit oxidative rancidity (described by consumers as old/stale flavour). Usually the colour becomes yellowish gray with a much higher b* value compared to the raw product. The a* value can also increase by 50%, probably as a result of concentrating the meat pigment. The physical characteristics of the packaging material are very important. Overall, the film should be moisture proof and ideally stretchable so that it can come in close contact with the meat (e.g., vacuum packaging is very popular in the meat industry). Having a tight package is important because it prevents water evaporation and ice accumulation inside the bag. It also ensures faster freezing by eliminating insulating air.

k. Slimy appearance – can be seen on the surface of the product and is the result of microorganisms capable of producing carbohydrate polymer chains to protect themselves (see also Chapter 15). Among the microorganisms that can be isolated in this case are the lactic acid bacteria of the genera *Lactobacillus, Enterococcus, Weissella* and *B. thermosphacta*. Slime formation is favored by moist surfaces and

is usually confined to outer surfaces/casings (Jay et al., 2005). Therefore, producers of cooked products are adding ingredients, such as whey proteins, that can bind the moisture and prevent exudate in the package. This is especially important in vacuum packaged goods where there is a physical force drawing moisture out of the product.

l. Greening of cured products – is usually caused by H_2O_2 and H_2S production in cooked products. In cooked products, both chemicals can interact with the nitrosohemochrome and oxidize the porphyrin rings. By doing so, the colour is changed from pink to green. As indicated before for non cured products, the greening can appear as a green core on the surface or throughout the product. A green core can appear after an aerobically stored product is sliced and exposed to air. It usually indicates inappropriate cooking temperature where the desired internal temperature has not been achieved and microorganisms capable of producing H_2O_2 or H_2S have survived. An outer green ring usually indicates high contamination levels of the meat surface or the casings. Some of the most common microorganisms known to cause H_2O_2 production in processed meats are *Weissella viridescens, Leuconostocs, Enterococcus faecium* and *Enterococcus faecalis*.

Greening of vacuum packed meat stored at refrigerated temperatures is usually caused by H_2S production, where the H_2S reacts with myoglobin to form sulphmyoglobin. The main microorganism responsible for this is *Pseudomonas mephitica.* The H_2S is usually formed by the degradation of the cystine amino acid, which contains sulfur. The green colour usually appears when the microorganisms reach $10^7/cm^2$ (Jay et al., 2005). As indicated before, internal green patches in freshly slaughtered turkey meat have also been reported. However, in this case, the problem is attributed to deep-muscle-myopathy caused by the death of muscle fibers at these regions, and not related to bacterial spoilage. The problem is associated with the fast growth of the breast muscle in the modern turkey and the inadequate development of blood supply.

m. Off odours – The spoilage of vacuum packaged meat products and the production of off odours, flavours, and colour is usually the result of metabolites produced by microorganisms. Long chain fatty acids cleaved into short chains can often be the byproducts of *Lactobacilli* and *B. thermosphacta* activity, and result in offensive off odours. Acetone and diacetyl have been reported to be the most significant compounds responsible for the off odour of vacuum packaged luncheon meat.

In fresh vacuum packaged products, the production of sulphide odours can be the result of *Pseudomonas* and *H. alvei* activity. The sulphide smell usually is evident when the number of microorganisms reaches 10^7-10^8/cm^2, which usually indicates extensive proteolysis by microorganisms using amino acids as an energy source. Slime formation can also be evident as was already discussed. Jay et al. (2005) reviewed some of the volatiles produced by bacteria causing spoilage of fresh and irradiated chicken. They have identified dimethyl disulfide, methyl mercaptan, H_2S, methanol and ethanol as the main compounds.

Spoilage of further processed, cooked poultry products can result from high microbial loads on the fresh meat, spices and casings contamination (especially natural casings). If inappropriate production procedures (e.g., warm temperature) are used, the shelf life may be significantly shortened. Examples of bacteria that can contribute to putrid off odours include *Pseudomonas* and lactic acid bacteria (see previous paragraph).

n. Souring – can occur in stored, cooked meats due to the growth of *Lactobacilli, B. thermosphacta* and *Enterococci* which are capable of fermenting different sugars (usually added to the product as milk ingredients or sugars). The microorganisms use the carbohydrates as an energy source and convert them into acids that cause souring. Processed meat products commonly contain a fairly varied microflora because of the different spices and other non-meat ingredients added. Therefore, if inadequate sanitation, quality control, cooking and cooling are not employed, on a continuous basis, a variety of problems can arise.

o. Gas production – Gas production in vacuum packaged sliced meats is usually the result of bacteria from the Clostridium family growing in the product. The meat is then unfit for human consumption. The main gas is CO_2 which is a water and lipid soluble gas and has some bacteriostatic effect. In a packaged meat system, the following chemical reactions can occur:

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow HCO_3 + H^+$$

The proportion of the carbonic acid which is produced in stored meat is related to factors such as temperature and pH (Jay et al., 2005).

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18

WASTE TREATMENT AND BY-PRODUCTS

18.1 Introduction

The food industry is facing increased pressure to reduce waste and become more efficient at recovering by-products. The term "agricultural waste" is used to describe residues that result from diverse agricultural activities such as the planting and harvesting of field crops, the production of milk and animals for slaughter, and the operation of feedlots. With regards to the meat industry, animal waste may be defined as carcasses or animal parts that are not intended for direct human consumption (Commission of the European Communities, 1990). Examples of poultry industry by-products include offal, bone, blood, viscera, feet and feathers but in certain regions these may be considered mainstream products (e.g., chicken feet/paws). Twenty to thirty years ago, meat that remained after automated or manual deboning was not harvested. Today, this is accomplished by mechanical deboners (as described in previous chapters) and the resulting meat is used as a major ingredient in emulsion-type meat products (e.g., bologna, frankfurters) and as a minor ingredient in ground meat products (e.g., sausages). The main by-products and wastes generated during the primary processing of poultry are shown in Figure 18.1.1.

An important driver behind finding better waste management solutions is the current global discussion regarding environmental preservation. Other major drivers include high land field fees in crowded urban areas and surcharges on waste water with high organic matter content. The meat industry generates a lot of waste water. Measuring its organic matter content is the first step in determining treatment(s) and estimating costs. There are several ways to measure and express the organic matter load: BOD_5 (biological oxygen demand); COD (chemical oxygen demand); total dissolved solids; suspended solids (SS); fats, oils and greases (FOG; these terms will be further explained below). Overall, meat processing effluents are high in nitrogen, phosphorus, solids, and BOD_5 levels (Table 18.1.1) and can potentially lead to eutrophication (Benka-Coker and Ojior,

1995; Arvanitoyannis and Ladas, 2008). It is often challenging to characterize the waste products of a typical plant because the load discharged varies seasonally, daily, or even hourly. Thus, a precise waste analysis is not simple.

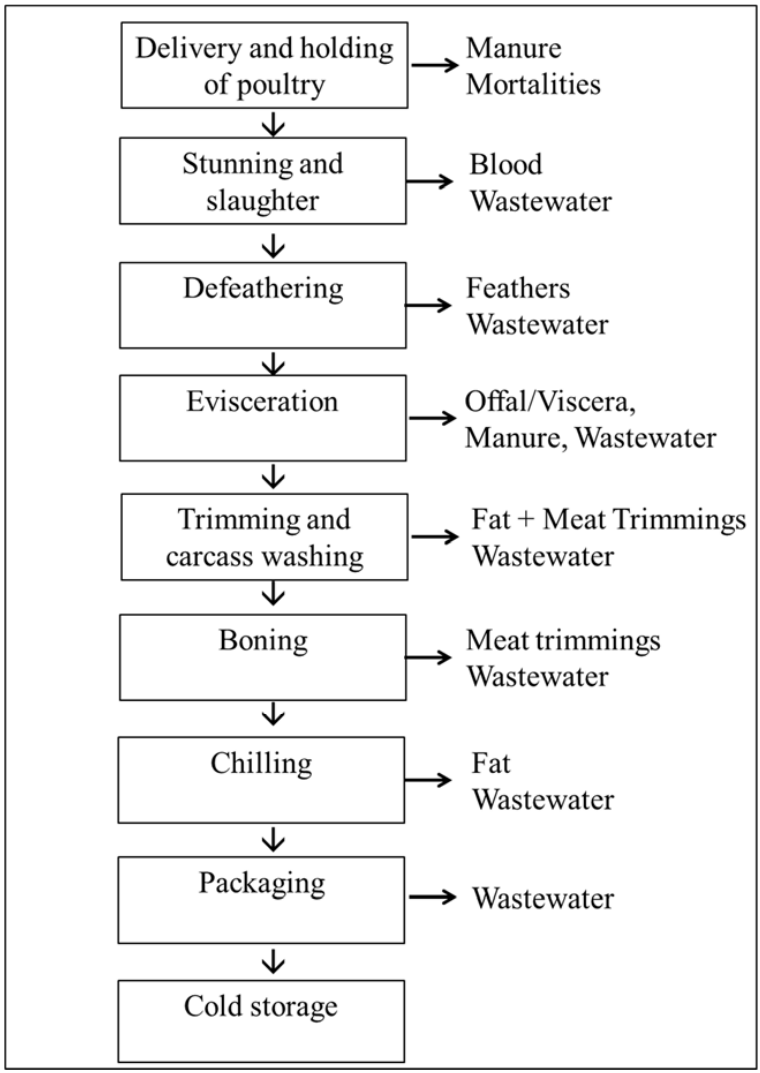


Figure 18.1.1 Overview of poultry meat processing operation and generation of by products and waste. Adapted from http://www.gpa.uq.edu.au/cleanprod/res/facts/fact7.htm.

Table 18.1.1 shows COD, BOD_5, TSS, VSS, and Total P values from four studies of abattoirs, all of which are at least several times higher than those of average domestic sewage. Such effluents cannot be directly discharged into the watershed (e.g., rivers, lakes) or even to a regular municipal sewage system. In order to reduce waste water surcharges, most medium and large meat processing plants have their own waste water treatment operation. Smaller plants, at the very least, have a primary means of filtering out some of the large materials (feathers, offal) and small meat pieces that contribute to high BOD values. Where there is an opportunity to recover and sell valuable commodities (e.g., feathers for feather meal, bedding, or ornamental fancy feathers), the industry will invest money in recovering and collecting the by-products in a more profitable way; see discussion below. Also note that meat/poultry by-products and wastes may contain up to 100 different species of microorganisms that are introduced when the feathers, feet, and intestinal contents are removed. These microorganisms include potential pathogens such as *Salmonella* sp., *Staphylococcus* sp., and *Clostridium* sp. (Salminen and Rintala, 2002).

Table 18.1.1. Characteristics of abattoir waste showing chemical oxygen demand (COD) of waste water, biological oxygen demand (BOD_5), total suspended solids (TSS), volatile suspended solids (VSS) and total phosphorous (P). Summary of data from Arvanitoyannis and Ladas (2008).

Source	COD ($mg\ L^{-1}$)	BOD_5 ($mg\ L^{-1}$)	TSS ($mg\ L^{-1}$)	VSS ($mg\ L^{-1}$)	Total P ($mg\ L^{-1}$)
1. Study 2002	2000-6200	1300-2300	850-6300	660-5250	15-40
2. Study 2003	5800	2200-9800	2400-9400	–	–
3. Study 2003	4000	1730	2580	1960	171
4. Study 2005	3980-7120	2030-4200	285-2660	–	54-92

Overall, by-product disposal is both a challenge and an opportunity for the meat industry. The goal is to sell the by-products (residual meat, bone residues, feathers) to outlets such as animal feed and pet food processors. It is expected that this trend will continue as the industry searches for more ways to increase the added value of by-products. To give the reader an idea of the size of the industry, the results of a 2010 North American survey are presented in Table 18.1.2. These quantities were derived from the annual processing of more than 55 billion pounds of poultry and 150 million head of cattle, hog and sheep (Jekanowski, 2011).

Water discharge from meat plants is a major issue because relatively high volumes are required to process each animal. The total potable water required to process a

single bird in the Netherlands varies between 5 and 20 liters (Veerkamp, 1999). In the USA, the amount required is higher, 22.7 liters (6 gallons; see Chapter 2 for trends over the past 20 years), due to the prevalence of water chilling. Avula et al. (2009) reported 26.5 liters/bird during primary and secondary processing and suggested ultrafiltration as a means of recycling water. This latter value is representative of several European operations. Overall, cleaning accounts for 30-50% of the total daily water consumption. Veerkamp (1999) discussed ways/processes to improve water use efficiency such as recycling the so called "red-water", using flat spray nozzles instead of showers, and using air rather than water chilling. More recently, innovations such as the Aero-scalder (which uses steam instead of water; see Chapter 5) have helped reduce water consumption in this operation by about 70%. However, the introduction of stricter microbiological standards has resulted in increased water requirements for the industry. Today, further reductions and increased recycling of water are becoming even more important as the cost of both fresh water (coming into the plant) and waste water disposal are steadily increasing all over the world. Water quality in terms of organic matter load, colour, and microbial count (including pathogens) is becoming an important issue. In several places the industry is already implementing new methods to recycle water (e.g., after a UV light treatment) in order to improve efficiency and reduce cost.

Table 18.1.2 Volume production of rendered proteins in Canada and USA in 2010. From Jekanowski (2011).

Type of Rendered Protein Product	Pounds	%
Ruminant meat and bone meal	2,853,257	30.9
Poultry by-product meal	1,744,176	18.9
Non-ruminant mammalian meat and bone meal	1,580,518	17.3
Mixed ruminant/non-ruminant meat and bone meal	1,403,261	15.2
Feather meal	673,147	7.3
Other proteins	491,209	5.3
Ruminant blood meal	240,150	2.6
Non-ruminant mammalian blood meal	234,162	2.5
Total	9,219,879	100%

The amount of animal by-product after selling the dressed bird or cut up portions is calculated as: carcass weight ÷ live weight x 100. Mountney (1989) reported expected yields of 77% for turkey broilers, 70% for chicken broilers, 58% for

Peking duck, and 78% for pheasant. Additional values are presented in Chapter 2. The leftover material (23 – 42%) is the amount of by-products and waste. Lortscher et al. (1957) reported that this portion can be divided into 17.5% offal, 7% feathers and 3.5% blood in the case of broilers, 12.5, 7 and 3.5% in turkeys and 17, 7 and 3% in fowl.

18.2 Waste Water Treatment

Meat processing plants generate a significant amount of waste water with a relatively high content of organic matter from protein, fat, and microorganisms. The processor must decide to treat the waste water or send it to a municipal sewage system (note: in recent years, many municipalities have refused to treat water with organic matter levels that are higher than the domestic sewage level). Therefore, it is in the best interest of the meat processor to treat the water, as much as possible, prior to sending the water to a municipal sewage system. The treatment can range from a simple filtration system to sophisticated aerobic lagoons. Overall, volume, capital, and operating costs determine the level to which a plant treats its waste.

The main steps of waste water treatment can be divided into:

a. Preliminary (e.g., screening of meat pieces, feathers)
b. Primary sedimentation
c. Secondary treatment (e.g., biological oxidation)
d. Secondary sedimentation
e. Tertiary treatment (e.g., filtration)
f. Disinfection (e.g., chlorination)
g. Sludge dewatering (receiving material from the secondary and tertiary treatments)

All of these steps will be described in more detail later in the chapter.

The processor may choose to install one or all of the components as shown in Figures 18.2.1 and 18.2.2. Cost analysis is the first step in determining the appropriate treatment. The numbers are based on capital expenditure, expected operational cost, volume of waste water, local and federal regulations, expected charges for waste water treatment by the municipality, and expected production figures for the plant. This is usually done by a qualified local consultant who can determine the scope of the operation required and provide accurate capital and operational costs.

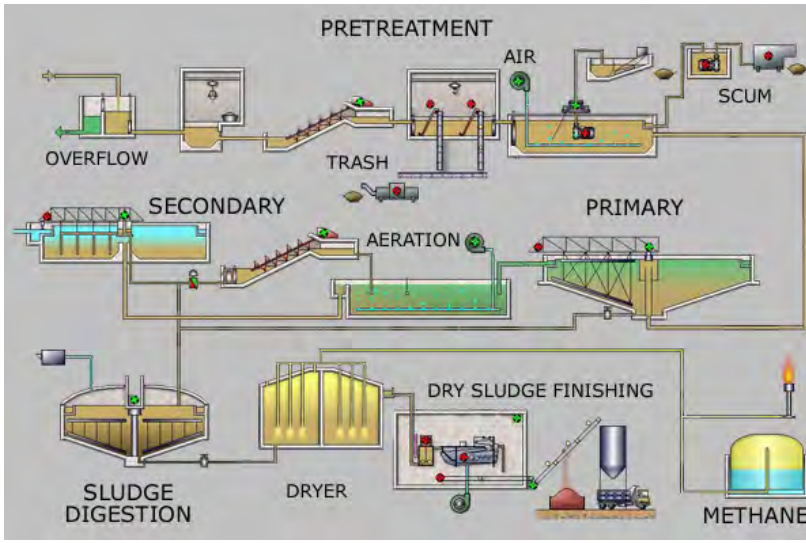


Figure 18.2.1 Illustration of steps involved in waste water treatment. A meat processor may choose to install all/several steps. From Wikipedia.



Figure 18.2.2 Aerial picture of a waste water treatment plant. From http://www.mewr.alexu.edu.eg/.

The main terms and criteria used to calculate surcharges for waste water treatment are listed below.

a. Biological oxygen demand (BOD) is a semi-quantitative measure of organic content in waste water. It is used to estimate the amount of oxygen required for microbial degradation of the affluent. BOD_5 refers to the amount of oxygen (in ppm) required to decompose the organic matter by aerobic microorganisms in a waste water sample over a five day period. Note that the decomposition can take more than five days, but this is a common index (Carawan et al., 1979). Table 18.1.1 shows abattoir waste water values ranging from 1,300 to 9,800 ppm with a more common value around 2,000 ppm. Earlier, Parker and Litchfield (1962) estimated that waste water from meat processing plants have a BOD_5 of 1,100 ppm. Packing house and stockyard waste water usually have a BOD_5 value of 600 and domestic sewage that contains no industrial waste has a value of approximately 200 ppm.
b. Chemical oxygen demand (COD) measures pollution by using a strong oxidizing compound, orange dichromate, while maintaining the reaction at a high temperature. In acidic conditions orange dichromate, $K_2Cr_2O_7$, oxidizes organic matter and turns into a green chromium ion via acid reflux. This is a faster method than BOD (about 2 hrs) and also measures non-degradable organic compounds such as cleaning solvents. Although there is some overlap with the BOD_5, regulatory agencies will not usually accept COD data unless it is reported as a COD/BOD ratio (note: values can also vary from site to site due to changes in waste water characteristics).
c. Total solids (TS) is a measure of the combined organic and inorganic matter in waste water. It is measured by gentle drying of a known volume of waste water in a predetermined volume of a crucible.
d. Total suspended solids (TSS) measures the total non-filterable residue that is retained by a membrane filter (glass or fiber) when filtering a predetermined volume of waste water. The solids are then dried for an hour at a temperature of about 103°C. Parker and Litchfield (1962) reported values of about 820 mg/L for waste water from meat plants and about 600 mg/L for waste water from packing houses and stockyards.
e. Total organic carbon (TOC) determines the amount of CO_2 released from a catalytic oxidation at 900°C. This is a very fast method that correlates fairly well with the standard BOD_5, but it requires a sophisticated laboratory set up.
f. Total oxygen demand (TOD) measures the amount of oxygen required for combustion of all the material in a water sample at 900°C.
g. Dissolved oxygen (DO) determines the amount of oxygen in the waste water by an electrode or by an iodometric titration. This is important during secondary treatment (usually done in an aerated lagoon during the biological oxidation step; see below).

h. Fat, oil and grease (FOG) are extracted with an organic solvent, separated, and then heated to evaporate the solvent. Values are reported as mg/L.

Overall, waste water treatment follows a logical sequence that starts with crude screening to remove large particulates (e.g., feathers, meat particles) and ends with breaking down dissolved organic matter (nanometer size) by microorganisms (Figure 18.2.3). Below is an explanation of the required steps.

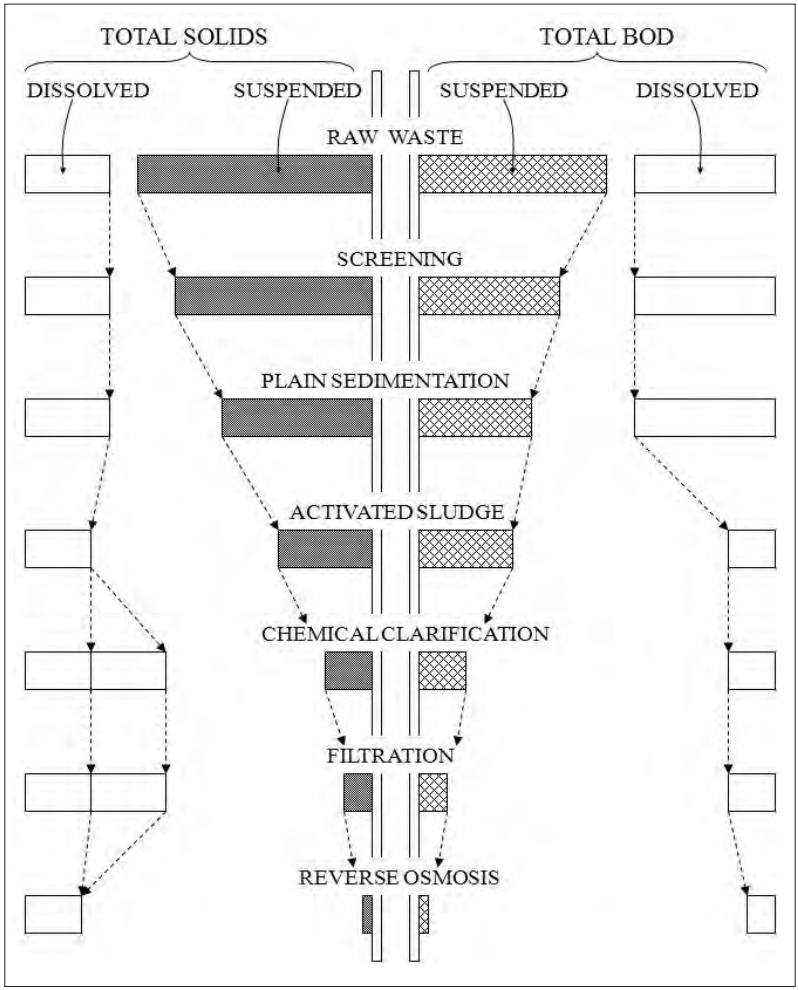


Figure 18.2.3 Diagram showing the relative effectiveness of reducing total solids and BOD by the different treatments. Redrawn from Hill (1976).

Preliminary treatment – first, screening is an efficient and inexpensive step designed to remove large particles by using a coarse screen that detains large particles such as meat pieces and feathers. This step also protects downstream machinery. Figure 18.2.4 shows a simple device used for screening. As simple as it looks, such a system is extremely useful in substantially reducing the BOD_5 value because it removes large pieces of organic matter. A second, smaller screen can follow the first. The collected solids are usually dewatered by compression and then sent to a rendering plant or landfill for solid waste disposal. It is in the best interest of the processor to remove organic matter as quickly as possible; i.e., before microbial degradation/fermentation and odour production takes place (Green and Kramer, 1979). If composting is to be used, it is important that the right group(s) of microorganisms are used for fast and efficient degradation.

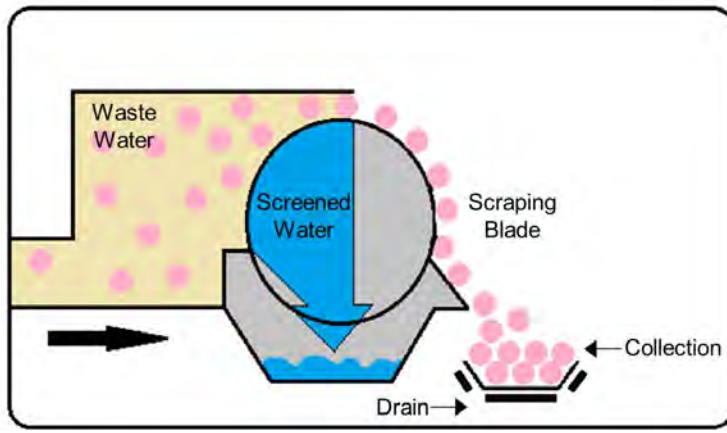


Figure 18.2.4 A self-cleaning rotary screen used as pretreatment of waste water discharge to separate solids (e.g., feathers, meat scraps) from water.

Screening is also used at the plant for items such as feathers, which are removed during the picking operation with the help of a water wash. Feathers can pick up 10-15% water during the scalding and de-feathering processes. Dewatering them by compression/centrifugation is also an easy and economical way to reduce handling and transportation costs.

Primary treatment – is used to remove small particles from the water. Relatively inexpensive equipment can be used to effectively separate the particles by weight through the sedimentation of heavy particles and flotation of light particles such as

oil and grease. An example of a procedure where a combination of sedimentation and flotation are used is shown in Figure 18.2.5. It takes longer for particles to settle as compared to mechanical screening. The particles that sink to the bottom are scraped away by a moving belt equipped with paddles and are collected in a lower pit that can be cleared by a pump. Compounds such as lime, alum, ferric sulphite, and synthetic polymers can be used to speed up solid separation. As shown in Figure 18.2.3, sedimentation can remove a substantial amount of particulate matter and reduce the BOD by about one third. Flotation to separate out fat and liquid oil is fairly simple. Also, there are chemicals and physical means (e.g., air bubbles coming from the bottom) that promote flocculation and can speed up the process. Floating particles are skimmed off the top. Over the past 20 years the agro-food industry has attempted to improve organic matter separation through new inorganic and organic coagulants (Aguilar et al., 2005). Effectiveness also depends on the composition of the waste water, temperature, the rate of mixing, and the order in which coagulants/flocculants are introduced. When dissolved in waste water flocculants may be either ionized (called soluble polyelectrolytes) or non-ionized (Arvanitoyannis and Ladas, 2008; Henze et al., 2008). The main advantage of using flocculants is that energy cost is fairly low since gravity and flotation are used.

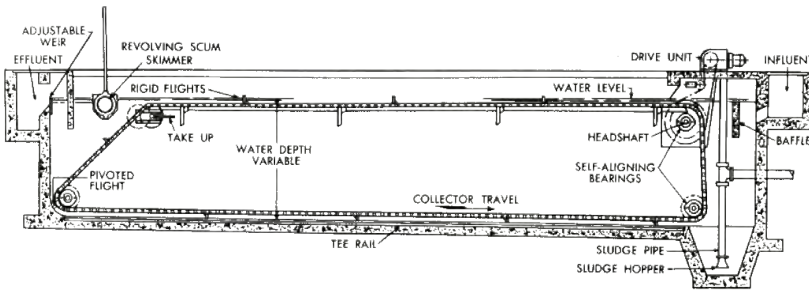


Figure 18.2.5 Primary waste water treatment showing sedimented sludge scraped to a pit at the bottom, while floating material (e.g., fat, feathers) is skimmed off at the top. Courtesy of Envirex Inc.

Overall, coagulation and flocculation are used to remove colloidal material. The major goal of these treatments is to capture small organic particles. The process can result in a 75–80% BOD_5 reduction and has the additional advantage of removing large quantities of nitrogen and phosphorus from the waste water. The efficiency of the process can be studied by comparing the particle size distribution before

and after the addition of a coagulant (Aguilar et al., 2005). Examples of specific coagulants include $Fe_2(SO_4)_3$, $Al_2(SO_4)_3$, and anionic polyacrylamides (AP) such as $Fe_2(SO_4)_3$ + AP, and $Al_2(SO_4)_3$ + AP polyelectrolyte.

Secondary treatment – is achieved through biological means and relies on the breakdown of dissolved organic matter by microorganisms. Such a treatment can range from aerobic or anaerobic lagoons to advanced activated sludge processes. The suspended organic matter is digested by microorganisms that metabolize it as an energy source. During the process, organic matter is captured by bacteria, metabolized, and some is released as gas (e.g., CO_2) and water. The microorganism biomass is later filtered out of the water in a much more cost-effective way than it would have been to filter out the dissolved organic matter (e.g., via ultra-filtration or reverse osmosis). In a typical aerobic activated sludge system (Fig. 18.2.6), a floating mechanical aerator is used to introduce oxygen into the water. Aerobic lagoons can be up to 3 m deep. The introduction of oxygen enhances biological oxidation and maintains an environment of dissolved oxygen in the range of 1-3 mg/L. The aerator also helps to keep the solids suspended (Marriott, 1999). As shown in Figure 18.2.3, the reduction in BOD after this point can be around 70% of the incoming waste water. The solid sludge can be transported to a landfill or used as a fertilizer while the remaining water is processed in a so-called polishing pond or sand filter.

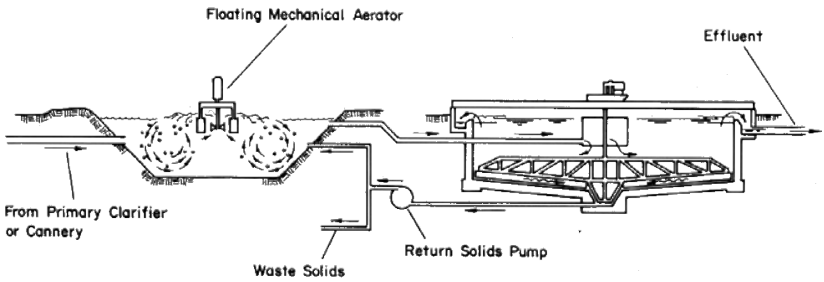


Figure 18.2.6 Secondary treatment – a re-circulating surface aerator feeding into an activated sludge system which contains aerobic microorganisms digesting dissolved organic matter. From Hill (1976).

Another option is to use anaerobic microorganisms where no oxygen is introduced. In a similar process to the aerobic lagoons, the organic matter in the water is utilized while biomass, gases (e.g., CO_2, CH_4), and water are produced. Construction of an anaerobic lagoon requires relatively low capital investment for the typical 1 to 3 m deep lagoons and operating costs are minimal since no agitation devices or air

bubbling equipment is required. Loading rates are usually in the range of 250-1,100 kg/hectare/day, where temperature is an important factor in determining the rate of organic matter loading capacity. When the temperature is ≥ 22°C, a BOD_5 reduction efficiency of 60-80% can be expected within 0.5-3 weeks (Marriott, 1999). Significant attention has recently been given to biogas production (e.g., methane) and its recovery as a renewable energy source. Anaerobic treatment is one of the major biological waste treatment processes used for the production of these gases. Salminen and Rintala (2002) studied the effect of hydrolic retention time (HRT) and loading on anaerobic digestion of poultry slaughterhouse wastes using a semi-continuously fed laboratory-scale digester at 31°C. Anaerobic digestion appeared feasible with loading up to 0.8 kg volatile solids (VS) m^{-3} day^{-1} and an HRT of 50–100 days. The specific methane yield was high, ranging from 0.52 to 0.55 m^{-3} kg^{-1}. On the contrary, at a higher loading (1.0 to 2.1 kg VS $m^{-3}day^{-1}$), the process was inhibited or overloaded. Arvanitoyannis and Ladas (2008) compared results from 12 studies dealing with anaerobic treatment of slaughterhouse waste water and also showed that the percentage of organic matter removal varies depending on the loading rate and reactor type. Overall, they reported 30-95% removal of organic matter with an average of 75%. They concluded that anaerobic digestion is an effective process for the treatment of slaughterhouse waste water but that one should be careful in selecting conditions.

Aerobic digestion in ponds remains the main form of biological treatment for removing soluble organic matter. Overall, a number of secondary biological systems are currently used (e.g., trickling filters, activated sludge systems). Trickling filter treatment is a relatively simple configuration where water flows over a stationary media, such as recycled tires and rocks, that is arranged in such a way that aeration is achieved by exposure to a large air surface. The microorganisms are attached to the rough surface of the media (e.g., plastic media, rocks) while the recirculating water trickles from above. After a certain number of cycles, the water passes through a clarifier to help collect the biomass.

Biological degradation is the main technology that makes use of microbes to oxidize and decompose the solute or suspended protein, fat, and carbohydrates. Furthermore, aerobic treatments are very effective at reducing odours and pathogens. As indicated above, aerobic treatments include aerobic lagoons, activated sludge processes, oxidation ditches, sequencing batch reactors (SBRs), trickling filters and rotating biological contactors are used for this purpose (Mittal, 2006).

Tertiary treatment – is one of the last phases and is applied to remove odours, flavouring compounds, and colour. A series of filtrations through coarse, then

medium, then fine gravel/sand (Fig. 18.2.7) is common for the separation and removal of small colour and odour compounds. Activated charcoal or carbon can also be used to remove these compounds since they have a high affinity for organic matter. The activated carbon should be replaced on a regular basis because it becomes ineffective after reaching a maximum load capacity. Sand filters are cleaned on a regular basis by back flushing. It is common to have a series of filters so that some stay in operation while others are being cleaned. A tertiary waste water treatment can also include an ion exchange unit (similar to a residential water softener) or an electro-dialysis unit where minerals (e.g., salt from a meat plant brine) are removed/exchanged.

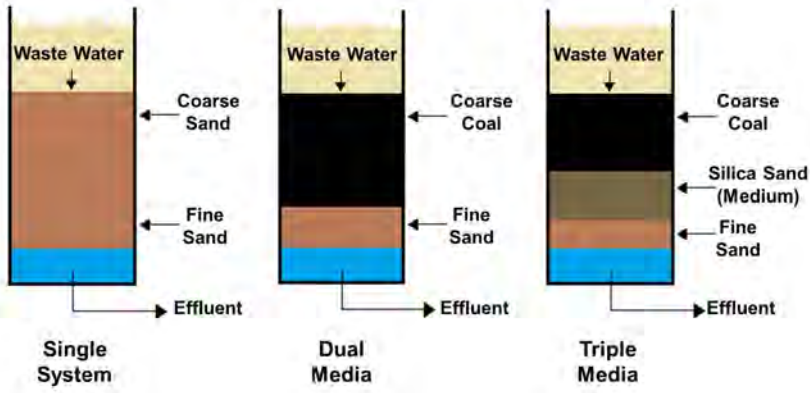


Figure 18.2.7 Tertiary treatment – using gravel/sand/polymers to filter small compounds such as odour, flavour, colour molecules.

Disinfection – is the last stage prior to discharge into rivers and lakes. Chemical agents such as chlorine and hydrogen peroxide are used to inactivate bacteria, viruses, etc. that were not filtered out during tertiary treatment. This is important as high microbial loads can pose a risk to humans and the environment. It is recommended that water be disinfected when both organic and microbial loads are lowest (i.e., the phenomenon that disinfecting agents, such as chlorine, react with organic material is similar to the situation described in a poultry water chiller; see Chapter 5). Disinfection can also be accomplished by gases such as chlorine oxide or ozone (O_3) and by physical means such as ultraviolet light and, to a lesser extent, microwave and gamma radiation.

Comments on water recycling – Due to environmental and budget constraints, technologies that recycle and treat waste water are increasing. Avula et al. (2009)

indicated that ultrafiltration of poultry waste water improves the quality of the recycled water and provides solutions to water resource limitations. Ultrafiltration is a pressure-driven process that separates materials based on molecular diameter. New membrane bioreactors that integrate biological degradation of waste products with membrane filtration are also quite effective at removing organic and inorganic contaminants from waste water. During the process, value added products such as crude proteins could be separated from poultry waste water, which could subsequently reduce the chemical oxygen demand. Ongoing research in membrane separation techniques involves exploration of new membrane materials and of new module configurations to address issues of membrane fouling and treatment of waste streams containing high suspended solids or viscous wastes. Overall, poultry processing plants use large volumes of water at several stages in the process due to set policies regarding pathogen reduction (see Chapter 2). Recovery of waste water can benefit the plant by reducing fresh water demand, waste water volume, and energy. For example, dissolved proteins that come from carcass debris/blood are major pollutants in the scalding and chilling operations. Ultrafiltration is one method that efficiently reconditions waste water and recovers protein and fat. Although the capital costs of ultrafiltration are high, the life cycle costs are comparable to other conventional treatments. Furthermore, the footprint of an ultrafiltration system could be 30–50% of that of conventional filters and may consume fewer chemicals.

18.3 Disposal of Solid Waste and Composting

Solids wastes are usually shipped by truck to a composting plant or a dump where they are properly buried (i.e., most countries have very strict regulations regarding waste disposal). Retaining solid waste near the processing plant can cause serious odour problems, spread disease (e.g., through wildlife), result in insect manifestation, and potentially pollute ground water. Composting is becoming a popular alternative for organic waste disposal since environmental issues are gaining attention and landfills are filling up quickly. Stabilizing organic matter through microbial activity provides humus that can be used as a farm fertilizer and/or to improve soil texture (Arvanitoyannis and Ladas, 2008; Jayathilakan et al., 2012). An inoculum of specially selected aerobic bacteria is recommended in order to speed the process and improve humus quality. Mesophilic and thermophilic microorganisms are involved and their growth succession is important in managing the composting process. In general terms, composting kills pathogens, converts nitrogen from unstable ammonia to stable organic forms, reduces waste volume, and improves the nature of the waste. During composting, solid waste should be aerated regularly by inverting or mixing the material. If

the waste material is too large or dense it should be ground first to increase the surface area exposed to microorganisms and air. The process can be completed within 1-4 weeks depending on factors such as waste type, temperature, aeration, and inoculation level. It is usually recommended that solid waste from different operations (e.g., meat, dairy and vegetable) be mixed together to get a better and faster fermentation. The composting area should be well managed and fenced to prevent wildlife (birds, mammals) from entering. In this way, composting provides an inexpensive alternative for the disposal of butcher wastes and meat scraps that cannot otherwise be sold (Mittal, 2006).

18.4 By-products: Edible and Inedible

The definition of edible and inedible can vary by country (e.g., chicken feet are categorized as edible in some areas and not in others). In North America, the meat industry considers everything produced by or from an animal, except dressed meat, a by-product or offal (Ockerman and Hansen, 2000). This includes both "edible" and "inedible" parts. The former consists of a variety of meats such as liver, hearts, and gizzards, which are referred to as the giblets in the poultry industry (see Chapter 5). Blood, which is sometimes used as an edible item, is also included in this category. The inedible portion includes parts such as the viscera (gut), head, and bones, which are commonly used in pet food, in growing fur-bearing animals (e.g., mink), and in feeding fish and hogs. Because of the danger of transmitting pathogenic organisms to other animals, the offal is usually heated to a high temperature (> 100°C, under pressure) to ensure microbial destruction. When the by-product will be used as feed, decontamination is mandatory in order to stop the spread of human pathogenic zoonoses (e.g., *Campylobacter*, *Salmonella* and *Yersinia*) and to minimize the microbial break down of amino acids that can result in the formation of toxic metabolites during storage.

The actual heating and rendering processes are described in more detail below. Treated offal is usually high in protein and can be mixed with other ingredients (e.g., cereal, vitamins) to produce a balanced animal feed and pet food. One of the main products, meat and bone meal (MBM), has been widely recommended and used in animal nutrition as a protein source in place of other more costly vegetable proteins (e.g., soy beans). The MBM has most of the essential amino acids, minerals, and vitamin B_{12} needed in monogastric and ruminant nutrition (Deydier et al., 2005).

As a result of the recent bovine spongiform encephalopathy (BSE) crisis in the beef industry, the use of animal by-products is now tightly controlled. As of November

2000, MBM can no longer be used to feed cattle, but can be incorporated in feed for pigs, poultry, fish or domestic animals (Deydier et al., 2003). In the European Union, there are currently two regulations (Regulation EC No. 1774/2002 and its amendment No. 808/2003) that legislate animal by-products not intended for human consumption. These regulations explain the disinfection and control conditions necessary to ensure pathogen removal in meat wastes.

The following sections describe the rendering industry and its production of animal feed and oils, the pet food industry, and the unique process of producing feather meal. The latter two have substantial economic potential for the meat and poultry industries.

18.5 The Rendering Industry

Rendering is a process that converts animal waste into stable, value-added materials. It refers to the processing of any animal products into more useful materials (e.g., animal feed) and/or specifically rendering animal fat into purified fats like lard or tallow. Animal fats have been used for decades to waterproof clothing and to make soap and candles. Some of the earliest documented evidence for using soap goes back to the Babylonians in 2800 BC. The Phoenicians and Romans were also knowledgeable in the art of soap making, which was performed by experienced individuals who operated small shops. Today, the rendering industry operates and recovers raw materials on a much larger scale (Table 18.1.2).

There was a major development in industrial-scale rendering in the early 19th century (Dainty, 1981) when animal by-products were first used in large scale fertilizer production. Prior to that, animal by-products were buried and basically had no economic importance. Furthermore, burying the material added costs to the meat processor who needed to pay for transportation, labour, and landfill space. In the 19th century, it was realized that the growing meat industry could recover money by transforming waste material into farm fertilizers. Today, the rendering industry produces hundreds of useful products that are divided into edible, inedible, oils, chemicals, meat meals, and bone meals (Okerman and Hanson, 2000). Some of the larger meat processing plants have their own rendering facilities/spin-off companies whereas smaller plants use the services of an independent rendering contractor who collects and processes the material. The available rendering systems can be generally divided into: a) dry batch, b) autoclave or wet rendering, c) dry continuous processing, and d) continuous low temperature system (Ockerman and Hansen, 2000).

a. The dry batch system includes a cooker with steam-jacketed walls that prevent the steam from coming into direct contact with the material inside. Sometimes a hollow steam-filled agitator is employed. Ground by-product material, usually bigger than 2.5 cm, is batch fed into the system. During the process, water and fat are released. There is no contact with direct live steam and the fat is not severely degraded (i.e., as in the autoclave system discussed below). The cooled material is then removed and the free-flowing fat is drained off. The remaining moist material is then pressed by a hydraulic press (i.e., batch type), a continuous screw press, or a decanter centrifuge to remove the water.

b. The autoclave system consists of a cooker filled with pre-ground raw materials that is hermetically sealed prior to a steam injection (≈ 140°C). The process usually takes 3-4 h and involves high pressures (e.g., 360 kPa) that are reduced to the regular atmospheric pressure of about 100 kPa toward the end. The slow pressure reduction is important to avoid emulsification of the aqueous and fat phases. Figure 18.5.1 shows a wet rendering process where the liquid is separated via centrifuge after the heating phase. Afterwards, a high-speed three-phase separator separates the fat and water.

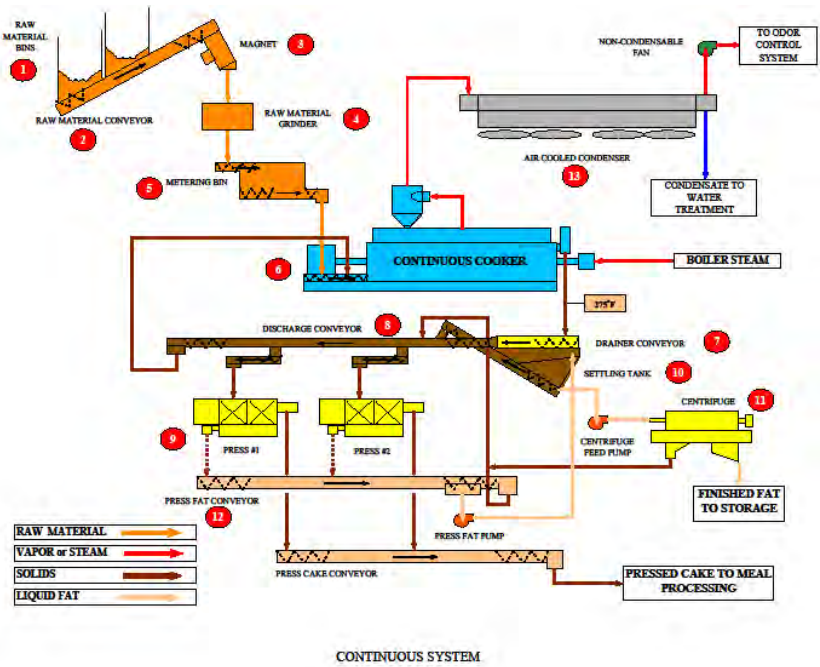


Figure 18.5.1 Illustration showing a wet rendering system for processing of meat by products.
http://assets.nationalrenderers.org/flow_charts.pdf

c. A continuous dry system is fairly similar to the dry batch rendering system. However, the material is continuously fed into the system and treated under atmospheric pressure. The cooker is usually horizontal, has a steam jacket, and sometimes has a hollowed, steam-heated agitator. The material enters at one end and exits at the other in a continuous manner. The time the material is exposed to heat depends on the size and retention volume of the cooker. The discharged material is dumped into a percolator that consists of a tank with a strainer at the bottom. The free fat is drained and the remaining material is pressed to remove the trapped fat. The remaining solids are then pressed and ground into a meat meal product.

d. A continuous, low temperature rendering system, sometimes called a mechanical dewatering system, employs a mechanical means to remove the water and fat. Overall, the raw by-products are ground up and then passed to a low temperature, dry or wet cooker (also called pre-heater or coagulator) where the material is kept at 60-90°C for 10-30 min. This causes some of the fat cells to break and release their contents. The material is then pressed using a continuous screw-type press and the fat and water are extracted. The remaining solids are then centrifuged for additional water and fat removal. This process results in a lower heat treatment and reduced energy costs compared to the other processes.

18.6 Pet Food

The pet food industry has been steadily growing around the world. In the USA it was estimated that people spent $55.3 billion on their pets in 2013 (APPA, 2013). Broken down, the expenditures were $22.2 billion on food, $13.2 billion on supplies and medicine, $14.2 billion on veterinary care, $2.3 billion on purchases of live animals, and $4.5 billion on grooming and boarding. Overall, this is a tremendous increase from 1993 ($16 billion) and 2003 ($32 billion). Ockerman and Hansen (2000) noted that the first commercially prepared dog biscuit was introduced in England in 1860. Canned cat food and dry meat dog food were introduced in the USA by 1930. New expanded pet food products were introduced in the 1950s and semi-moist pet food in the 1960s. The demand for pet food (estimated to be over 1 million tons/year of poultry, meat and seafood by-products) has provided the meat industry with a good and stable source of income and pet owners with high quality and nutritious pet food.

The USA pet population increased steadily by 1.3% annually between 1990 and 1997 (Hoepker, 1999) and in 1997 it was estimated that homeowners in the USA kept 56 million dogs and 68 million cats. This partially explains why the pet food

industry has grown so quickly. It should also be mentioned that today people are willing to spend more on their pets and that there are well over a thousand different pet food items estimated to be available in the US market. An annual growth of 4% in pet food retail sales in Japan is also expected due to changing social trends rather than an increase in the number of total pets. Some of the increases are the result of new pet superstores, premium pet foods, and increased awareness/knowledge of feeding pets a nutritionally balanced diet.

The meat industry ships fresh and/or frozen materials to the pet food industry (i.e., freezing is used when delays between shipping and processing are expected). The pet food industry cooks the meat at high temperature and mixes it with other ingredients to produce a balanced diet for different pet food categories. Common ingredients include corn meal, soybean meal, and vitamins. Examples of labels appearing on three types of pet foods are provided below.

Dry dog food

Ingredients: ground corn, wheat shorts, poultry by-product meal, corn gluten, soybean meal, poultry fat preserved with mixed tocopherols (to preserve flavour), rice, molasses, tripolyphosphate, dry whey, calcium carbonate, salt and vitamins.

Protein (min)	21.4%
Fat (min)	10.6%
Crude fiber (max)	4.3%
Moisture	10.0%

Canned dog food

Ingredients: poultry by-products, meat by-products, chicken, ground wheat gluten, minerals and vitamins (calcium, potassium, zinc, iron, iodine, vitamins A, B1, D3 and E), bone meal, citrus pectin, guar gum, sunflower oil, tri polyphosphate, natural flavours.

Protein (min)	8.7%
Fat (min)	6.6%
Crude fiber (max)	1.4%
Moisture (max)	77.0%

Canned cat food

Ingredients: chicken and chicken by-products, meat by-products, vitamins and minerals, vegetable gums, natural flavours, natural colours, caramel and water added for processing.

Protein (min)	8.4%
Fat (min)	4.3%
Moisture (max)	81.0%
Ash (max)	2.5%

The first formula, dry dog food, is mainly based on cereal products that provide a high percentage of protein and some carbohydrate. Poultry by-product meal is included as a main protein and mineral source. The poultry fat is supplemented with tocopherol (an antioxidant) to protect it from oxidation during heating and storage.

The second formula, canned dog food, adds a cereal component to improve the texture, add bulk, and add crude fiber (plant material) to the formula. The formulation also contains different gums (pectin, guar) to assist in texturizing the product. Natural flavour ingredients, usually poultry or beef extracts, are also included.

The third formula, canned cat food, illustrates a formula based on meat (listed as chicken) and meat by-products that has been fortified with vitamins and minerals. As with other foods, ingredients are listed in descending order by weight but the nutritional labeling requirements for pet food are not as stringent as they are for human food. For example, the pet food manufacturer can declare a minimum protein content and does not have to provide a list indicating the amount of vitamins and minerals whereas fortified human food must have a precise declaration of all ingredients).

Pet food is sold in different ways (wet, semi dry, dry) and protein content can range from 10 to 50%. "Wet" canned food usually has about 12-14% protein, semi dry food has 21-25%, and dry food has 20-50%. Recently, there has been substantial product development activity in the high end pet food industry as margins in that sector are high. Pet food companies have also invested in products that adjust for the nutritional needs and flavour and texture preferences of different pets. Advanced processing equipment (e.g., extruders) is becoming more popular as the need to texturize and shape the food is important in this highly competitive market segment.

18.7 Utilization of Feathers

Feathers are unique to the avian species. They represent about 7% of the live body weight of a broiler (Lortscher et al., 1957) and are also considered to be of major economic importance (as stated in Chapter 2, over 50 billion pounds of poultry was produced in the US in 2013). The feathers are made of a complex keratin protein matrix. The amino acid sequence of a broiler's feather is very similar to that of other poultry/bird feathers and the keratin found in reptilian claws. Feathers are a rich source of protein with approximately 90% protein, 8% water, and 1% fat. Once processed into a regular feather meal, it contains about 70-80% crude protein. However, before using feathers as an animal feed, the protein complex has to be broken down as explained below. Feathers are also used for bedding, ornaments, sporting equipment, and as filler in chemical fertilizer (Ockerman and Hansen, 2000).

According to Hardy and Hardy (1949) and Pacific Coast (1997), feathers can be classified as:

a. Saddle feathers – long, narrow, vaned feathers from the saddle and back of a rooster
b. Hard feathers – stiff quills, heavy vanes and a very small amount of fluff
c. Half fluff – vaned feathers with fluff along the lower half of the quill
d. Three-quarters – vaned feathers with fluff along the lower three-quarters of the quill
e. Fluff – body feathers with firm shafts bearing only fluff, or the soft part of a feather
f. Plumules – small down feathers with soft shafts, bearing only fluff
g. Down – feathers without a shaft, composed of only a tuft of fluff

When feathers are used for animal feed they need to be hydrolyzed to break down the complex protein (keratin) structure; otherwise they would be indigestible. The feathers are first washed to remove dirt and then they are dewatered by compression or centrifugation because they do absorb some moisture during processing and washing (e.g., at the meat processing plant they usually pick up between 7 to 15% moisture during the scalding and picking operations; Lortscher et al., 1957). After some of the water has been removed the feathers are cooked for 1-2 h to hydrolyze the complex protein structure. Heating is commonly done in a pressure cooker (under 2-3 atm of pressure), which increases the rate of hydrolysis. The feather's digestibility is proportional to cooking time and temperature where higher temperature and longer cook times result in higher amino acid availability. The cooked feathers are then dried (e.g., air) and ground, resulting in a product

known as feather meal. The grind size should be such that all particles pass through a US No. 7 screen and 95% pass through a US No. 10 screen. The common composition of a feather meal is: 75% crude protein (some contain up to 90%), 10% moisture (maximum), < 6% fat (maximum or minimum as specified), and 3-4% fiber (maximum).

Feather meal is rich in sulfur containing amino acids such as cysteine, arginine, and threonine, but is deficient in lysine, histidine, methionine, and tryptophan. When the meal is fed to poultry or swine (monogastric animals), these limiting amino acids should be added. The common feeding level is 0.5 to 1.5% of the diet (Ockerman and Hansen, 2000). When fed to beef cattle (ruminant animals), feather meal efficiency can be improved by adding urea.

Bedding – this industry commonly uses small, fine feathers. Down is the most preferred material because it possesses a unique structure that allows it to hold large volumes of air (Fig. 18.7.1) and down is an excellent insulator. Down usually represents 12-15% of the total feather weight in ducks and geese. The remaining feathers on the bird are designed for water and air flow so the bird can swim/fly.

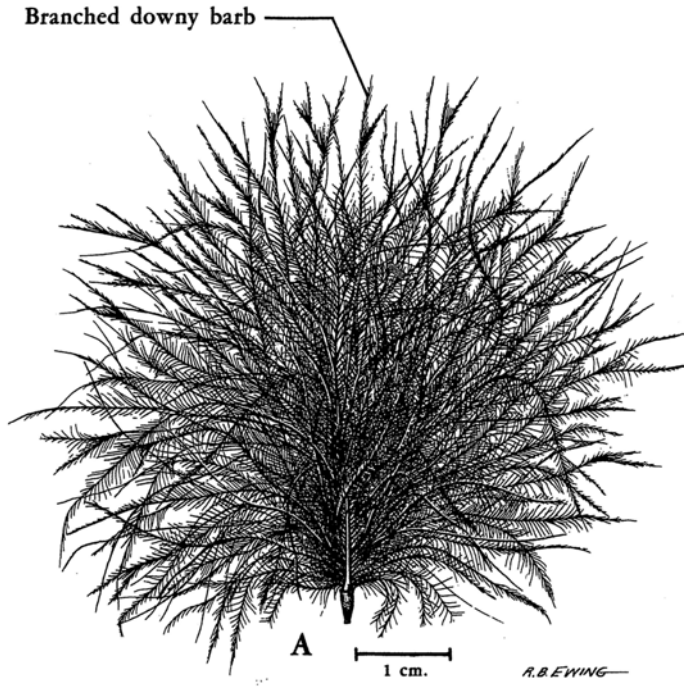


Figure 18.7.1 Structure of a down feather from lateral body apterium taken from a Single Comb White Leghorn. From Lucas and Stettenheim (1972).

In the bedding industry feathers are thoroughly washed and rinsed and then blow-dried or steam-dried. This process promotes opening the structure of the down feathers (fluffing), which enhances the feather characteristics as a bedding material. Breathability, compressibility, and the ability to return to its original shape and volume are also important characteristics in selecting feathers for bedding (Mountney, 1989). The fill-power or "loft" is a measurement used for feather quality, which provides a numeric value to describe the amount of space the down will fill under a standard pressure. It is desirable for feathers (used for bedding) to have maximum volume when in use and minimum volume during storage (e.g., goose down usually has a higher fill-power compared to duck down when obtained from birds of similar age). A high fill-power of 750 in^3/oz is given to feathers that are strong, soft, have high insulating efficiency and durability, and have little loss of resiliency over time. A fill-power of 300 in^3/oz is given to smaller clusters of down with lower resilience and therefore faster wear is expected.

Feathers are sorted into different size groups after cleaning and drying. Sorting is done by air currents which blow the down and feathers through a series of vertical baffles, suspended from both the top and bottom of the separator. Lighter down feathers are blown further away than the heavier feathers (Pacific Coast, 1997). According to US regulations, a product identified as down must contain 80% down and no more than 20% other feathers. This distinction was made because it is almost impossible to get a complete down separation i.e., some light feathers, usually no longer than 6 cm, will also be blown into the down compartment.

After the introduction of synthetic fibers there was a reduction in the use of down for bedding. However, high quality down is 4 x more thermally efficient and 10 x more durable than synthetic fibers and a surge of high end down filled bedding/ coats has been seen in recent years (Ockerman and Hansen, 2000). Also, feathers are classified as a natural product and contain no toxins, require no toxins to produce, do not pollute, and are biodegradable.

Ornamental feathers – tail and wing feathers from pheasant, rooster neck hackles, ostrich, etc. need to be removed before exposure to hot scalding water. This is done by hand and is obviously time consuming and more expensive than mechanical defeathering (i.e., a picker uses fast moving rotary rubber fingers in a fairly aggressive way that damages the shape and structure of the feathers). Feathers used for sporting equipment, such as for fetching arrows, are carefully hand selected to assure quality (note feathers for an individual arrow must all come from either the right or left wing to provide a proper rotation of the arrow; Mountney, 1989). Feathers can also be used for manufacturing artificial fishing lures and for shuttlecocks used in badminton. Coloured feathers are used for decorative purposes and are sometimes dyed and trimmed to a desired shape and pattern.

Careful cleaning of feathers is required when feathers are used for bedding, clothing, or sporting equipment. If the feathers are going to be saved for more than a day prior to processing, they can be soaked in a 5% salt, 0.3% hydrochloric acid solution. The feathers are washed about half a dozen times with a soap solution and cleaning detergents to remove all dirt. A mild soap should be used to protect the essential oils in the feathers and a neutral pH should be maintained to protect the feathers (Mountney, 1989). Sometimes a special high flash point gasoline is used to remove foul odours. In such a case, the processor can later lightly spray the feathers with mineral oil to replace some of the original oil. In some processes, where decolourization is required, blanching agents such as hydrogen peroxide, chlorine, or potassium permanganate are also used. Inappropriate cleaning will cause problems with mildew, degradation due to microbial activity, and reduce the insulating properties.

With the increased demand for natural products in the marketplace, feathers are gaining popularity and that is good news for the poultry industry. Attention toward recovering by-products from meat and other ingredients is also expected to rise as the price of material disposal is continually increasing.

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