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Poultry Processing and Products

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24.1 Poultry processing

Primary and further processing of poultry is a multi-billion dollar industry in the US. The majority of poultry raised and commercially processed in the US is composed of chickens, turkeys, and ducks, with more than 9 billion birds processed in 2010 (Table 24.1). Total retail product weight exceeded 58 billion pounds, with an estimated retail value of \$100 billion.

The general process of turning live birds into meat is similar for all three species, but details of the process can be distinctly different for specific steps. Differences are due to bird size and physiology differences, requiring unique equipment and species-specific methods. Poultry meat is further processed into many forms as a result of customer and consumer demands that developed in the 1980s (Figure 24.1). The industry was able to respond to this demand since the profit margins were higher for further processed items than for raw whole carcasses or parts. Also, equipment had been developed to automate further processing and packaging on a large scale, and otherwise defective whole carcasses not marketable as raw Grade A could be further processed and sold as value-added. Since the vast majority of poultry meat is represented by broiler chickens, the following sections will describe broiler processing. Two further sections will address differences specific to turkey and duck processing.

The basic steps of broiler chicken processing are shown in Box 24.1. The processing plant is divided into a slaughter area, a separate evisceration area, a chilling area, and, depending on the products produced, further processing areas. In addition to the processing areas, plants contain

employee areas such as locker rooms, breakrooms, and restrooms; office areas for management and a separate space for USDA employees; accessory areas such as coolers, shipping and receiving docks, warehouse storage, maintenance and repair, and box making; and waste (offal) and waste water processing. The commonality among plants is that live birds are processed or further processed into food, but any individual plant is uniquely different from any other plant.

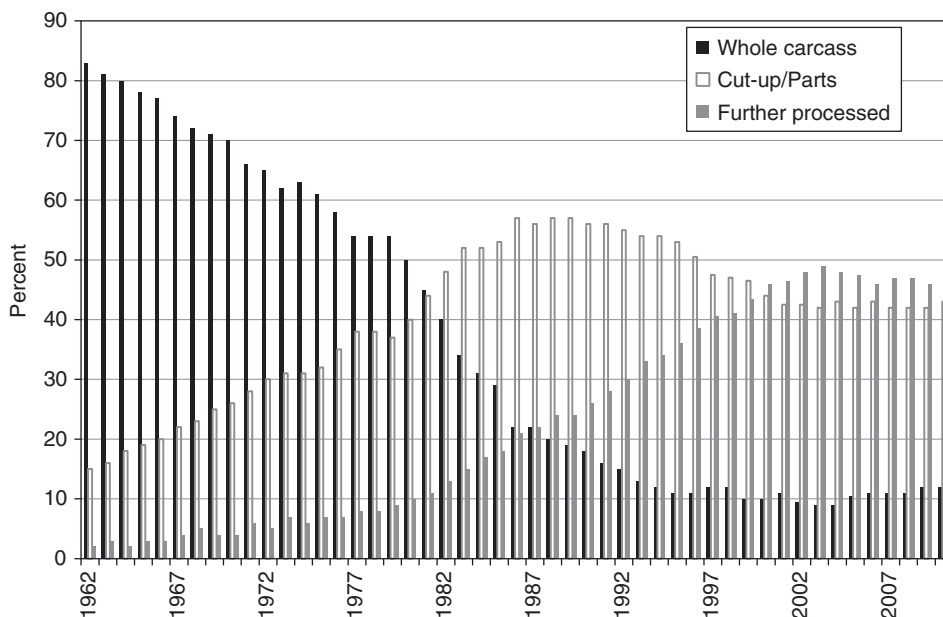
24.1.1 Preprocessing

Prior to processing, several steps are taken to prepare the live birds. First, feed is removed from broilers approximately 8–12 h before slaughter. Feed withdrawal is important to reduce gastrointestinal contents within the bird, which reduces the chance of ingesta or fecal contamination during processing. One negative aspect of feed withdrawal is that birds lose weight, which reduces payments to the contracted growers. Microbiological problems occur from overly long withdrawal as contamination increases due to gut fragility during evisceration. Also, pH of the crop increases, which encourages the growth of *Salmonella*, adding to potential pathogen contamination. Per animal welfare guidelines, birds are not fasted more than 24 h.

The poultry house is cleared of equipment prior to arrival of the catching crew, then birds are loaded into metal multilevel coops. These coops are loaded onto trucks and birds are transported to the processing plant. Upon arrival, the birds are weighed as a group and then are held in a holding shed to provide some minimal protection from the environment prior to unloading.

Table 24.1 Live weight, number of animals, and pounds inspected of chickens, turkeys, and ducks slaughtered under USDA inspection in 1990, 2000, and 2010 (data from USDA National Agricultural Statistics Service)

Species	Year of production	Live weight (individual animal average, in pounds)	Number of animals inspected (in millions)	Pounds inspected (in billions)
Chicken	1990	4.4	6017.6	26.4
	2000	5.0	8424.2	42.2
	2010	5.7	8789.1	50.1
Turkey	1990	21.3	271.2	5.8
	2000	25.6	268.0	6.9
	2010	29.1	242.6	7.1
Duck	1990	6.6	20.8	0.137
	2000	6.6	24.5	0.162
	2010	6.8	23.6	0.162

**Figure 24.1** Percent of market share for chickens expressed as whole carcass, cut-up parts, or further processed meat by year from 1962 to 2010 (data from the National Chicken Council, Washington, DC).

24.1.2 Primary processing

24.1.2.1 Slaughter

The coops are unloaded from the truck and a machine tilts and dumps the entire coop onto a conveyor that transports the birds into the plant to the live hang area. Employees pick up each bird and hang them upside down by the feet on a stainless shackle. Shackles are spaced 6 inches apart and are attached to rollers on a continuous track; depending on size of the plant and speed of the line,

there may be several thousand shackles. Birds remain on these shackles for the duration of steps in the slaughter area, approximately 6–7 min total. The live hang room is the beginning of the slaughter area.

On the shackle line, the birds first pass through an electrical stunning device. A non-conductive fiberglass trough of water (fresh or salted) with a metal mesh grate immersed in the water hangs below the shackles. As the bird is pulled through, the head touches the water and immersed grate. An electrical control box has one

Box 24.1 Major steps of broiler processing and further processing

1. Preprocessing Feed withdrawal House preparation Loading Holding Unloading	2. Slaughter Live hanging Stunning Killing Bleeding Scalding Picking Head removal Hock cutting	3. Evisceration Oil gland removal Venter Opener Eviscerator Inspection – traditional Viscera removal/giblet harvest Crop removal Lung removal Carcass washing IOBW (Inspection – HIMP) Chilling
4. Secondary processing (no ingredients or heat treatment) Cut-up Deboning Portioning Grinding Mechanical separation	5. Further processing (ingredients or heat applied or both) Marination Coating Cooking Glazing Freezing	6. Packaging and shipping Packing Labeling Palletizing Transport

HIMP, HACCP-based Inspection Models Project; IOBW, inside-outside bird washer.

electrode connected to the metal grate in the water, and the other electrode is connected to a metal bar that touches the shackle above the bird's feet. The body of the bird connects the electrical circuit and the bird is stunned by the current (approximately 10–20 mA) passing through the head and body. Stunning as conducted in the US is reversible, and should the bird be removed from the line immediately after stunning, it will regain full consciousness and mobility in approximately 5 min. In other countries higher voltages and amperages are used to irreversibly stun birds. EU processors electrocute poultry in stunners as an alternative method for stunning and killing (although birds are still bled immediately after electrocution). As a result of higher amperage (150 mA), poultry in the EU is subject to more carcass damage, especially broken wings and breast hemorrhages.

Immediately after exiting the stunner trough, an automated kill machine cuts the throat of the bird. Metal guide bars hold the head and neck against a spinning circular blade; some machines have two blades in an effort to cut both sides of the neck. In the US, birds slaughtered for human consumption must be killed by exsanguination (blood removal). Other forms of slaughter are approved,

including decapitation and pithing, which also provides blood loss. Using an automated killer or neck cutter requires a manual back-up method. A person will manually cut the neck of any birds that may have been missed by the machine.

After the neck is cut, exsanguination takes approximately 2 min. Only about 50% of the blood is lost during exsanguination. The blood loss is necessary to allow the bird to fully expire and ensure there is no blood pressure in skin or muscles so no bruising or discoloration occurs. For birds that still have any blood pressure, the skin will turn pink or red during scalding, a condition termed “cadaver,” and these carcasses will be condemned as not suitable for human consumption. Blood, because of its high nutrient content, is collected in a trough or pan and is not allowed to enter the waste water stream. It is usually sold to a renderer for processing into blood meal.

After exsanguination, the carcasses are scalded. This requires that the carcasses are pulled through troughs or baths of hot water. Some plants utilize multiple baths at various temperatures, and all have agitation to increase the hot water moving through feathers and achieving better skin contact. Feather follicles in the skin relax in hot water and allow better feather removal. Plants utilize

many time and temperature schemes during scalding, but are grouped into two primary methods. The first scheme uses lower temperature, typically 125°F (69.4°C), for up to 2 min. This temperature preserves the outer layer of skin and is used by processors that either market whole birds based upon skin color (bright yellow bird skin, for example) and for those further processors that do not apply batter and breading to skin-on parts (the outer cuticle that is left on does not favor breading adhesion). This lower temperature has traditionally been termed “soft scald.” Higher temperature scalds, up to 145°F (80.5°C), for up to 2 min (but usually less), are termed “hard scald.” The cuticle is removed, along with most skin color, which allows better breading adhesion for further processors.

Immediately after exiting the scalders, the carcasses pass into picking machines. Banks or rows of picker fingers (which are blunt, hard rubber, ribbed, and approximately 4 inches long and 0.5 inches wide) are mounted on metal plates that spin at high speed and are horizontal to both sides of the carcass. Two banks are sufficient for smaller broilers, although some processors use additional specialty pickers to concentrate on the neck or leg regions. These spinning fingers exert tremendous pressure and force on the carcass and strip off the feathers quickly. A downside to this process is broken wings, and in some cases broken legs. The picking process is typically accomplished in less than 2 min. After the picker, a guide bar with a hook at the end is positioned to pull the heads off the carcasses.

24.1.2.2 Evisceration

At this time the carcasses must be passed into the evisceration area of the plant. US Department of Agriculture (USDA) Food Safety Inspection Service (FSIS) rules traditionally required a physical separation or partition between slaughter and evisceration. Carcasses must be removed from the slaughter shackle line, pass through the partition, and be rehung on a second continuous shackle line for evisceration. The yellow feet are cut from the carcass as part of removing the bird from the slaughter shackle line. The rehang process may be manual with employees hanging the carcasses onto the evisceration line upside down by the hock after the feet are cut and the carcass drops onto a table or conveyor. Alternatively, some plants use an automated foot cutter and rehang machine; as feet are cut, the machine holds the carcass then slides the hocks onto the evisceration shackles.

The evisceration area organization and equipment may vary between processing plant and company, usually

based on type of evisceration system (group of processing machines offered by different vendors) and type of federal inspection system. Based on production, a typical plant will have one slaughter line feeding into two evisceration lines. For example, a 140 bird per minute slaughter line will supply two 70 bird per minute evisceration lines. In one traditional inspection system, two USDA FSIS inspectors are placed on each evisceration line; in another system a 180 bird per minute slaughter line feeds two 90 bird per minute evisceration lines with three USDA FSIS inspectors per line. A third, more recent innovation is a 140 bird per minute slaughter line and one evisceration line (also 140 birds per minute) with two inspectors on the line just prior to chilling. A traditional system employs a series of machines to remove the viscera from the bird but leave it attached to the carcass for inspection. Newer systems remove the viscera and either clamp it above the carcass or drop the viscera onto a tray below the carcass. Both the carcass and viscera must be observed during inspection to determine if the carcass is suitable for human consumption.

Regardless of the equipment system and inspection regime, carcasses entering the evisceration area go through a series of steps to produce a carcass suitable for chilling. Following rehang, the carcasses have the oil or preen gland removed from the base of the tail. A multistep viscera removal process is accomplished by three pieces of equipment in sequence. First, the venter uses a probe to locate the cloaca, then a circular knife descends to cut the cloaca and attached colon free of the carcass. Then the opener uses a small blade to open the abdominal cavity from the cloacal opening (enlarged by the venter) to the tip of the keel bone. Lastly, the eviscerator drops a triangular paddle into the opened carcass to scoop out the viscera from the abdominal cavity.

In traditional inspection plants, which comprise more than 80% of operations in the US, the USDA FSIS inspectors examine the carcass and viscera for any sign of disease and abnormality. Inspection stations on the shackle line have specific requirements, including adjustable chairs, amount of light, and mirrors behind the carcasses to give inspectors the opportunity to view the back of the carcass. Inspectors view approximately 30 carcasses per minute but this number varies depending on the type of plant and line speed. In newer HACCP-based Inspection Models Project (HIMP) systems, one inspector per evisceration line is placed just prior to the chiller. Signs of seven major disease signs for broiler chickens are observed and recorded: synovitis, sepsis, leukosis, infectious process, air sacculitis, tumors, and skin lesions (by FSIS in traditional plants, by plant personnel in newer

inspection systems). A number of other minor diseases and disorders may also affect product disposition, and other diseases specific to other species, such as osteomyelitis for turkeys. The inspectors designate disposition of each affected carcass, from washing to trimming of parts to whole carcass condemnation. Condemnation rates vary among plants and species, but approximately 1% of total pounds of poultry inspected are condemned.

A newer inspection system, termed *Salmonella* Initiative Program (SIP), is a hybrid program that enables plants to conduct experiments and request variations from normal processing procedures. For example, some plants have increased line speeds after providing data that the practice is not detrimental to food safety. Plants have also received exemptions for refrigerated product exceeding 40 °F after processing after showing the product did not contain higher numbers of pathogens nor promote their growth. In return for FSIS exemptions, plants must conduct pathogen testing of carcasses at several areas during processing to show they are in control of the process and provide the data to the FSIS.

After inspection, the viscera are separated into edible (giblets, or heart, liver, and gizzard) and inedible portions (intestines, spleen, gallbladder, etc.). The inedible viscera, heads, feet (if not sold), feathers, and blood are termed offal. Offal is collected and sent to a rendering plant for conversion into feed additives. For giblet processing, the gizzards are split open and the lining peeled away; hearts are trimmed of aorta, and livers have the gallbladder cut or peeled. These giblets are then placed in a small chiller separate from carcasses. After chilling, some may be sent to be packed inside whole carcasses, some are destined for pet food, and some may be packed for raw or frozen supermarket cases.

Carcasses, after inspection, pass into a series of other machines along the shackle line. A lung machine vacuums out lung tissue. A cropper machine pushes a turning probe through the carcass and out the neck, winding the crop tissue around it and removing it from the carcass. A neck breaker dislocates the neck at the base. If the carcass is eventually to be sent for deboning, many plants leave the neck attached; necks may be labeled as white meat if left attached to the frame after deboning, which adds value to mechanically deboned meat.

The final important piece of equipment in evisceration is the inside-outside bird washer (IOBW). As the name describes, pressurized water is sprayed on the exterior and interior of each carcass to remove any extraneous material or fecal contamination. The FSIS has established a policy of zero tolerance for fecal material entering the chilling tank, so this is the last point to remove feces

and ingesta. Other equipment in evisceration also employs low-volume water sprays that are typically chlorinated, including the opener, eviscerator, and cropper, but the IOBW is the primary for washing the carcass. The drawback of using IOBWs is water usage as each machine may use 40 gallons of water per minute. During a 480 min work day, with an IOBW on each of two evisceration lines, nearly 20,000 gallons of water would be used.

24.1.2.3 Chilling

Poultry chilling in the US is usually (more than 95% of plants) conducted with immersion chilling. There is typically some separation between the evisceration and chilling areas, but not always a physical barrier as found between slaughter and evisceration. FSIS regulations for chilling require that broilers be chilled to 40 °F (22.2 °C) or less within 4 h of slaughter. Larger birds have up to 8 h for chilling. Carcasses drop off the evisceration line shackles into large vats that may be 8–12 feet wide, 8–10 feet deep, and several hundred feet in total length. Some processors use a smaller tank termed a prechiller prior to the main chilling tank, and some use a small chiller at the end of chilling to apply an antimicrobial rinse.

The two main types of chillers are drag and auger chillers, referring to the method used to move carcasses through the tank. Drag chillers use bars spaced a few inches apart that form a grid that projects into the tank from top to bottom. These grids are several feet apart and are attached to a track above the tank. Motors move this series of grids along the tank to push carcasses along. Auger chillers use a central auger in the tank that spans the entire tank length; motors turn this large screw that pushes the carcasses through the tank. Both chiller designs add fresh water at the exit end so carcasses are exposed to the cleanest water just before exiting the tank. Chillers employ cold water systems termed rechillers that recycle the cold water and usually apply chlorine. Air nozzles at the bottom of the tank agitate the water and keep carcasses moving and assist in heat transfer. Dwell time for an efficient chiller filled with broilers is approximately 1 h. Some plants that debone carcasses use longer chill times of 2–3 h to allow carcasses to pass through rigor mortis so meat can be removed from the carcass upon exiting the chiller. Bacterial cross-contamination occurs with immersion chilling but overall numbers of bacteria are decreased by the washing action of the chillers.

Very few US plants have adopted air chilling as is practiced in the EU. Air-chilled birds remain on shackles after evisceration and are transported into rooms that are refrigerated, requiring a dwell of 2.5 h or longer for

smaller carcasses and much longer for turkeys. Air is a less efficient method of heat transfer, resulting in longer chill times, and much longer shackle lines and many cold air compressors and fans are required for carcass heat removal. Cross-contamination of bacteria is less likely with air chilling but still occurs, although in a different pattern than with immersion chilling. Generally air-chilled carcasses have less overall contamination per carcass, but carcasses that are contaminated have higher numbers of pathogens since there is no washing effect from immersion chillers.

24.1.3 Secondary or further processing (raw)

There are many potential product form outcomes for carcasses exiting the chiller. The carcass may be packaged for sale, with or without giblets, but this market form has decreased over the years. Most carcasses are cut into parts, meat is deboned from the carcass, or both. Secondary processing usually refers to further processing of the raw carcass into value-added product forms. Therefore cut-up and deboning are both considered areas of secondary processing. Although whole carcasses were the main product form prior to 1980, customer demands for more convenient food products drove the poultry processing industry toward cut-up parts and boneless, skinless meat. Just as important, consumers were willing to spend more for convenience foods and value-added products. Processors also found an outlet for USDA non-Grade A carcasses. If a part was trimmed due to defects, the rest of the carcass could be cut into parts and sold at a higher price per pound. Automated cut-up equipment and improved packaging systems were becoming available. All of these factors combined have greatly diminished the whole carcass product form, and if not for the recent increase in rotisserie chicken products, whole carcasses would be nearly extinct in the market.

24.1.3.1 Cut-up

The simplest and most original cut-up device was simply a person with a knife. To meet increased demand, more automation was needed, and an early device still in use in some plants is a circular saw. A trained employee with appropriate protective gear can cut a chicken into eight pieces in a few seconds. Even that rate is not fast enough to produce several hundred thousand pounds per shift, so fully automated lines were developed and installed

prior to 1990. Whole carcasses are hung on a continuous modified shackle line system with multiple stations with knives or circular blades; some recent advanced systems are computer controlled. Virtually any cut can be programmed, from a simple cut to separate the front half from the back half of a whole carcass, to a 13-piece cut (two wings, two drums, four thigh pieces, and five breast pieces). Precision machines require consistently sized carcasses, so scales are placed on the shackle line and an unloading mechanism sorts those that are too large or too small. Some plants use a combination of methods, with a machine to cut front halves from whole carcasses, then remove the wings, while the leg quarters are cut on other machines or by hand.

A more recent development is the placement of a hybrid cut-up and deboning line at the chiller exit. Chilling times are increased to ensure carcasses have more time to enter and exit rigor mortis. Cutting meat from the bone or wings from front halves too early (less than 3–4 h) may result in tougher breast meat. Carcasses are immediately placed on a cone line as they exit the chiller, which is described further in the next section. Wings are removed by manual knife cuts during the breast meat deboning process, and drums and thighs may be removed or left on the carcass and deboned.

Wings have become a popular snack item in the past few years. Although a market exists for whole wings, the “buffalo” wing market requires cut-up wings. They may be cut manually, but a wing wheel machine that resembles a ferris wheel cuts whole wings into drumettes, flats, and wing tips as it revolves. A human loader continuously adds a fresh supply of whole wings as the cut wing portions fall into different containers or conveyor belts.

24.1.3.2 Deboning

As in the cut-up department, a person with a knife was sufficient for early deboning practices. Most deboned meat is the breast (fillets and tenders), with some thigh meat also available to the retail market. To keep up with demand, a continuous conveyor track with deboning cones mounted approximately every 24 inches is utilized. A deboning cone is a blunt cone shape approximately 4 inches tall and 3 inches in diameter, composed of either white plastic or stainless steel. The line is 30–50 feet long and customized for other lengths as needed. As the cones move, a line of people with specific assignments occupy one side of the line. One person loads either front halves or whole carcasses, others then cut the wings loose from

the shoulders, others strip the whole breast (with skin still attached to the butterfly fillets) from the front half. Subsequent employees manually pull the tenders from the front half, and others separate the butterfly fillets from the skin. If whole carcasses are deboned then the thigh and leg meat is cut free from the carcass, and skin separated from the meat for some products. There are multiple variations of this process, with a typical alternative process where wings are left on the front half to facilitate breast removal, then trimmed off later with the skin.

There are several versions of automated deboning machines for removing breast meat. One is a modified version of a cone line, with stations that mechanically cut wings, cut and remove the fillets, and slide the tenders free. Another system uses a modified shackle system, where stations use robotic knives to cut the wings, fillets, and tenders from the front half frame. Frames, or skeletal remains after deboning, may be sold as offal but are usually collected for mechanically separated meat production.

24.1.3.3 Portioning

Portioning is conducted on deboned meat, usually breast fillets. A person with a knife and a scale or template was the original portioner, but now much is done by machines. One machine relies on a hard plastic three-dimensional template. A fillet is placed in it, and a cover pressures the meat into place while slicing any excess that is outside the mold. Another type of machine has a loading conveyor belt with laser guides for manual placement of fillets or other boneless meat. As the meat enters the machine, it is imaged and a computer program determines the optimum cut to maximize required product. Cuts are made by robotic arms with high-pressure water spray nozzles that cut the meat into precise patterns as determined by the computer.

Meat from either machine is usually weighed to finish the portioning and sorting process. Weight scanning conveyors with multiple drop stations may be used to sort boneless meat by weight, or meat may be weighed manually.

Portioning is important to supply meat at a certain weight, length, width, and thickness. Although it does not seem important other than for marketing, fast food retail operators rely on portion-controlled meats as a food safety method. For example, a breaded fillet of a certain size is placed in a fryer with a set temperature and a timer set for 3.5 min; an overweight or overly thick portion may not reach a safe internal temperature with the programmed settings.

24.1.3.4 Grinding

A growing market segment for poultry meat is ground product. Boneless skinless meat (breast meat, dark meat, or both) is coarsely ground through a plate. Particle size of the grind is determined by plate size and is normally $\frac{1}{4}$ to $\frac{3}{16}$ inch (6.4–9.6 mm). Most of this product is tray packed for the retail market. It has become more popular due to the typically lower fat content than ground beef or pork. The grinding is similar to what is used for poultry sausages, without the additives or casing process. One drawback to this product is the typically higher prevalence of pathogens, including *Salmonella*. The product is not more contaminated than any other raw poultry meat product, but the grinding and batching process tends to spread a few cells over and into a large quantity of ground product. Proper cooking is also essential since bacterial cells are distributed throughout the product thickness. The grinding process also produces more nutrients for bacteria as the muscle sarcoplasm (especially water and protein) is freely available which could shorten shelf life.

24.1.3.5 Mechanical separation

Deboned meat trim or scraps, skeletal frames, necks, and any edible portion of a carcass, with or without bones, may be sent for mechanical separation. Common acronyms include MSC (mechanically separated chicken meat), MST (mechanically separated turkey meat), and MDP (mechanically deboned poultry meat). In the separator machine, meat is first ground, then forced under high pressure (when the meat and bones are reduced to small particles in a paste) through screens that remove bone and most connective tissue. The pressure quickly heats the meat so cooling systems are used to keep it from cooking during the process.

The resulting meat paste is usually bulked packed into 40 or 50 pound boxes or 2000 pound totes. It may be left fresh or frozen after packing. The majority of this meat is destined for further processors to be formulated into products such as hot dogs.

A combination of the heat during the process, the grinding process itself, and the high levels of heme from bone marrow can cause contamination and shelf life issues for this product. Although bacterial spoilage is an issue, the fat and heme present can also result in a relatively quick chemical rancidity. Some buyers request a curing agent be added to the meat paste during production. A powdered form of salt, sodium nitrate and nitrite is added at low levels, which provides a redder color and controls some bacteria, such as *Clostridium* spp., and extends shelf life.

Table 24.2 Representative further processed poultry product retail forms from raw poultry portion(s) and processing step(s)

Raw poultry portion	Further processing step											Finished product form				
	Cut-up	Deboned and skinned (B/S)	Chopped/formed	Marinated			Fully cooked (F/C)			Individually quick frozen (IQF)	Glazed					
				Ground	Needle injection	Vacuum tumbled	Ribbon blender	Batter/breaded (B/B)	Parfried				Fryer	Oven	Water	Canning
Broiler carcass (whole) chicken				✓												Rotisserie
Broiler wing	✓			✓											✓	Hot wings
Broiler fillet or tender	✓	✓		✓			✓								✓	Chicken tender
Broiler fillet, tender, thigh	✓	✓	✓	✓			✓								✓	Chicken nugget or patty
Broiler fillet, tender chicken patty	✓	✓	✓				✓								✓	Roasted
Broiler thigh, drum chicken	✓	✓		✓			✓								✓	Teriyaki
Broiler fillet, thigh	✓	✓		✓			✓								✓	Chicken fajita strips
Broiler fillet, thigh sausage	✓	✓		✓			✓								✓	Chicken
Broiler split breast	✓	✓		✓			✓								✓	IQF split breast
Breeder chicken fillet, tender chicken	✓	✓		✓			✓								✓	Canned
Turkey carcass (whole)				✓												Frozen turkey
Turkey fillet, thigh			✓													Ground turkey
Turkey fillet, thigh burgers	✓	✓	✓	✓			✓								✓	Turkey
Turkey fillet, tender	✓	✓	✓	✓			✓								✓	Turkey ham
Duckling fillet	✓	✓		✓			✓								✓	Duck breast

24.1.4 further processing by ingredient addition and/or heat treatment

Raw whole carcasses, parts, deboned meat, and similar products still retain market share in the US, but the growth of market share is from further processed items. Further processing is in this context the addition of ingredients, and/or heat treatment to poultry meat to create a variety of value-added products. Poultry companies involved with further processing usually have several hundred product labels. Products may be produced and labeled under the company's own name brands, private labeled for retail sale, and produced for the fast food or hotel-restaurant-institute wholesale market. Some processed forms (as shown in Table 24.2) include marinated, chopped and formed, breaded, glazed, parfried, oven roasted, fried, chargrilled, and individually quick frozen (IQF). Major product forms include patties (breaded or roasted), nuggets, tenders, fillets, wings, drums, and thighs, prepared and either parfried (partially cooked in oil for less than a minute) or cooked in many different possible forms. There are many ways to categorize and describe further processed poultry products, but due to the complexity and overlap of processes it is difficult to separate further process products into simple descriptions. Examples of production lines for further processed items are shown in Figure 24.2.

24.1.4.1 Marination

The majority of further processed meat is marinated and is typically one of the first and most extensive of operations in further processing plants. Marination, in the simplest form, is addition of liquid solution to meat for improving functional quality. The functional properties provided include increased water-holding capacity of the meat, with perceived increase of juiciness by the consumer. The added weight of the water is positive for the producer as a yield increase. Other functional properties may include a slight increase in tenderness, and a perceived increase in flavor from the salt and other added ingredients if spices, broth, or juices are added. Basic marinades include water, salt, and sodium phosphates. A typical mixture would be 90% water, 6% salt, and 4% phosphate added at up to 10% of raw product weight. More marinade could be added by reducing the phosphate content for reasons discussed in the following paragraph. More complex marinades may include spices, citrus juices, chicken broth, vinegar, or any flavor additive required for the formulation.

Mixing the marinade solution is somewhat different than other solutions; first, the water should be chilled,

then phosphate slowly added while stirring, and the salt and other ingredients added after the phosphates have dissolved. A limiting factor when formulating and adding phosphates is that in the cooked and finished product, the USDA stipulates that phosphate may not exceed 0.5% by weight. The total amount of marinade added to a product must be displayed on the final label. There is no limit to the type of ingredients that can be added to marinades (other than practical limitations such as flavor and ability to dissolve in solution) as long as the ingredient is Generally Recognized as Safe (GRAS).

24.1.4.2 Meat: bone-in and whole muscle

Whole carcasses may be further processed and in fact are an important “new” product form for producers as the resulting form is rotisserie chicken. Parts, such as split breasts, drums, thighs, and wings, may also be marinated. Different product types receive different marinade levels, and also require different types of marination equipment. Whole carcasses or bone-in, skin-on parts are injected with needles in an injector machine. A bed of needles injects marinade under pressure as the meat passes along a conveyor. The needles are on springs so the needles do not penetrate into bones. Injectors can marinate product at a high rate of throughput and a higher rate of pick-up, sometimes exceeding 20% by weight of raw product. A potential downside is that surface bacteria may be carried into the interior of the meat. Typical marinades for injection are no different from marinades described previously. The amount of marinade pick-up must be taken into account to keep final product phosphate content below 0.5% as described above.

Boneless skinless meat, usually fillets, tenders, and thighs, are marinated in a vacuum tumbler. A large vessel roughly resembling a barrel, containing from 50 to 10,000 pounds, is filled with meat and marinade, sealed, and a vacuum is created. Larger vessels are double-walled so that refrigerant can be added to keep the contents cool during marination. The vessel rotates to provide a tumbling action for approximately 20 min. Baffles inside the vessel promote further movement to maximize marinade pickup. Skin-on carcasses and parts cannot be vacuum tumbled without the loss of skin from the tumbling movement.

24.1.4.3 Meat: muscle formulation

Boneless meat, including any that is unfit for other product forms (for example, minor downgrade whole-muscle parts, trimmings, etc.), is reduced to smaller particle size (approximately one-eighth to one-fourth inch, 3.2–6.4

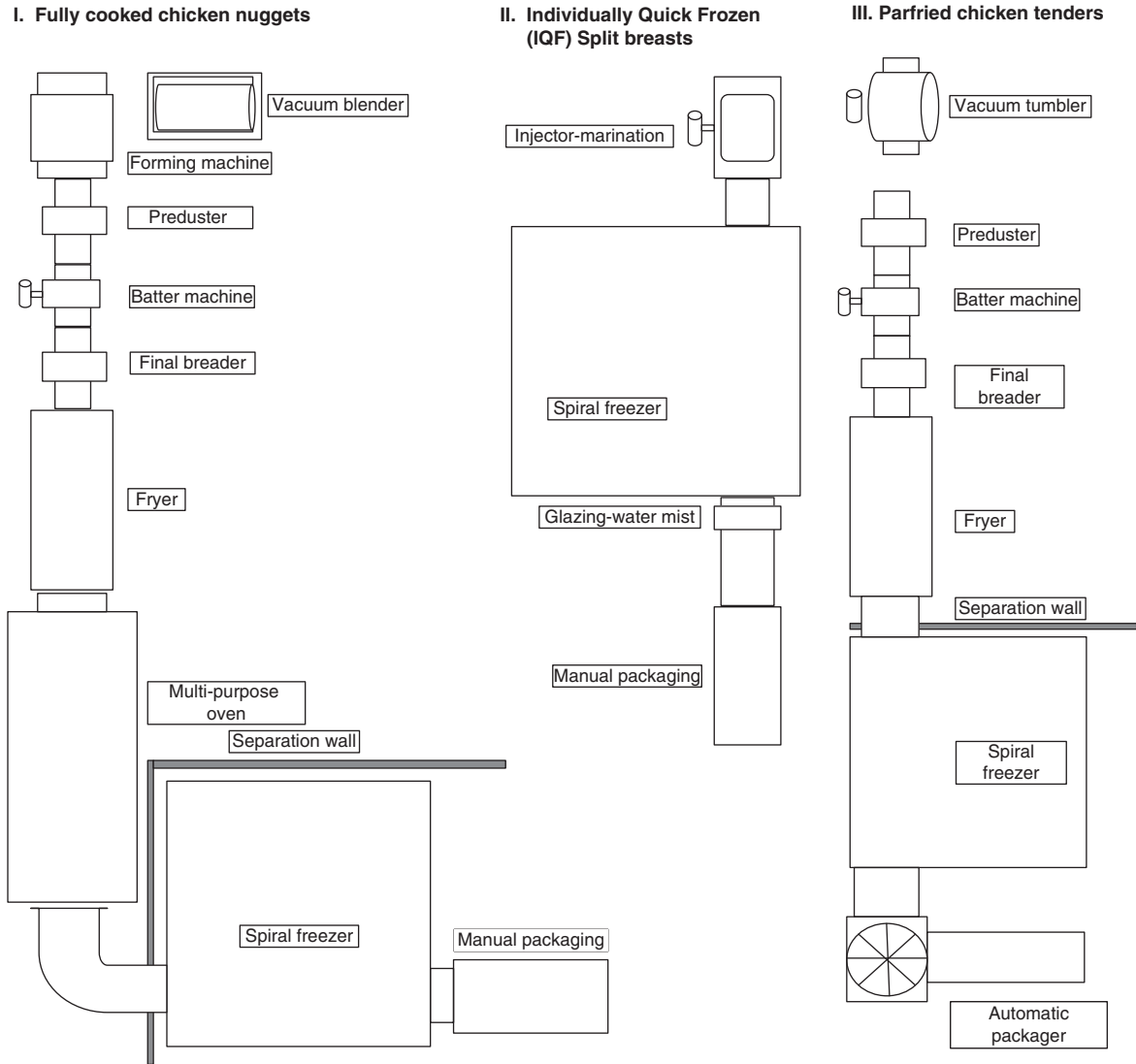


Figure 24.2 Examples of equipment lines in a plant for further processed products (not to scale).

mm) by many methods. Equipment includes meat grinders for larger particle size product, and comminutors or bowl choppers for much smaller particle products. The USDA FSIS allows skin to be incorporated “in natural proportions” to the meat block, or approximately 20% by weight. The skin obviously adds weight at a cheap price, but also has some binding capacity, and adds flavor mainly through its lipid component. A number of other ingredients may be added for functional reasons. Salt acts as a binding promoter by extracting myofibrillar proteins from the muscle and is also a flavor enhancer. Cornstarch

increases binding; sugars add color and flavor; gums add binding capability and may enhance texture; and soy proteins add flavor and nutritional value to formulations.

Spices and flavoring agents may be added at this stage depending on product specifications. Salt is a common additive, as are various peppers, vinegars, fruit and vegetable juices and extracts (such as lemon juice). The mixture of small particle size meat and ingredients is referred to as a meat batter. Ingredients, along with the meat block (bulk, reduced particle-size raw meat), are typically mixed in a ribbon blender. The blender allows fine mixing

control, and may be operated under vacuum if marinade is added. Some of these blenders also may be double-walled to provide cooling capability or directly incorporate carbon dioxide into the meat block for temperature control.

Processing methods include forming machines. The meat block, in bulk quantities, is added to the machine's hopper, and the meat mixture is forced by pressure into molds, then stamped out onto a conveyor belt for additional processing (breading, glazing, etc.). Molds may be simple round nugget or patty sized and filled with batter, or shaped for specialty markets such as stars or dinosaur shapes for children. Other molds replicate a whole-muscle fillet or tender shapes and are filled with larger meat chunks to form a higher value product. Once breaded, these appear to be whole-muscle fillets. A different product and process is turkey meat chunks in a matrix of meat batter placed in plastic bags, then cooked in the bag to form a turkey ham and oven-roasted turkey breasts.

24.1.4.4 Coatings

Numerous, widely different coatings are applied during further processing at different processing points. The simplest is a water spray for parts or deboned meat that coats the product immediately after it is frozen. The spray forms an ice glaze on the IQF product which reduces sticking once bagged, adds an attractive sheen to the product, and adds weight (although the average weight gained is deducted from the label weight).

Perhaps the most popular coating system for poultry is batter and breading, resulting in one of the best known poultry products in the US, fried chicken. The basic process is a three-step system, with raw or marinated parts placed in a dry predest, followed by a wet batter coating, then a final dry breading. A typical system adds approximately 20–30% by weight to the incoming product. The USDA FSIS allows up to 40% breading addition, but the product must be labeled as a fritter if pick-up exceeds 40%. Above 60% and the product is labeled as other than chicken, such as chicken meat-flavored breading. Higher pick-ups may be achieved by thickening the batter, or adding passes of the product through multiple predest and batter applicators. There is incredible variety in the ingredients used in these coatings; types of grains (although usually corn or wheat based), salt and other spice content, color additives, and particle size all contribute to different outcomes in finished product. Predests and breadings with smaller particle sizes result in a finer,

more homogenous coating and even coloration, and probably smoother and slightly chewy mouthfeel. A large particle-size breeder will produce more uneven coloration and texture, providing a more colorful and crunchier coating.

Equipment to add bread coatings utilizes a continuous conveyor line of stainless steel wire to move product through the system. The predester is loaded with the dry mix, and it falls or sifts onto the product from above, and the wire conveyor also pulls the product across a bed of predest to coat the bottom. The product then enters the batter machine with a pool of batter coating the product, with some machines also cascading batter from above the product. A dry mix is combined with water at the machine and is typically refrigerated to both thicken the batter for increased pick-up and to extend the shelf life of the recirculated liquid. The product is then conveyed into the final breeder machine, usually the same machine as used for the predest. Additional in-line batter and breeder machines may be used to increase the pick-up for frittered products. A different type of predest or final breeder machine is barrel shaped. It is in-line, mounted at an angle, and turns as product enters the top and exits the bottom. These are usually used for smaller whole-muscle pieces to be frittered, such as tenders, or specialty items such as chicken livers. Another specialty product is tempura batter, a unique, thick application for products such as corn dogs or Asian products. The battered product falls immediately into a fryer to set the batter, and may be parfried or fully cooked.

Other coatings are glazes for oven-roasted products. Whole-muscle or formed fillets are placed on an oven line for cooking. Prior to oven entrance, product is dipped into a glaze, a slightly thickened water-based liquid usually with added sugar. This imparts additional weight but mainly has an esthetic effect, adding a slight color and glossy appearance. Other products may have a sauce glaze applied after cooking and before freezing, such as hot wing items.

24.1.4.5 Heating

Because there are many products and preparation methods, there are many ways to heat or cook poultry meat. More meat is cooked by the further processor currently than before as more major fast food customers are requiring fully cooked items due to food safety concerns in their restaurants. For heating and cooking, ovens and fryers are designed to be used for in-line processing to keep product moving through the heating process. Water cookers also

have a system to pull items through the system. Steam kettles and rack ovens (similar to the smokehouse cookers) used for some items such as whole spent hens and turkey loaves are batch only. In-line microwave cookers are still used but are rare.

Fryers may be used to parfry or fully cook poultry items. Fryers currently sold are indirect heat models, where a non-flammable liquid is heated external to the fryer body, then pumped to the fryer and circulated through tubes in the bottom of the fryer, which heats the frying oil. Older model fryers used direct heat. Gas jets under the fryer were ignited and these heated the tubes in the fryer bed. However, these were discontinued because they were too dangerous to operate due to fire hazard and resulted in several plant fires. For parfrying, batter/breaded items dwell for 30–60 sec to set the coating adhesion and color. Fully cooked item dwell depends on the size and type of product. Most products are not fully cooked in fryers any longer due to poor yield as fluid escapes, health-conscious consumers requiring lower fat products, and the greatly reduced oil quality from the long dwell and escaping fluids and breading crumbs or fines. Stainless wire belting pulls product along the fryer bed. An overhead belt operating at the same speed as the bottom belt is also used so that items floating in the oil are moved along and out of the fryer. The hot oil is circulated, filtered to remove crumbs and fines, and reused until the quality is degraded. Eventually the accumulation of free fatty acids and oxidation products renders the oil unusable. Fryer oil temperature is closely monitored to keep product cooking at a temperature lower than the flashpoint of the oil and extend the life of the oil.

The typical in-line oven cooking system is between incoming product and a freezer. Product may arrive at the oven belt from a batter/breader line, from a marination line, from a fryer used for less than a minute to set the coating, from a forming machine, or a bulk loader placing product on line. Product enters the oven to reach a particular temperature and then is immediately frozen to increase yield. Some roasted products may be chilled and packaged without the freezing step.

There are several general in-line oven types and many variations among the designs. Simplest is the tunnel oven heated by gas jets, electrical heat, or steam. More recent designs combine heating systems to maximize yield and product quality. Special batter and breaded coating systems can be cooked in an oven without a fryer by combining or alternating dry and moist heat as the product passes through the oven, along with fans for convection heating. Another type is a spiral oven, where the wire conveyor spirals

upward. This design promotes a smaller footprint within the plant and also requires less energy for heating product. Another oven utilized for non-breaded items conveys product through on plates that are heated, while heated plates also contact the product from above. The plates sandwich the product above and below, acting as a griddle press.

Traditional cooking technology is still used, such as batch cooking whole birds in steam kettles. The meat is deboned afterward, while broth is captured and sold as another product. Whole birds may also be bagged and passed through water cookers or placed in racks and wheeled into batch ovens. Turkey loaves and formed roasts are also bagged and cooked in the same type of oven.

Poultry meat is also canned. Meat from old birds, usually breeders past their laying capability, is processed and deboned. The canning process is the same as for low-acid foods, with similar time and temperature requirements to eliminate pathogens and spores. The meat from old birds is used because it is tough and contains more connective tissue. The tender meat from younger birds would dissipate into solution inside the can from the salt and harsh canning procedures (extreme heat and pressure over time).

24.1.4.6 Freezing

Very few further processed poultry are sold or marketed as fresh. Rotisserie chickens or roasted parts and some cooked-in-bag products such as turkey loaves are refrigerated rather than frozen. Most other products are frozen, and many options are utilized. Tunnel freezers with conveyors pass product through forced cold air impingement at -35°F (-37.2°C). Older versions still in use force carbon dioxide into the tunnel to create powder (snow) or pellets that are in direct contact with product to produce a quick freeze. Even faster freeze is accomplished with liquid nitrogen with an effective temperature below -150°F (-101.1°C). Sometimes the tunnel freezer is used as the sole method for freezing, but may also be used as a prefreezer to crust freeze cooked product and maximize yield, before another freezer such as a spiral freezer brings the product to a range of -20°F to 0°F . Another method is a plate freezer, similar to the plate oven, except the plates are cold and provide fast heat transfer. These freezers are normally used for smaller, flatter items such as boneless skinless beasts, tenders, or patties. For higher volume throughput, further processors are employing in-line spiral freezers. These freezers utilize fans and large condensers to quickly freeze products. The footprint to throughput ratio is small, and less energy is needed than for tunnel freezers with equal freezing capacity.

24.1.5 packaging and labeling

Processed and further processed items are packed into initial packaging on the line, and then into secondary containers. There are literally hundreds of different types of packages. Basic types include foam trays with plastic over-wrap, plastic bags, resealable pouches, shrink-wrap bags, and paper cartons.

Raw or fresh poultry is typically packaged in one of three types of systems/materials: ambient, vacuum, or modified atmosphere packaging (MAP). Ambient atmosphere packages are polystyrene foam trays with stretch film which are common for parts and deboned meat. An oxygen barrier is not used so as to minimize *Shewanella putrefaciens* growth and accompanying noxious odors associated with the product. Vacuum packaging can be used for whole carcasses (bags) or for parts or deboned meat (thermoform pouches, either single-use or resealable). Vacuum packages can extend shelf life to a limited degree by reducing aerobic bacteria growth (although growth of anaerobes and facultative anaerobes is promoted). MAP is used for parts, deboned meat, or ground product. Some shelf life extension is accomplished via low oxygen (20–30% CO₂, balance nitrogen), high oxygen (75–80% O₂, balance CO₂) or high carbon dioxide (60% or higher CO₂) flushes, depending on the product type.

Many types of systems are available for further processed and frozen products. Shrink-wrap bags or pouches, form-fill bags, rigid trays with sealed film overlay, cook-in bags, cook-in sealed trays, resealable bags, pouches, or trays are all currently used for various items. The plastics used are oxygen barriers, and some also incorporate oxygen or odor scavengers to protect products. Packaging for value-added products must balance consumer convenience with product protection.

Packing may be done by hand, but many processors use automated weighing and bagging equipment for smaller size items such as nuggets and tenders. The product falls into a sorter and then into a number of bins that have scales incorporated; each bin drops its contents into bags that are sealed as they exit the machine. Cook-in bags are used for raw poultry destined for water or batch cooking, usually whole birds or loaves. Regardless of pack method, once in the initial package, multiple units are placed into secondary containers, typically a cardboard box. Boxes are stacked and palletized in preparation for storage and shipment. Some products, such as mechanically separated meat sold to other further processors, may be placed in plastic liners inside large cardboard containers that contain 2000 pounds and are preattached to pallets.

Labels are approved according to federal regulations for inspected products. Labels are required for both initial and secondary packaging, depending on the end use of the product. Labels must contain information such as product name, net weight, ingredients, manufacturer name and address, nutritional information, and safe handling instructions, and the plant (P) number assigned by the USDA. Barcodes are added to packages for inventory purposes of the manufacturer and retailer but are not required by the FSIS. However, barcodes and distribution information are extremely helpful when conducting product recalls.

24.1.6 Shipping

Poultry products, whether fresh or frozen, raw or further processed, must be shipped from the plant to commercial locations. Important factors for maximizing product quality and profit include moving the packaged products immediately into coolers or freezers. Second, the products must be rotated quickly and efficiently out of holding and onto transportation. Trucks transport most items due to flexibility of movement and, until recently, relatively cheap fuel costs. Processors with railroad access may send lower profit bulk items with long shelf life, such as frozen leg quarters, via railcar to seaports for export. Third, the truck trailer or railcar must be inspected and found to be in good working condition and clean before product is loaded. Lastly, the carrier must be required to carry an insurance policy in case of accidents or refrigeration equipment failure.

Most non-further processed poultry produced for domestic consumption is shipped “fresh”; poultry may be chilled to 26°F (–3°C) before it is considered to be frozen by the USDA. The crust-frozen raw product retains a longer shelf life when shipped long distances. Further processed items, especially battered and breaded items, are shipped frozen. More than 19% of US poultry production was exported throughout the world in 2012, with major markets in Asia, the Russian Federation, and Mexico. Practically all export shipments are frozen non-further processed parts or mechanically separated chicken (MSC). Approximately 12% of US turkey production is exported.

Data from the USDA National Agricultural Statistics Service showed that in 2010 approximately 10% of broiler pounds processed and 59% of turkey pounds processed were frozen. Duck meat is stored for longer periods, so although 43 million pounds were processed in 2010, there were 73 million pounds in frozen storage (excess from the previous year’s production).

24.2 Turkey processing

The overall procedures for transforming live animals into meat are similar for turkeys as those previously described for broilers, with notable exceptions. Males (toms) and females (hens) are sexed at the hatchery and raised separately. Larger males (up to approximately 20 kg) are grown longer to maximize breast meat yield that is deboned for further processing. Lighter and younger females (approximately 5–10 kg) are grown more for the whole carcass market, including retail holiday sales. Preharvest steps are generally similar to broilers, except the feed withdrawal program may differ as many turkeys are still on natural light versus artificial lighting, requiring adjustments to the program. Achieving an 8–12 h withdrawal is more difficult as it is determined by the last feeding time, which depends on day length. Also, live turkeys are loaded onto trucks by herding the animals up ramps from the house to the trailer then manually placed in the cage.

Unloading of turkeys would seem to be a simple process, and not associated with stunning, but recent developments are significantly changing these portions of turkey processing operations. The traditional system involves the truck trailer pulling into a loading dock with different heights of dock on both sides of the truck. The slaughter shackle line extends onto these loading docks, and workers pull the live turkeys from the trailer coops and hang them upside down on the shackles. The work is especially difficult for unloading large tom turkeys so the unloaders are highly paid, but working conditions are most unpleasant as the area is basically a covered shed without heat or air conditioning. Injuries are common to both workers and the turkeys, and since the shackle line is very long the turkeys are on the line for several minutes prior to stunning. Because of the labor, animal welfare, and quality issues, some turkey processors have implemented various types of gas stunning technology. Gas, or modified atmosphere, stunning is conducted by applying gas or gas blends (typically 30% carbon dioxide and 60% argon in air, or 90% argon in air, or 40% carbon dioxide, 30% oxygen, 30% nitrogen) to turkeys in a confined space to render them unconscious. The procedure for some systems has the advantage of stunning birds before hanging, alleviating problems described earlier. Meat quality is improved by inflicting less stress on birds and also from fewer broken wings due to flapping after hanging. Negatives to the system include higher costs and proper implementation; if not conducted correctly, gas stunning stresses the birds as they react to low oxygen

levels. Gas stunning may be conducted by placing a shroud over the entire truck trailer and pumping in gas; individual coops may be removed from the trailer and placed in a chamber, and, for smaller hens, they may still be hung on shackles and then the line enters a chamber filled with gas.

Turkey processing after stunning is generally similar to broilers, but with more people used and less automation to eviscerate the turkeys. The lines run much slower with fewer animals processed per day compared to broilers at 140 birds per minute: depending on the inspection system, either 45 birds per minute for carcass weights above 16 pounds or 51 per minute for carcass weights below 16 pounds. A different shackle may be used to hang the neck as well as the feet, allowing easier access to the internal cavity. Chilling times are twice as long (8 h to $\leq 40^{\circ}\text{F}$ (4.4°C)) due to the considerably larger carcass size. Alternatively, when carcasses are processed for a further processor, a short immersion chilling time is used and carcasses are immediately deboned, then only the meat is chilled. Turkey further processing is also generally similar to broilers, with the main difference in market forms. Major market segments include the traditional whole frozen carcass and formulated turkey loaves and ham products, but not many batter and breaded parts or formed items.

24.3 Duck processing

Ducks or ducklings (less than 8 weeks old) are processed similar to broilers. They are grown similarly and reach market weight of 6 pounds live weight by 35–40 days. For processing, they are loaded onto truck trailers more similar to turkeys as they are walked onto multilevel trailers. They are unloaded by walking them off the truck after arrival at the plant. Live birds are hung on the shackle line by the feet and go through slaughter, evisceration, and chilling equipment similar to broilers. Although an electrical stunning system is used, ducks are much harder to stun since they have little exposed tissue on the head to conduct electricity, and their feathers and thicker, fattier skin also impede electrical flow. Gas stunning has not been successful with ducks due to their diving reflex and ability to not breathe for several minutes. Feather picking is also much more difficult because of the physiology of the skin and feathers. Multiple passes through various specialty pickers are required, and after picking the carcasses pass through a series of hot paraffin and cold water baths. The paraffin sticks to the carcass and small pinfeathers, and when removed by workers

most of the pinfeathers and hairs stick to the wax. During evisceration, some plants have more people and less equipment, while other plants are more automated.

Duck further processing has increased significantly during the past 20 years. Previously duckling was sold as a whole frozen carcass for the holiday or specialty market. Now duckling carcasses are deboned and meat is marinated, battered and breaded or glazed, parfried or cooked, just as broiler meat is currently further processed.

Duckling processing yields valuable by-products not usually captured by the broiler or turkey processors. Feathers are collected, washed and dried, sorted and baled at the plant. Although it is a cyclical market, in some years feathers are worth more per pound than duck meat. Tongues are harvested from duck heads for specialty Asian markets, and are always worth more per pound than duck meat. Feet are collected (similar to chicken paws), but are worth more than broiler feet. Livers are collected and may be used for *paté* or *foie gras*. Abdominal (leaf) fat is harvested from carcasses, cooked with water in steam kettles to render the fat, then skimmed and cooled. It is packaged as high-value lard sought by gourmet chefs for pastry. Approximate retail prices in 2012 for various duck products were (on a dollar per pound basis): raw whole carcass \$3.00–3.50; tongues \$17.50; fat \$7.25–13.00; raw liver \$5.75; and feet \$3.25. Another specialty market is the head-on, feet-on (HOFO) market, where carcasses are sold with head and feet intact. To improve carcass appearance, birds are pithed (killed by insertion of a metal rod into the brain through the roof of the mouth) or have a knife inserted into the throat through the mouth to cut the carotid arteries and jugular veins. This occurs after stunning, and does not leave a visible external cut on the neck. Since the heads and feet remain, the birds are not USDA inspected. The non-inspected HOFO carcasses are exported or sold locally; all quality standards are negotiated between the plant and customers.

24.4 Microbiology and food safety

Extensive information, including several textbooks, is available on the subject of poultry microbiology. In general, regardless of the type of poultry processed, shelf life extension and pathogen control are dependent on low numbers of microbes on live birds and proper handling during processing and distribution. Heavily contaminated birds entering the plant or temperature abuse of the processed carcass and products create opportunity for both diminished shelf life and increased pathogen levels.

24.4.1 Spoilage

Fresh poultry rarely exceeds 2 weeks of refrigerated storage before microbial overgrowth degrades the quality to the point of inedibility. Several genera are typically reported to cause poultry spoilage, including *Pseudomonas*, *Acinetobacter*, *Lactobacillus*, and *Shewanella* species. Fresh poultry that is marinated has also shown a propensity to spoil from yeast overgrowth. Frozen poultry, even without microbial spoilage, usually spoils after several months due to chemical spoilage (rancidity) as the monounsaturated and polyunsaturated fats common in poultry meat undergo oxidation.

Microbial spoilage of fresh poultry is accelerated, as previously noted, by higher loads of bacteria remaining on the product from live conditions or introduced to the product during processing. After processing, periods of higher temperature conditions (temperature abuse above 40°F) promote bacterial growth of psychrotrophic and psychrophilic bacteria, which shortens the time to spoilage (Figure 24.3). Chilling followed by refrigerated conditions select for these bacteria, which is a cost of controlling pathogens that are typically mesophiles.

24.4.2 Food safety

There are several bacteria that cause human illness and are associated with consumption of poultry meat or products. The US Department of Health and Human Services Centers for Disease Control and Prevention (CDC) collect and publish human food-borne illness data. In 2011, the CDC published estimates that the five leading causes of food-borne illness were norovirus (58%), *Salmonella* spp. (11%), *Clostridium perfringens* (10%), *Campylobacter* spp. (9%), and *Staphylococcus aureus* (3%). Norovirus is not normally associated with poultry but the four bacteria have been implicated in consumption of poultry products. Another important bacterium associated with further processed poultry is *Listeria monocytogenes*, which the CDC estimated is the third leading cause of death from food contaminated with bacteria.

Salmonella (non-typhoid) has been closely associated with poultry consumption for many years. The CDC estimated that 17% of salmonellosis in the US is due to poultry consumption. *Salmonella* has more than 2000 serovars, and survives in many different environments outside the intestinal tract since it is a mesophile and facultative anaerobe. It readily colonizes bird intestines (without any deleterious effect on the animal) and the housing environment. Many control methods have been

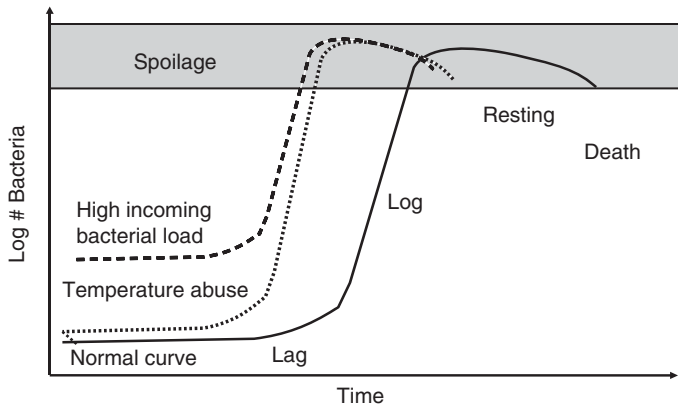


Figure 24.3 Example of a bacterial growth curve (solid line) showing increase of numbers of bacteria over time divided into lag, log, resting, and death phases of a typical microbial population present on a raw refrigerated poultry product, from 0 to 20 days. Other lines represent the decrease in shelf life due to shortened lag times from product subjected to temperature abuse (dotted) or containing higher initial numbers of bacteria (dashed).

developed to control *Salmonella* contamination, but so far it has been impossible to eradicate from poultry.

Clostridium perfringens is a ubiquitous bacterium found in live poultry environments. In high numbers, it causes enteritis in young chickens and poults. As a mesophilic spore former, it is almost impossible to eliminate from poultry. Live poultry can carry vegetative cells and spores, and after cooking the spores may vegetate. In low numbers, *C. perfringens* is unlikely to cause illness, but in mishandled poultry leftovers or temperature-abused cooked product, numbers quickly develop to levels causing human illness.

Campylobacter jejuni and *E. coli* are commonly found in poultry intestines. Outside of intestines, the organism is found in contaminated water and milk, but is not considered hardy in most environments. It requires a micro-aerophilic environment and therefore does not survive long in aerobic conditions. However, it is very motile and can travel to better conditions if sufficient moisture is present. The USDA began requiring poultry plants to monitor and report *Campylobacter* incidence in 2011–2012, depending on plant size. This action was taken since the CDC estimated that 24% of campylobacteriosis in the US is due to poultry consumption. Cold temperature, dry conditions, and acidic environment reportedly help control incidence, but these conditions do not normally exist in US poultry processing plants.

Staphylococcus aureus can be found on live poultry, but is also commonly associated with humans who can be carriers. It is associated with poultry mainly due to postcook contamination of dishes containing poultry such as chicken salad or catered poultry. It survives well at higher salt levels and is a facultative anaerobe, and can be an environmental contaminant. *S. aureus* toxin is heat stable,

so contaminated foods can still cause illness after cooking or reheating.

Listeria monocytogenes has been associated with several foods, including processed and fully cooked poultry. Since it does not survive cooking it is introduced via the environment post cook. *Listeria*, a psychrophile, survives very well in cool, moist environments, which characterize poultry processing plant fully cooked packaging rooms. The organism lives in the refrigeration condensers, drain pans under the condensers, and floor drains, and therefore has the opportunity to contaminate product via condensation or during cleaning in breaks.

24.5 Sustainable poultry production and processing

More people are choosing to grow and process their own animals for meat in the US, especially poultry in the south east. North Carolina has become a leading state in small poultry flock growing and processing. In 2012, approximately 100,000 poultry were slaughtered at two small federally inspected processing plants. At least four mobile processing units (MPU) are available in the state for rental, producing an additional unknown number of processed poultry for sale to neighbors, farmer's markets, and local restaurants. The state allows up to 20,000 poultry per farm to be grown and slaughtered, exempt from federal inspection as long as product is not placed in interstate commerce. The NC Department of Agriculture conducts occasional inspections and records review but does not inspect each animal.

Breeds other than commercially available broilers and turkeys are used because they seem better adapted

Table 24.3 Domestic production and exports of broiler meat (×1000 metric tonnes) of the top four producers in world broiler production, 1997–2012 (data from USDA Foreign Agricultural Service)

	Country	1997	2002	2007	2012
Domestic production	USA	14,952	14,467	16,536	16,476
	China	10,400	9558	11,500	13,700
	EU	8177	6850	8111	9480
	Brazil	4562	7355	10,305	12,750
Exports	USA	2565	2177	2618	3211
	China	367	438	358	400
	EU	944	850	623	1080
	Brazil	665	1588	2922	3478

to pasture or mobile coop conditions than the white-feathered commercial hybrids. The pasture breeds are slower growing, may have slightly better disease resistance, and are more mobile for foraging, possibly because of slower growth and lower body weights.

Carcass yields from these birds are generally lower compared to commercial hybrids for breast meat, but have similar yields for other parts (wings, drums, thighs, back). Meat texture has generally been reported to be more tender from commercial hybrid strains than from pasture raised or *Label Rouge*-type broilers. Reports on meat color have been varied with no particular pattern observed between multiple studies. Similarly, subjective sensory panels evaluating meat for color, flavor, texture, juiciness, and other profiles have found mixed results between commercial hybrids and pasture or *Label Rouge* broiler meat. Although anecdotal claims are made that pasture-raised or *Label Rouge* broiler meat is superior to commercially available meat, no clear trend exists in scientific studies.

Resources are available to consumers interested in sustainable poultry rearing and processing (see Further reading). The sustainable poultry market segment is expected to grow due to consumer awareness of these products and willingness of new small farmers to add poultry to their diversified products. Also, major commercial processors are addressing sustainability in various ways. Most are considering or have already implemented measures that reduce or eliminate antibiotics given to birds during rearing, promoting environmentally positive uses of poultry litter, and reducing waste at the plant, particularly packaging waste. Of course, these measures also reduce live bird and processing costs, as well as appealing to sustainability-conscious consumers.

24.6 Conclusion

The US is the world's largest producer of poultry and second largest exporter (see Table 24.3). Other countries such as Brazil and China are rapidly expanding their production capabilities. While China's production has been mostly to support domestic consumption, Brazil already exceeds the US as the world's largest poultry exporter. This was accomplished by exporting more than 27% of production, compared to the US exporting 19% of domestic production.

In the US, per capita consumption of poultry has exceeded both beef and pork consumption, and is gaining on total red meat consumption. The poultry processing industry has continued to grow as a business and currently employs more than 300,000 people. The industry should remain at or near the top of world production in the foreseeable future just by supplying the demands of the expanding US population. Constraints on future US expansion include rising feed costs, labor shortages, and availability of water.

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