Marination and Brining of Poultry Products: Value Added

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In the U.S., the per capita consumption of poultry has continued to rise since the 1960's with the largest increase in production of further processed and convenience products (Figure 1). Because of the emphasis on value-added products, the poultry industry has become focused on improving product yield and meat quality. Commonly used methods of adding value to poultry meats include brining and marinating. Historically, the purpose brining and marinating meat was to preserve the meat. While meat preservation is still an important issue, today, brining and marinating are commonly used to increase yields by increasing water retention and improve meat quality characteristics, particularly meat tenderness.

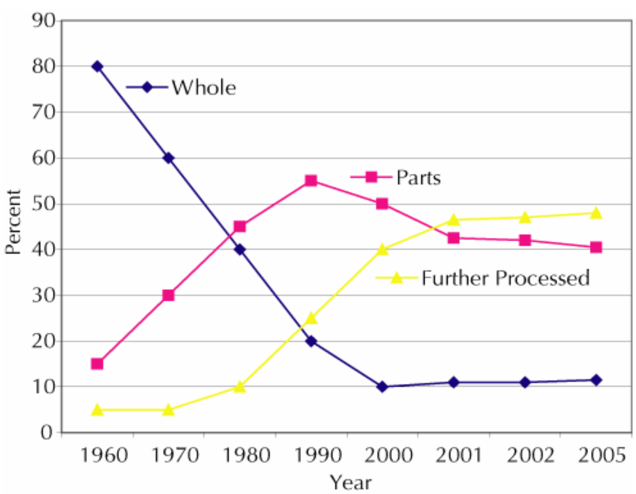

Figure 1. Percentage poultry industry production from 1960 through 2005.

The terms brining and marinating are often used interchangeably, yet they actually refer to two different solutions having some similar functional ingredients. Brining typically involves injecting the meat with a salt water solution or soaking the meat cut or whole muscle in a salt water solution. Therefore, the basic ingredients in any brine preparation would minimally include salt and water. In addition, brine formulations will include some type of phosphate, most commonly, sodium tripolyphosphate (STPP) (Barbut *et al.*, 1989). The role of functional ingredients such as salt and phosphates will be in more detail. Other ingredients that may be used in a brine formulation include spices and seasonings such as sugar, honey, pepper, garlic, onion and other flavorings. Cure salts such as sodium nitrite are used in cured product formulations. During processing, brines can be used as soak solutions, injected into the meat and then soaked or they may be injected into the meat and then tumbled. In addition to improving the quality of meat cuts or whole muscle, brining can be used as a functional step in the production of value added formed and sectioned meat products.

In the market, meat injected with salt/phosphate solution products is typically referred to as "enhanced" while meat soaked in marinades is typically referred to as marinated product. Like brining, marination evolved as a method of meat preservation; however, unlike brining, the process consists of soaking meat in seasoned or savory acid liquid or sauce to enhance the flavor and tenderness of the meat. Marinades typically include a mixture of oil and acidic liquids such as vinegar, lemon juice or wine and other spices. Salts and phosphates may also be used with marinades, but the pH of the system is lower than that of a typically brine formulation.

Functional properties of meat and ingredients in brines and marinades

Salts

Two of the most common ingredients in brines and marinades are salt (NaCl) and some type of phosphate, most commonly, sodium tripolyphosphate (STP) (Barbut *et al.*, 1989). Salt (NaCl or KCL) is one of the oldest and most effective food preservatives used (Salt, Institute). Aside from the fact that salt easily dissolves in water, salt is included in poultry meat formulations to: (1) enhance product flavor; (2) increase moisture retention; (3) act as a synergist with STP to extract salt soluble proteins; (4) inhibit the outgrowth of *Clostridium botulinum* via salt's synergistic role with so-

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dium nitrite (cure); (5) at high concentrations, salt applied to the surface of meat dehydrates the meat and serves as a preservative (Keeton, 2000).

Because salt easily dissolves in water, the ionic strength of the water increases. Poultry meat contains approximately 70% water, which is ionic in nature due to the monovalent minerals present in muscle tissue as soluble salts and the ionized forms of these salts (e.g. cations – Na^+, K^+ & anions – Cl^-, S^-) (Hedrick et al, 1989). However, the ionic strength of the muscle tissue fluid is lower than that of brine, and through the process of osmosis, the brine solution will be absorbed by the meat until a state of equilibrium is reached. Salt content of meat product is not a regulated ingredient and is self limiting because high concentrations will negatively affect the palatability of the product. Typically, finished brined-poultry meats and products will contain approximately 2% salt on average. Depending on the products, salt levels can range from 1.5% up to 3%. Because of dietary restrictions on salt intake, ingredients such as potassium chloride (0.75% in a 60:40% NaCl/KCl combination), phosphates and other high ionic strength compounds can help increase water holding capacity (WHC) while maintaining low levels of salt. Although, KCl is not readily used in further processed products because it can lead to astringent off-flavors in the product (Claus *et al.*, 1994).

In addition to salt levels, purity of salt is also important. Sea salts and impure salts contain metals and minerals that can interfere with the brine system and decrease the effectiveness of other ingredients such as phosphates.

Water Holding Capacity

While salt increases meat tenderness, the state of the myofibrillar proteins will determine how effective the salt will be with improving meat characteristics (Camou and Sebranek, 1991). The most important myofibrillar proteins associated with meat quality characteristics and water binding are actin (thin filament), myosin (thick filament) and their combined structure actomyosin, which are found in the salt soluble fraction. Salt soluble (>0.4 M) proteins make up approximately 50-55% of the total myofibrillar proteins. Salts function by unfolding myofibrillar proteins and solubilizing them in salt-water solutions. Myofibrillar proteins unfold due to electrostatic repulsion of the Cl^- ions and charged binding sites are exposed (Rust, 1987). In addition to exposing more charged sites where water can be bound, the electrostatic repulsion will increase the space between the thin and thick filaments. Increasing the size of the space between filaments increases the amount of water that can be retained by the muscle. Water occupying this space is referred to as free water and is held there by the "steric effect" (Lawrie, 1991). Free water makes up the majority of water that is retained by meat. Immobilized water refers to water that is also entrapped but is further held by a net charge attraction. Bound water is bound to the ionizable groups of amino acids of the proteins and other groups able to form hydrogen bonds. Around 4% of the water is bound to the muscle proteins and cannot be removed, immobilized water accounts for 10-15% and can be removed by cooking, and the remaining water is loosely bound or free which can be lost by processing procedures such as cutting, grinding, and storage. Therefore, anything that influences the spacing between the thick and thin filaments or the ability of the proteins to bind water can affect water holding properties of the meat.

pH and WHC

A related factor influencing water binding is meat pH. The rate and extent of pH decline during rigor development in muscle can influence myofibrillar protein functionality thereby altering meat tenderness, color, water holding capacity and meat protein binding ability (Judge *et al.*, 1989). As rigor develops, myosin combines with actin to form actomyosin. Actomyosin, while not a poor water binder, is not as good as myosin and not as readily solubilized. Additionally, lactic acid accumulates and muscle pH drops to 5.6 or 5.7 in normal tissue (Pearson and Young, 1989). In broilers, rigor mortis takes 4-6 hrs to complete and in turkeys, 6-8 hrs. As pH declines during rigor, there is an efflux of fluid from the myofibrillar space caused by the decrease in negative electrostatic repulsion between filaments (Swatland, 1993). As rigor is resolved, the muscle pH is nearing the isoelectric point for the myofribrillar proteins, which is approximately 5.1. Decreased water holding capacity occurs because actin and myosin are near their isoelectric point in post-rigor meat and the net charges on the protein will be a minimum as will space between filaments for water to be held or bound. Furthermore, researchers have reported increased protein functionality from prerigor meat. For example, Xiong and Brekke (1999) found greater extractability of myofibrillar proteins from prerigor meat as compared to postrigor meat. Also, the researchers observed that early postmortem meat had increased water retention compared to postrigor meat. Postrigor meat has decreased spacing between filaments and decreased protein functionality; therefore, less free water will be retained.

Decreased water holding capacity is even more evident in meat from animals that have accelerated post-mortem metabolism after slaughter. Briskey (1964) postulated that the low pH resulting from rapid metabolism early postmortem when combined with high carcass temperatures caused extensive protein denaturation in the muscle thereby affecting meat quality characteristics. The loss of protein functionality due to extensive protein denaturation is considered to be the primary factor associated with the development of pale, soft and exudative (PSE) meat characteristics (Warris and Brown 1987; Fernandez *et al.*, 1994; Santos *et al.*, 1994). When meat conditions such as pale, soft, and exudative meat exist, the water holding capacity and other meat quality characteristics are further compromised because of the extensive protein denaturation. Differences in water holding capacity, brine pick-up and retention have been reported to vary with fillet color and initial fillet pH. Allen *et al.* (1998) compared brining and WHC of broiler breast fillets characterized as "lighter than normal" fillets to fillets characterized as "darker than normal." Their findings suggested that the fillet color and pH were highly correlated with water holding capacity and percentage of brining pick-up and retention. Fillet characterized as lighter in color had an initial lower pH, lower brine pick-up and higher drip and cook loss compared to fillets that were characterized as dark. At meat pH below 4.5 and above 10 irreversible changes occur affecting protein functionality and decreased water-holding capacity (Pearson and Young, 1989). The water lost due to irreversible loss of protein functionality includes free, immobilized, and bound water. Therefore, it should be noted that meat with extensively denatured proteins, such as PSE, brines or marinade ingredients cannot overcome the all of protein functionality lost.

Phosphates

Phosphates vary in their solubility and effect on muscle pH, but generally alkaline phosphates improve water retention by shifting the pH further away from the isoelectric point of the myofribrillar proteins and by unfolding of muscle proteins, thereby exposing more charged sites for water binding (Pearson and Gillett, 1996). Additionally, actomyosin bonds in postrigor meat are cleaved by phosphates thereby increasing the potential for swelling of the filaments (Offer and Knight, 1988). Phosphates are able to shift pH due to their buffering capacity. Typically, short chain phosphates such as orthophosphates and pyrophosphates have the best buffering capacity while the longer chain phosphates have less buffering capacity; therefore, the percentage of diphosphate or pyrophosphate will determine the strength of the buffering capacity. Depending on the type of phosphate used, pH of the solution can be increased or decreased. Acid phosphates include monosodium phosphate, monoammonium phosphate, and sodium acid pyrophosphates while alkali phosphates include di- and trisodium phosphates, sodium tripolyphosphates, and tetrasodium phosphate. Acid phosphates would typically be used in marinades where the solution pH is low. Because low pH tends to decrease water binding, alkaline phosphates would be more likely used in brine solutions to maximize water holding capacity.

When phosphates are used for increasing water holding properties of meat, USDA requires that phosphate concentrations are no higher than 0.5 % of the finished product weight. Although there are many phosphates to choose from, STPP remains the most commonly utilized in brine solutions because it is easy to use and inexpensive. STPP accounts for approximately 80% of the phosphates used in further processed meat products. Other commonly used phosphates included in solutions are sodium pyrophosphate and sodium hexametaphosphate. Alkaline phosphates such as STPP serve to increase WHC, increase cook yield, extract muscle proteins, reduce oxidative rancidity, preserve meat color, increase flavor retention, and reduce microbial growth (Barbut *et al.*, 1990).

The most functional phosphate is pyrophosphate; however, the solubility index is low. For this reason longer chain, STPP is commonly used and blends of phosphates are used to optimize solubility and functionality. When added to water, STPP is hydrolyzed forming the functional diphosphate. Pyrophosphates are a more soluble form of diphosphates and are therefore easier to use. In poultry products, sodium pyrophosphates and STPP has been shown enhance the water holding capacity and salty taste in frankfurters formulated with reduced salt levels by 20 and 40% (Barbut *et al.*, 1988).

Tetrasodium phosphates produce good binding ability because of their high pH (approximately 11) while sodium acid pyrophosphate decreases pH and as a result, decrease WHC and yield. Also, tetrasodium pyrophosphate allows for the greatest bind in emulsion products but has a pH of 11, which can be caustic. Furthermore, tetrasodium phosphate begins to create a soap when combined with fats (Pearson and Gillett, 1996). In contrast, sodium acid pyrophosphate is acid in nature and has poor water binding properties in comparison to the alkaline phosphates. Additionally, in curing systems, acid phosphates can lead to off-color because of rapid curing.

Today, blends are becoming more popular based on their solubility and functionality in a variety of meat product formulations. Sodium hexametaphosphate (SHMP) is a water soluble form of sodium phosphate that is also known as Graham's Salt. However, the solubility of hexametaphosphate is not as good as other tripolyphosphates so the phosphate can be blended with others giving better solubility properties. For example, blends including sodium hexametaphosphate combined with tripolyphosphate improve the solubility of sodium hexametaphosphate. Desirable properties for blends include proper alkaline pH, good solubility, ability to hydrolyze to form diphosphate, calcium compatibility, the ability to solubilize myofribrillar proteins, and the ability to expose charged binding sites to increase WHC (Townsend and Olson, 1987).

In poultry, research indicates when poultry meat was injected with solutions of STPP and SHMP there was no difference in fillet tenderness between aged fillets (4 h) and fillets marinated but not aged (deboned 1 h postmortem) (Goodwin and Maness, 1984). Moreover, Zheng *et al.*, (2000) compared the functionality of tetrasodium pyrophosphate (TPP), STPP, and hexametaphosphate on poultry breast fillet moisture pick-up and retention. Their results indicated that TPP treated breast fillets had the highest yield while STPP has similar effects on purge. They also concluded that SHMP had the highest moisture pick-up but the lowest retention. Alvarado *et al.* (2000) investigated using salt and phosphate as a remediation for PSE broiler breast meat. Regardless of the phosphate brine treatment, moisture binding or retention properties of the PSE meat were not restored to the level of the control group.

Many phosphates are not easily soluble in most salt brine solutions; therefore, phosphates are typically dissolved in room temperature water prior to adding salt and then chilled before use. Some new blends of phosphates on the market have increased solubility regardless of the addition of salt. Some of the new commercial blends of phosphates do not need to be put into solution before salt because of modifications that make them more soluble. Excess phosphate addition can cause "soapy" flavors, rubbery texture, and poor color. Furthermore, phosphates can precipitate forming a white residue on meat surfaces that is due to inorganic monophosphate.

While phosphates possess very functional properties in meat systems, lately consumers have perceived phosphate use as a negative. Other additives that have been utilized as phosphate replacers include sodium citrate and carageenans to increase water holding properties. Low-sodium, phosphate free products tend to be formulated by increasing the amount of protein, particularly non-meat proteins, or by decreasing the amount of water that is added (Miyaguchi, *et al.*, 2004). Several additives, for example, sodium citrate, and other ingredients have been used in phosphate-free meat products to enhance their WHC.

Acid marinades

Acid marinades are becoming more popular as antimicrobial ingredients, particularly for their ability to reduce *Listeria monocytogenes* in ready-to-eat meat products. Typical marinades utilized for their antimicrobial properties include sodium lactate; potassium lactate; sodium citrate; sodium lactate combined with sodium diacetate; and combinations of sodium lactate with potassium lactate and diacetate. Sodium lactate levels regulated by the U.S. are 2.9% pure sodium lactate or 4.8% when using a 60% lactate solution in cook poultry products (Keeton, 2001). When formulating with sodium lactate, salt concentration would likely need to be reduced as the sodium lactate enhances the salty flavor. According to U.S. regulations, sodium acetate and diacetate are approved as flavoring compounds at a maximum level of 0.25% of the formulation weight (Keeton, 2001). Research has shown that sodium lactate in cooked strained beef and beef roasts and sodium diacetate in turkey slurry reduced the growth of *L. monocytogenes* (Miller and Acuff, 1994). However, during refrigeration, there were surviving *L. monocytogenes* organisms that increased in numbers. Cooked chicken treated with lactate and dipped into an *L. monocytogenes* cocktail was shown to have a longer lag phase compared to the control. However, *L. monocytogenes* growth still occurred during refrigerated storage. In general, sodium lactate and diacetate are thought to inhibit bacterial growth by extending the lag phase.

While acid marinades may act as antimicrobials, they also impact meat quality and functionality. Traditionally, acid marinades were used to improve the flavor and texture of prepared meats during storage. Where alkali salt-phosphate brine systems serve to increase WHC and tenderize meat, acidic marinades that are highly acidic (pH below 5.0) tenderize the meat by denaturing proteins, but the marinades do not improve WHC to the extent of alkali brine. Most of the time salt and acid phosphates are used in combination with acid marinades to help with marinade retention. Other meat quality characteristics have been examined in stored product formulated with acid marinades. Specifically, Yang and Chen (1993) reported that chicken fillets marinated in solutions of citric acid and Na_3PO_4 found that Hunter Lab "L" and "b" values decreased ($P<.05$) and "a" increased ($P<.05$) as storage time increased. The researchers postulated that the decrease in L value was related to the pH of the raw product. In another study, cooked cured ham products were formulated with varying levels of sodium lactate, sodium diacetate or buffered sodium citrate. When comparing the different ham formulation for appearance, internal color, structure and firmness, only minor differences were observed between the different ham formulations. However, the addition of 0.2% Na-diacetate had a negative effect on the odor and taste of the ham product (Stekelenburg and Kant-Muermans, 2003).

Additional Ingredients

Carrageenans

Carrageenans are water soluble polysaccharides of the galactan group with alternating 1,3 and 1,4 linked galactose residues, which are part of the cell walls of red seaweed (Imeson, 1992). Because of their hydrocolloid nature, carrageenans and xanthan gum serve as thickening and gelling agents to control moisture, texture and to stabilize foods (Elliason, 1996). There are three types of carrageenans that differ based on their structural variation of the galactose (sugar) molecules. These include kappa, iota and lambda carrageenans. Due to their differences in structure they also possess different functional properties in meat products. Specifically, kappa and iota carrageenan forms gels that are thermostable; whereas lamba does not form a gel but does add viscosity to products as a thickening agent. The ability of kappa carrageenan to form a gel in meat products has been proven to give a range of advantages by increasing yield, consistency, sliceability, spreadability, cohesiveness and decreasing purge, fat content and slicing loss. Moreover, the water binding properties and gel network formation of carrageenans in meat application does not disrupt the protein network; rather, it compliments it. Reports have shown that kappa carrageenan combined with salt increased the strength of meat emulsions as indicated by higher shear values for bologna prepared with kappa carrageenan. Although kappa carrageenan forms thermostable gels, it does not possess good freeze thaw properties. In contrast, the iota carrageenan forms elastic gels and provides freeze/thaw stability for meat applications where repeated thawing and freezing is likely (Huffman, *et al.*, 1991). Although lambda carrageenan does not gel, it produces higher viscosity than do kappa or iota. Because different carrageenans have different properties, blends of the different forms are often used to achieve the desired functional properties. Although blends and individual carrageenans will have different properties, they are typically used at levels ranging from 0.5-1.5% in meat application, and in cured hams the level is maximum of 1.5%.

Sodium salts of kappa and iota carrageenans are soluble in cold water, while K^+ and Ca^{2+} of kappa and iota are not soluble. Salt makes carrageenan insoluble in water and therefore causes carrageenans to be dispersed in the system only (not thickening the solution only dispersed). Therefore, carageenan should be added after the disassociation of the salt and phosphates so it doesn't bind water (swell) before it is incorporated in the meat product. In some cases, it is necessary to disperse carageenan without salt. Where salt is not used, there are coated carrageenans that offer solublity properties in pure water. Furthermore, carrageenans can be added as dry powder to some meat formulations.

The hydration of carrageenan is a temperature dependent process. Kappa and iota type carrageenans need to be heated to temperatures above 75°C and 40°C, respectively, to completely dissolve in aqueous solutions. As the temperature increases the carrageenan hydrates, the viscosity of the system increases, and water is retained. Heating to 68-72°C during cooking ensures complete dissolution of carrageenan. Cooling to 50-60°C will allow the carrageenan to form 3-D gel matrix that is firm and cohesive.

Starches

Starches are long chains polysaccharides consisting of glucose molecules. Linear chain glucose molecules make up amylose; whereas the longer chain complex branched formations are referred to as amylopectin. Because amylose and amylopectin contain an abundance of hydroxyl groups, they readily form hydrogen bonds with water and other molecules to form a three dimensional network (Glicksman, 1979). Starches differ based on the ratio of amylose to amylopectin and come from a variety of plants including corn, wheat, potato, tapioca, and other crops such as rice. Waxy grains are high in amylopectin, which forms clear gel compared to the opaque stronger gels formed from high amylose starches. In foods, particularly meats, starch inclusion improves texture and juiciness due to the water binding properties of starch. Specifically, the starch granules swell or hydrate in the presence of heat and water. The extent of swelling, gelatinization tem¬perature, and the properties of the solution are critically important for food applications.

Starches are available as native, modified, and pregelatinized. Native starches contain 18% to 28% amylose, with the remainder as amylopectin. Modified corn starch is the most widely used starch in meat processing. Starches can be modified in several ways to give the desired functional properties. Specifically, they can be acid, heat or enzyme-treated to yield shorter starch polymers such as dextrin, polydextrin, and malto-dextrin. Modification by adding functional groups such as carboxymethyl group increases the starch's solubilty in water. Adding carboxymethyl groups also facilitates crosslinking which toughens the starch and increases its resistance to heat and acids (Fenema, 1986).

In poultry batters, Barbut *et al.* (1996) studied the affect of adding regular and modified starches (corn, potato) and a cold-swelling starch on the structure of white meat batters. They found that the cook loss was reduced by all starches (50-95% compared to the control), but modified starches had the least cook loss. Furthermore, cooked meat batter hardness was increased by all starches, except the cold-swelling starch. Scanning electron microscopy assisted revealed interactions between the meat protein matrix and some of the gelatinized starches after the cooking process. While modified starches are used throughout the poultry industry, they are used often in the production of turkey deli loaves for their ability to bind and retain water and to improve texture.

Soy Protein Flour and Isolates

The addition of non-meat protein also improves the rheological properties of meat products. In processed meats, soy flour, soy protein concentrates, and protein isolates are often used (Pearson and Gillett, 1996). Soy proteins are often used to enhance meat product binding, extending, gelation, cohesion and emulsification in meat applications. Because of their functional characteristics, they are typically used to reduce the cost or product formulations. Defatted soy flour, soy protein, and protein isolates have varying levels of protein. Soy flours are often used as extenders in applications such as sausage or to extend ground beef; however, meat formulations using a high percentage of soy flour may have a beany off-flavor. Removing the carbohydrate portion and increasing the protein reduces the off-flavor associated with soy. The soy flour contains approximately 50% protein; whereas, the soy protein concentrate is around 70% protein, and the isolate is around 90%. The water binding properties of soy are related to the protein content in the flours, concentrates and isolates. Specifically, they bind 1 to 6 grams of water per gram of protein.

As the protein content of the soy product increases so does the price. Because of their high protein content, soy proteins are often utilized in restructured meat product because of their binding and gelling characteristics (Hermannson, 1986; Pearson and Gillett, 1996). In poultry, soy protein isolates are often used to reduce cost in applications such as poultry rolls where lower value meat cuts may be used. Specifically, the binding, water holding capacity, juiciness, texture, and storage stability are improved with the addition of soy protein isolates. In product formulation for foodservice, soy protein isolates have been used in formulation of poultry nuggets, patties, and other restructured products such as strips. Additionally, the texturizing properties of isolated soy proteins are excellent for fresh poultry sausage links and patties, and mechanically deboned poultry meat.

Injecting, Tumbling and Massaging

There are several methods used to marinate or brine meat including immersing the meat in the brine or marinade solution, injecting with a brine or marinade solution, tumbling with a solution or injecting and tumbling. Injection marination has been used for many years and involves piercing the meat with needles that pump brine or marinade into the meat. Marinade pick up can be adjusted by line speed and injection pressure. Any product including whole birds, boneless cuts, or bone-in parts can be marinated by injection systems. Benefits are consistency of marinade application, a reduction of labor and increased speed of application due to on-line process. Drip loss can be minimized by injection followed by tumbling combinations; however, there is a potential for introducing pathogens into the meat.

The tumbling process, which has been widely used in the red meat industry and is a physical operation in which meat pieces are subjected to gravitational and abrasive forces to improve meat quality characteristics. Tumbling is typically used as a processing step for restructured products. The physical forces against other meat pieces help to disrupt muscle fibers and extract the essential salt soluble proteins that are necessary for binding meat sections together. In addition, tumbling increases the uniformity and speed of diffusion of a brine or marinade solution throughout the meat. As a result, increased yields and tenderness are observed.

Tumbling of poultry meat has become a more popular method of marination. A large rotating tank is filled with a known quantity of meat and marinade (NaCl, STPP, seasonings). The mixture then tumbles or rotates at a given speed for 20 minutes to one hour. Intermittent tumbling for times of 10 to 30 min improves protein functionality because rest periods allow the meat time to absorb the brine more effectively. Applying physical forces following a rest period also enhances the ability of the tumbler to break open the surfaces of the meat when the tumbler is in motion. Tumbling improves appearance, sliceability, texture, flavor, and yield of poultry meat and products.

During tumbling it is important that the meat product and tumbler must be kept cool either by refrigeration or addition of ice to reduce the amount of heat generated by tumbling. Increased heat can denature proteins and reduce uptake and retention. Speeds are adjustable and most tanks have paddles to increase agitation. Pulling a vacuum during tumbling helps to increase the speed, uniformity and depth of brine penetration. In addition, the vacuum helps to open the meat structure thereby allowing brine solution to enter and solubilize myofibrillar proteins. Commercial tumblers are able to marinate large quantities of meat (900-3500 kg).

Blending is very similar to tumble marination, however it is used for whole muscle or course ground product. Ribbon paddles are used to blend the marinade into the product. Advantages include better process control, more even mixing, and the ability to add coolants such as carbon dioxide, which can be important when forming products. However, the uses are limited because blending cannot be used for bone-in or whole muscle skin-on product.

Massagers were designed to mimic mixers utilized for emulsion type products. Larger pieces of meat cannot be manipulated with a mixer, so massagers were developed for this purpose. Massaging functions in a similar manner to tumbling, but it is a less severe treatment, which leaves the meat surface more intact. This can be undesirable if the batch is not properly manipulated, resulting in insufficient cure distribution, lower cooking yields, and decreased bind. Gillett *et al.* (1981) reported that hams that were massaged and pumped to 30% above boneless green weight improved bind, color uniformity, color intensity, and moisture retention when compared to samples pumped to 30 % that had not been massaged.

In summary, the valued-added and further processed poultry markets will continue to grow as consumers demand for convenient meal choices that require little preparation time will remain a predominant trend in food selection and purchases.

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