EFFECTS OF BRINE TEMPERATURE ON HAM AND BACON PROCCESSING CHARACTERISTICS

BY

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THESIS

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Abstract

Prior to the invention of refrigeration, the addition of salt during meat processing was used for meat preservation. Present day, cured meats have a combination of salts and sodium nitrite that will inhibit most psychrophilic flora (spoilage bacteria) thus increasing shelf life of products. Thermal processing of meat products to an internal temperature of 65˚C to 77˚C is sufficient enough to kill most harmful microorganisms. Brine chillers are used in industry to keep cure at a cool, constant temperature. If brine temperature exceeds 10˚C, along with the addition of erythorbate, there will be a rapid reduction of nitrite to nitric oxide gas which will escape before brine injection. With brine temperatures below 10˚C, the reduction of nitrite to nitric oxide to nitrosylhemochrome will remain in the brine without evaporation, allowing a greater amount of nitrite in the brine available to cure the meat. Research has been conducted at the University of Arkansas on the effects of brine and ham temperature on injection yield, instrumental color, tenderness, and sensory characteristics of cured hams; however, no research has been conducted on the effects of brine temperature on ham and bacon processing and sensory characteristics. Therefore, two experiments were conducted to evaluate the effects of brine temperature on ham and bacon processing characteristics as well as an additional experiment designed to test the effects of a brine and ham temperature combination on processing characteristics. The objective of these experiments was twofold: 1) evaluate the effects of brine temperature on ham and bacon processing characteristics and 2) evaluate the effects of brine temperature and meat temperature on ham processing characteristics. For this set of experiments, a total of 170 pork knuckles and 60 pork bellies were used to evaluate the effects of brine temperature. In the first ham experiment, 111 ham knuckles and 60 bellies were randomly allotted to 1 of 3 brine treatment groups; 1) -1˚C (Cold), 2) 7.2˚C (Average), or 3) 15˚C (Warm).

For the second portion of the experiment, 59 of the 170 ham knuckles were randomly allotted to 1 of the 3 same brine treatment groups as the previous experiment. However, each of the knuckles were tempered to equal the brine temperature in which they were alloted. In the first experiment (brine temperature with equal temperature hams), processing characteristics including initial weight, pumped weight, drained pumped weight, initial pump uptake percentage, drained pump uptake percentage, cooked weight, cooked yield, and chilled weight did not differ ($P \geq 0.32$) among treatments. A trending difference ($P = 0.06$) occurred among treatments for evaporative chill loss percentage. Instrumental color differed ($P < 0.02$) among treatments with a 1.2 unit greater L* (lighter color) value for warm, however, the magnitude of difference was not great enough for consumers to notice a difference. A trending difference ($P = 0.07$) was detected for a* values, and no differences were detected in b* values. No differences were detected in moisture or extractable lipid content among brine temperature treatments. A trending difference ($P = 0.07$) was detected in springiness values, although there were no differences for hardness, fracturability, cohesiveness, chewiness, or resilience among treatments. No differences were observed for sensory characteristics among brine temperatures. The second experiment (brine temperature and bacon processing) produced no differences among any processing characteristics, proximate analyses, or sensory characteristics for bacon. The third experiment (brine and ham temperature at equal temperatures) produced many differences in processing characteristics including pumped weight ($P = 0.01$). Knuckles designated as Average and Warm temperatures were 0.15 kg heavier than knuckles designated as Cold. Similarly, initial and drained pump uptake percentage of the Average and Warm knuckles were 14% and 10% greater ($P < 0.0001$) than knuckles designated as Cold. Cooked weights of Cold hams were 0.12 kg less ($P = 0.04$) than Average temperature hams, but neither were different ($P \geq 0.16$) from

Warm hams. Cooked yield percentage was 10% less ($P < 0.0001$) in Cold knuckles compared with Average and Warm hams. Chilled ham weight was 0.13 kg less ($P = 0.02$) in Cold hams compared with Average hams, but neither were different ($P \geq 0.13$) from Warm hams. Initial weight and evaporative chill loss percentage were not different ($P \geq 0.05$) among treatments. Cold hams tended ($P = 0.10$) to have 1.10 greater L* (lighter) than Warm hams, but neither were different ($P \geq 0.24$) from Average hams. Instrumental yellowness (b*) of Cold hams was 0.7 units greater (more yellow, $P < 0.001$) than Average and Warm hams. However, a* values did not differ among treatments. Differences ($P < 0.0001$) were detected for percent moisture, with a trending difference ($P = 0.06$) for extractable lipid content. No differences ($P > 0.21$) were detected for hardness and fracturability among treatments, a trending difference ($P \leq 0.09$) was observed for springiness and chewiness, and a difference ($P \leq 0.03$) was observed for cohesiveness and resilience. Overall, brine temperature did not affect ham or bacon processing characteristics when meat temperature was held constant. However, when meat temperature is manipulated to be equal with brine temperature, several processing characteristics, including initial pump uptake, are affected. However, food safety becomes an issue as meat temperature is increased. Overall, when meat temperature is held at refrigerated temperatures, brine temperature did not influence processing characteristics.

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Chapter 1: Review of the Literature

1.1 Introduction

Historically, meat processing was defined as the addition of salt for meat preservation. This was prior to the development of refrigeration technology (Price and Schweigert, 1987). Salt inhibits spoilage by reducing the water activity in meat, thus inhibiting microbial growth (Aberle, 2001). However, for salt to effectively extend the shelf-life of processed meat products, salt content must exceed approximately 9% in the finished product. This is considerably greater than the 1 to 3 % salt included in most conventionally cured meat products (Aberle, 2001). Therefore, other ingredients, such as sodium nitrite provide the desired bacteriostatic effects.

The invention of gunpowder in the 9th century by Chinese alchemists brought attention to the ingredient saltpeter (Wisniak, 2000). During the medieval times, salt and saltpeter were used in meat curing, and the effects of color from saltpeter were noted (Binkerd, 1975). By the late 19th century chemists investigating meat curing determined that nitrate is converted to nitrite by bacteria, and that nitrite is responsible for the development of cured color (Binkerd, 1975). In January 1923, the Bureau of Animal Industry of the United States Department of Agriculture gave permission for the first direct use of nitrite by a meat processor under federal inspection (Binkerd, 1975).

For cured meats, the combination of salts and sodium nitrite will inhibit growth of most of the psychrophilic flora (spoilage bacteria), thus making these product's shelf life considerably longer (up to 3 months) under the proper conditions including vacuum packaging, refrigerated temperatures, and proper lighting (Price and Schweigert, 1987).

During thermal processing, meat products are generally heated to achieve an internal temperature of 65˚C to 77˚C to sufficiently kill most microorganisms including the trichinae

which is associated with pork (Aberle, 2001) However, hams are generally cured at the temperature of the given room in which they are stored (Leach, 2007). Brine chillers are used in industry to keep the cure at a low, constant temperature. At temperatures above 10˚C, along with the addition of erythorbate, there will be a rapid reduction of nitrite to nitric oxide gas which will escape before brine injection (Hunt, 2012). With colder brines (<10˚C), the reduction of nitrite to nitric oxide to nitrosylhemochrome will remain in the brine without evaporating, providing a greater amount of nitrite available in the brine for meat curing.

1.2 Fresh meat chemistry

Consumers use color as their main criterion in meaking purchasing decisions, claiming discolored meat (brownish) to not be as fresh as a bright red meat product (Mancini and Hunt, 2005). Myoglobin is the main heme pigment responsible for the fresh meat color (Govindarajan, 1973). Myoglobin is produced by and found in muscle cells, and is responsible for 50-80% of meat pigments depending on the muscle (Price and Schweigert, 1987). Although myoglobin comprises the majority of the pigments in muscle, hemoglobin (blood heme pigment), makes up 12-30% of the total pigment in meat because only approximately 80% of the blood is removed during exsanguination (Govindarajan, 1973). Myoglobin has a prosthetic heme group which contains an iron atom in a hydrophobic core, six bonds exist in the iron atom (Hunt, 2012). The prosthetic heme is formed by four pyrrole rings connected by methine bridges with an iron atom in the middle, this prosthetic heme is responsible for the color of myoglobin (Govindarajan, 1973). Of the six bonds, four connect iron to the heme ring, the 5^{th} is attached to the proximal histidine-93, which leaves the 6^{th} site available to bind with oxygen, carbon monoxide, water and nitric oxide (Hunt, 2012). The redox state of iron in the heme ring and the molecule bound to it determine the state and color of myoglobin.

Myoglobin exists in the deoxymyoglobin state when there is no ligand present at the 6th binding site and the heme iron is in the ferrous (reduced) state (Mancini and Hunt, 2005). When oxygen binds to the 6th site it converts the purple colored deoxymyoglobin pigment to oxymyoglobin, bright red color often referred to as blooming (Fox, 1966). When myoglobin is in the oxymyoglobin state, the interior of the meat is still deoxymyoglobin (Price and Schweigert, 1987). As the surface of the meat product is exposed to oxygen longer, the oxymyoglobin penetrates deeper beneath the surface (Mancini and Hunt, 2005). Between these two layers there is a thin brown layer of oxidized-iron pigment, which is metmyoglobin (Price and Schweigert, 1987). Discoloration is referred to as the amount of metmyoglobin on the surface of the meat; this is because metmyoglobin, which is beneath the surface located between superficial oxymyoglobin and interior deoxymyoglobin, gradually thickens and moves to the surface (Mancini and Hunt, 2005).

When carbon monoxide is introduced into packaging, it can bind to the vacant sixth position of deoxymyoglobin and form a bright-red color that is relatively stable forming carboxymyoglobin (Mancini and Hunt, 2005). In the presence of sulfhydryl substances, bacteria producing sulfer, myoglobin can be reversibly reduced to sulfmyoglobin, resulting in a green color (Brewer, 2004). When meat products are cured, the end product is nitrosylmyoglobin (brownish color) if uncooked and nitrosylhemochrome (bright pink) if cooked (Fox, 1966).

1.3 Cured meat chemistry

Cured meat color depends on the reaction of nitric oxide (NO) binding at the 6th site within myoglobin to produce nitrosomyoglobin which in the presence of heat creates the characteristic pink color of cured products (Ockerman, 1996). In an acidic environment, nitrite

is converted to nitrous acid which reacts with nitric oxide and nitrite to form nitric acid (nitrate) (Honikel, 2008). Nitric oxide has a greater affinity for the sixth binding site of the heme group than water, therefore, the myoglobin pigment is converted to nitrosomyoglobin (Roman, 2001). Nitrite will bind with the other additives, such as sodium chloride, influencing the reduction of nitrite to nitric oxide by accelerating the reaction due to the formation of nitrosyl chloride (Price and Schweigert, 1987). The cured pink color of cured meats is dependent on three factors: the amount of myoglobin pigment in the muscle, the degree of conversion to the nitrosyl pigments, and the state of the proteins in the meat (Price and Schweigert, 1987).

Denaturing the globin portion of the protein, by heat treatment, will have a stabilizing affect on the bond between nitric oxide and the heme group creating the pigment called nitrosohemochrome resulting in the bright pink color associated with cured meat products (Roman, 2001). When cured meat is heated to 65.6˚C, nitrite will reduce to nitric oxide and reduce the iron in the heme to the ferrous state (Fox, 1966).

1.4 The nitrite controversy

Based on the meat and meat by-products in the formulation, U.S. meat inspection regulations limit the amount of nitrite permitted to 200 parts per million (ppm) for most cured meat products, 120 ppm for bacon and 156 ppm for comminuted meats. Ham or pastrami products are limited to a maximum of 200 ppm of sodium nitrite and dry cured products are allowed a maximum of 625 ppm of sodium nitrite due to the longer curing times that allow for more sodium nitrite dissipation (Nuñez, 2012). Because nitrite is depleted as curing reactions progress, residual nitrite concentrations in finished products are much less after thermal processing or aging (Aberle, 2001).

Consumers fear additives and preservatives in their foods especially if they do not fully understand the purposes said additives and preservatives were added (Bedale, 2016). In many parts of the world, natural and organic foods have experienced an increase in popularity due to the perceived health benefits. In the US, there are USDA regulations on these natural and organic foods and how they must be produced. Furthermore, for a product (such as ham, bacon, and frankfurters) to be considered natural and organic, the requirements do not permit the addition of nitrite or nitrate (Sebranek, 2007). However, the addition of a concentrated vegetable extract from celery, which contains nitrate, is used to meet the labeling requirements for an uncured, natural product (Sebranek, 2012).

Issues that have been raised in the past decades concerning red and processed meats have included the formation of carcinogens in food or chemical toxicity after ingestion of meat. However, none of the issues are representative of relevant concerns for nitrite or nitrate at the current levels that these are regulated for use in foods (Sebranek, 2007). The International Agency for Research on Cancer (IARC) assessed more than 800 epidemiological studies that investigated the association of cancer with consumption of red and processed meats. The largest amount of data collected was concerned with colorectal cancer, and found positive associations for colorectal cancer for both red and processed meat consumption (Bouvard, 2015).

1.5 Curing methodology

There are several different ways to cure fresh meat products. Dry curing is where the meat is rubbed with salt, nitrite and sugar, and allowed to cure for 4 to 6 weeks (Price and Schweigert, 1987). Cure penetration for dry curing is usually about 2.5 cm per week (Aberle, 2001). Fox (1980) reported diffusion rates of sodium chloride and nitrite in pork

semimembranosus muscles to be 0.19 x 10^5 cm^2 sec^{-1} and 0.12 x 10^5 cm^2 sec^{-1}, respectively, and diffusion rates of sodium chloride and nitrite in pork semitendinosus muscles to be 0.22 x 10^5 cm^2 sec^{-1} and 0.13 x 10^5 cm^2 sec^{-1}, respectively.

Another form of curing is submerging the cut in a pickle, which is a solution containing curing ingredients which have been dissolved in water. This process is a slower method, compared with multiple needle injection pumping or artery pumping, due to the extended amount of time it takes to cure fully to the center of the product, usually taking up to 24 hours (Jespersen, 1977, Aberle, 2001). Another popular technique of curing is stitch pumping. In stitch pumping, the pickle is injected through a hollow needle into various locations on the cut, usually through the thickest portion of the cut and near the joints (Aberle, 2001). Finally, another form of curing is called artery pumping. This form of curing involves a pickle solution being pumped directly into the vascular system. This requires a great deal of care to not rupture blood vessels by excessive pump pressure (Aberle, 2001).

With the increased importance on rapid production of bacon and hams in a short time period, multiple needle injection pumping is most often used (Price and Schweigert, 1987). Quantity of pickle injected into the product is adjusted by belt speed volume and strokes per minute, allowing the processor to determine how much or how little of cure is being injected into the product (Price and Schweigert, 1987). Hams are generally pumped to a certain weight (ranging from 110% to upwards of 150% of green weight; formulations for the brine may differ based on the amount of cure pumped into the ham because the greater the volume pumped, the less concentrated the nitrite or other ingredients will be), usually macerated to increase tenderness, tumbled to disrupt the surface muscle structure to produce a tacky protein exudate on the surface which forms a binding agent and improve cure distribution and penetration (Price and

Schweigert, 1987). The advantages of using pump pickling are as follows: allows salt and other ingredients to be delivered to the center of the product faster, compared with cover pickle which could take considerably longer (minimum of 24 hours) especially for larger pieces of meat, and to prevent spoilage (Price and Schweigert, 1987). The pressure of the injector forces the brine to have a relatively uniform distribution throughout the meat. Therefore, the curing period is shorter because of the almost instant uniform brine distribution, especially with the use of erythorbates to accelerate the reduction of nitrite to nitric oxide, resulting in a quicker turnover usually less than 24 hours (Romans, 2001).

1.6 Lipid oxidation

Oxidative rancidity will occur in lipids and develop peroxides when exposed to molecular oxygen in the air (Aberle, 2001). The hydroperoxides (--OOH) are found on the carbon atom adjacent to a double bonded carbon atom in a fatty acid model (Price and Schweigert, 1987). Autoxidation describes chemical reactions causing oxidative rancidity. The rate of autoxidation is enhanced by pro-oxidants, such as metal ions, heat, ultraviolet light and low pH which will produce strong off odor and flavor within the meat (Aberle, 2001). Any fatty acid that has one or more double bonds in the carbon chain, such as unsaturated fatty acids, will be vulnerable to a cleavage caused by the oxygen taking the place of the double bond and forming aldehydes and shorter fatty acids. Pork fat consists of unsaturated fatty acids, which have the ability to absorb oxygen, contributing to a shorter shelf life in comminuted pork products due to the exposed surface area compared with a whole muscle product (Romans, 2001). Addition of natural antioxidants, such as grape seed extract (Rojas, 2007), reduced thiobarbituric acid reactive substances (TBARS) values and off-odors in cooked beef and pork patties. Jongberg et al. (2013) reported the addition of green tea extract reduced TBARS values in sausages that had

been subjected to oxidative stress by UV-irradiation. Lowe (2014) reported that TBARS were numerically greater with bacon from bellies as storage time after processing increased and stored in oxygen-permeable polyvinyl lined boxes frozen at -33˚C compared with storage in vacuum packaged and held at 2˚C.

1.7 Cured meat flavor

Warmed-over flavor (WOF) is caused by oxidation of the intramuscular phospholipid fatty acids (Reineccius, 1979). Oxidation proceeds at a very rapid rate following heating, or denaturation, of the hemoproteins and converts protein-bound ferrous ion to the ferric ion (Price and Schweigert, 1987). Presence of heme compounds and metal ions may also hasten the oxidation of meat lipids (Kerry, 2002). Warmed over flavor can be inhibited through the use of any metal chelators, antioxidants, tocopherols (Vitamin E), and vacuum packaging (Reineccius, 1979). Antioxidants, such as ascorbic acid and nitrite, can inhibit WOF by complexing with the Fe2+ (Price and Schweigert, 1978). Honikel (2008) reported that due to the lack of oxygen in meat tissue when nitrite is added, the development of rancidity or a warmed over flavor is retarded. Fooladi (1979) observed nitrite reduced WOF in cooked pork, poultry, and beef samples when held at 4˚C for 48 hours demonstrating that the addition of nitrite retards oxidation of cooked samples due to the lack of oxygen present in the muscle tissue when nitrite is added. The reaction with nitrite to form cured pigments retains the iron in the heme and it is inactive as a catalyst for lipid oxidation, which accounts for the prevention of WOF (Price and Schweigert, 1978).

1.8 Nitrite and nitrate

Nitrite in meat curing has many different functions which include contributing characteristic flavor of cured meat, stabilizing meat color, retarding development of rancidity and inhibiting the growth of spoilage microorganisms including *Clostridium botulinum* (Pearsons, 1996; Savell, 2000). *Clostridium botulinum* affects the central nervous system of victims and can cause death resulting from respiratory failure, which occurs in a large percentage of cases (Aberle, 2001). If nitrites are added to meat with pH of 5.5, the salts are dissolved due to their good solubility in the aqueous solution. It can be expected that about 99% of nitrite in pH 5.5 is existing as an anion (NO_2-). The small amount of undissociated nitrous acid is in equilibrium with its anhydride N_2O_3 which is in equilibrium with nitric oxide and nitric dioxide. The NO molecule can be oxidized to NO_2 in the presence of oxygen. Because oxygen can be acquired, nitrite is considered an antioxidant (Honikel, 2008).

In the past couple of decades the consumer demand for natural and organic meats have increased, which developed questions regarding the safety of using natural nitrites (Sebranek, 2012). Pietrasik (2016) reported a significant difference in residual nitrite between low sodium restructured hams containing Prague powder (93.75% NaCl and 6.25% synthetic nitrite) and restructured hams with potassium chloride and celery powder, with the hams cured with celery powder having greater levels of residual nitrite over a 12 week period. Meyers (2013) reported similar results with sliced ham, with residual nitrite for the nitrite added hams decreasing more rapidly than the hams containing natural nitrite. Therefore, the use of Prague powder can be better monitored compared with natural nitrite, for the control of residual nitrite.

1.9 Sodium ascorbate, sodium erythorbate, and non-meat ingredients

Sodium ascorbate and erythorbate are isomers, meaning they are compounds with the same molecular formula, but different structural formulas. Both compounds have the same function, accelerating cure development, although erythorbate is more stable than ascorbate by not reacting as quickly in solution to produce gaseous nitrogen oxide (Price and Schweigert, 1987). Thus, making erythrobate the preferred compound during curing (Pearsons, 1996). Ascorbates are found to speed color development, compared with the use of nitrates and nitrite alone, by reducing metmyoglobin to nitroslymyoglobin, because nitric oxide is able to bind to nitroslymyoglobin (Price and Schweigert, 1987).

Salt, or sodium chloride (NaCl), is used in nearly all curing methods (Pearsons, 1996). Salt has many different functions including contributing characteristic flavors to the product, acts by dehydration and altering of the osmotic pressure so that it inhibits bacterial growth and subsequent spoilage, and by moving through meat via osmosis thus enhancing the transport of nitrate, nitrite, and sugar into the muscle (Pearsons, 1996; Savell, 2000). However, other cations (potassium chloride, potassium lactate, and glycine) can be fully or partially substituted with NaCl (Gou et. al. 1996). A substitution of 30% KCl increased the bitterness of the product, but the intensity of the salt flavor was not important until a level of 50% because below this level the other taste characteristics and color parameters were unaffected (Gou, 1996). Meat formulations delivering a salt concentration of 2% or more in the finished product will achieve the necessary ionic strength (Sebranek, 2009). However, at lower concentrations such as 0.5-1.0%, the Cl^- ion from salt will interact with meat proteins to increase the negative electrical charges on the proteins increasing the water-binding properties (Sebranek, 2009). Cations decrease the attractive forces between the adjacent protein molecules and allow the added water

to increase in volume, therefore increasing the distance between proteins and the meat will swell to twice the original size of the proteins (Offer and Tinick, 1983; Honikel, 1994). This increase in surface hydrophobicity enables the interactions between proteins and fat particles, allowing the hydrophobic regions of the proteins to interact with each other and then form a three dimensional structure upon heating. The addition of cations produces three effects: the swelling and dissolving of myofibrillar proteins to increase the amount of immobilized water; the increase in surface hydrophobicity of muscle proteins that leads to fat binding; and the formation of a heat-stable network by hydrophobic properties upon heating (Honikel, 1994).

Sugar is primarily added to cures for flavoring of the products by counteracting the harsh hardening effects of salt by preventing some moisture loss and a direct moderating action on flavor (Pearsons, 1996). Sugar also provides a source of energy for reducing bacteria that reduce nitrate to nitrite during long cures, and assists in lowering the acidity (pH) of the cure (Savell, 2000). If the amount of sugar is reduced in the bacon production, rapid darkening of bacon may be caused, making it challenging to fry the bacon to the desired degree of crispness while retaining an attractive color (Price and Schweigert, 1987).

Phosphates are added to cure solutions to increase water-binding capacity, improve color retention due to increased water-binding, and ultimately increase yield of finished products (Price and Schweigert, 1987). Alkaline phosphates increase water holding capacity in two ways: raising the pH and solubilizing the muscle proteins (Price and Schweigert, 1987, Pearsons, 1996). Popular alkaline phosphates used in curing solutions include sodium hexametaphophate (pH=6.9), sodium pyrophosphate (pH=10.5), and sodium tripolyphosphates (pH=9.9) (Price and Schweigert, 1987). Brines should not include more than 5% of alkaline phosphates at 10% pump level, and the final product should not contain more than 0.5% of added phosphates (Savell,

2000). Meat already contains 0.10% natural phosphates (phosphorus), and should be subtracted from the final calculations of phosphates in the cure (Price and Schweigert, 1987). If the level of phosphates in the cure are too high, or even if the salt levels are too high, the phosphates may evaporate out of the solution because they are not easily soluble in solution. Therefore, it is common practice then to dissolve the phosphates in water first before adding any other curing ingredient (Price and Schweigert, 1987).

Water serves as a solvent, carrier and dispersing agent for salt, nitrate, nitrite, sugar, phosphates, and other ingredients typically included in cured meat (Sebranek, 2009). Excess water content in the cured product delivered by a brine injection process is called added water. Added water in meats may increase the yield of finished products to exceed the original weight, even after cooking. A USDA labeling regulation is designed to inform consumers of the added water and added weight in the cured meat product (Romans, 2001). New standards for cured pork products are based on the minimum percentage of meat protein on a fat-free basis (PFF) present in the finished cured pork product (Price and Schweigert, 1987). The intent of these regulations is to exclude all other proteins from PFF calculations such as plant proteins, animal derived proteins (bone and blood), and any extracts from proteins (Price and Schweigert, 1987). Wright (2005) reported proximate composition of bacon to be 14.47% protein, 40.02% moisture and 45.51% lipid content. Based on a PFF calculation by Price and Schweigert (1987), [(% meat protein/(100-% fat)]*100, the bacon will have a PFF of 26.56. For labels of “Ham with Natural Juices” or “Ham with Water Added” the PFF must be at least 18.5% or 17.0% respectively (Aberle, 2001).

1.10 Effect of pH and temperature on curing reaction

According to the American Meat Science Association Meat Color Guide, one precaution in the handling of brines containing nitrite and erythorbate is to keep temperature below 10˚C. Warmer temperatures, along with erythorbate will rapidly reduce nitrite to NO gas which will escape before brine injection and result in poor or no cured color development in the cooked product. Shahidi and Pegg (1990) reported increases of nitrite from 25 ppm to 156 ppm proved to increase redness in ground pork loin. Leach (2000) reported hams at a temperature of 3.9˚C cured in a brine solution that was tempered to 3.9˚C had a less vivid cure color when compared with hams that were colder (-1.7˚C) and cured in a brine that was colder (-1.7˚C). Leach (2000) goes on to explain that there was a difference of 0.21 pH units of cured hams (3.9˚C) cured in a brine solution (3.9˚C) having the greatest pH values of 6.62 compared with cured hams at colder temperatures cured in colder brines. Boles (1997) reported that beef semimembranous muscles injected with no brine had a significantly greater cook yield compared with brine treatments (0˚, 4˚, 8˚, and 12˚C), suggesting that the addition of brine or even brine temperature can affect cook yields.

The reduction of nitrite to nitric oxide is effective when meat pH values are between 5.6 and 6.0 (Toldrá, 2002). Arkfeld et al. (2016) reported pH values of Rectus femoris muscles to be 6.06 and Vastus lateralis muscles to have a pH of 5.74. Therefore, meat with a low pH (below 4.6) accelerates the reactions from nitrite to nitric oxide which promotes the development of cured meat color and aids in protecting it from fading by light sources (Aberle, 2001). During postmortem pH decline of the loin, a normal ultimate pH of loin will result in values between 5.3 through 5.7 (Aberle, 2000). Therefore, according to Toldrá (2002), normal postmortem pH decline will result in pH values most effective to convert nitrite to nitric oxide.

The objective of this study was twofold: 1) evaluate the effects of brine temperature on ham and bacon processing characteristics, and 2) evaluate the effects of brine and meat temperature on ham processing characteristics.

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Chapter 2: Effects of brine temperature on ham and bacon processing characteristics

2.1 Abstract

The objective of this study was twofold: 1) evaluate the effects of brine temperature on ham and bacon processing characteristics, and 2) evaluate the effects of brine and meat temperature on ham processing characteristics. Effects of brine temperature on ham were analyzed as a randomized complete block design with the fixed effect of brine temperature and block (ham source) serving as a random effect. Effects of brine temperature on bacon were analyzed as a randomized complete block design with the fixed effect of brine temperature and block (smokehouse cycle) serving as a random effect. Finally, effects of brine/meat temperature on ham were analyzed as a completely randomized design with the fixed effect of brine/meat temperature. A total of 111 hams and 60 bellies were used to evaluate the effects of brine temperature and a total of 59 hams were used to evaluate the effects of brine/meat temperature. Experiment 1: hams (N = 111) and bellies (N = 60) were allotted to 1 of the 3 brine temperature treatment groups; 1) -1˚C (Cold), 2) 7.2˚C (Average), or 3) 15˚C (Warm). Experiment 2: hams (N = 59) were allotted to 1 of the 3 same treatments groups, however, the hams were tempered to equal the brine temperature for the treatment in which they were alloted. In the first experiment (different brine temperatures but constant ham temperature), processing characteristics including initial weight, pumped weight, drained pumped weight, initial pump uptake percentage, drained pump uptake percentage, cooked weight, cooked yield, and chilled weight did not differ ($P \geq 0.32$) among treatments. A trending difference ($P = 0.06$) occurred among treatments for evaporative chill loss percentage. Instrumental color differed ($P < 0.02$) among treatments with a 1.2 unit greater L* (lighter color) value for warm, however, the magnitude of difference was not great enough for consumers to notice a difference. A trending difference ($P = 0.07$) was detected for a* values, and no differences were detected in b* values. No differences were

detected in moisture or extractable lipid content among brine temperature treatments. A trending difference ($P = 0.07$) was detected in springiness values, although there were no differences for hardness, fracturability, cohesiveness, chewiness, or resilience among treatments. No differences were observed for sensory characteristics among brine temperatures. The second experiment (brine temperature and bacon processing) produced no differences among any processing characteristics, proximate analyses, or sensory characteristics for bacon. The third experiment (brine and ham temperature at equal temperatures) produced many differences in processing characteristics including pumped weight ($P = 0.01$). Knuckles designated as Average and Warm temperatures were 0.15 kg heavier than knuckles designated as cold. Similarly, initial and drained pump uptake percentage of the Average and Warm knuckles were 14% and 10% greater ($P < 0.0001$) than knuckles designated as Cold. Cooked weights of Cold hams were 0.12 kg less ($P = 0.04$ than Average temperature hams, but neither were different ($P \geq 0.16$) from Warm hams. Cooked yield percentage was 10% less ($P < 0.0001$) in Cold knuckles compared with Average and Warm hams. Chilled ham weight was 0.13 kg less ($P = 0.02$) in Cold hams compared with Average hams, but neither were different ($P \geq 0.13$) from Warm hams. Initial weight and evaporative chill loss percentage were not different ($P \geq 0.05$) among treatments. Cold hams tended ($P = 0.10$) to have 1.10 greater L* (lighter) than Warm hams, but neither were different ($P \geq 0.24$) from Average hams. Instrumental yellowness (b*) of cold hams was 0.7 units greater (more yellow, $P < 0.001$) than Average and Warm hams. However, a* values did not differ among treatments. Differences ($P < 0.0001$) were detected for moisture content, with a trending difference ($P = 0.06$) for extractable lipid content. No differences ($P > 0.21$) were detected for hardness and fracturability among treatments, a trending difference ($P \leq 0.09$) was observed for springiness and chewiness, and a difference ($P \leq 0.03$) was observed for

cohesiveness and resilience. Overall, brine temperature did not affect ham or bacon processing characteristics when meat temperature was held constant. However, when meat temperature is manipulated to an increased temperature with a similar brine temperature, several processing characteristics, including initial pump uptake percent, are increased compared with colder temperature hams and brine. However, food safety becomes an issue as meat temperature is increased. Overall, when meat temperature is held at refrigerated temperatures, brine temperature did not influence processing characteristics.

2.2 Introduction

Historically, meat processing was defined as the addition of salt for meat preservation. This was prior to the development of refrigeration technology (Price and Schweigert, 1987). Salt inhibits spoilage by reducing the water activity level in meat thus inhibiting microbial growth (Aberle, 2001). However, for salt to effectively extend the shelf-life of processed meat products, salt content must exceed approximately 9% in the finished product. This is considerably greater than the 1 to 3 percent salt included in most conventionally cured meat products (Aberle, 2001). Therefore, other ingredients, such as sodium nitrite provide the desired bacteriostatic effects.

Increases of nitrite up to 156 ppm from 25 ppm proved to increase redness in ground pork loin (Shahidi and Pegg, 1990). Leach (2000) reported hams at a temperature of 3.9˚C cured in a brine solution that was tempered to 3.9˚C had a less vivid cure color when compared with hams that were colder (-1.7˚C) and cured in a brine that was colder (-1.7˚C).

Hams are generally cured at the temperature of the given room in which they are stored (Leach, 2007). Brine chillers are used in industry to keep the cure at a low, constant temperature. At brine temperatures above 10˚C, along with the addition of erythorbate, a rapid

reduction of nitrite to nitric oxide gas will occur which allows the nitric oxide gas to escape before brine injection (Hunt, 2012). With colder brines (<10˚C), the reduction of nitrite to nitric oxide to nitrosylhemochrome will remain in the brine without evaporating, allowing a greater amount of nitrite in the brine and available for meat curing. However, an increased level of residual nitrite could lead to health concerns. Methemoglobinemia may occur when nitrite reacts with hemoglobin, rendering it incapable of carrying oxygen, which can lead to cyanosis (Bedale, 2016).

Brine temperature will have little to no effect on ham and bacon processing characteristics. However, when meat temperature is incorporated with brine temperature, processing yields may be impacted. Therefore, the objective of this study was to evaluate the effects of brine temperature on ham and bacon processing characteristics, as well as the effects of brine and meat temperature on ham processing yields.

2.3 Materials and Methods

All meat samples were obtained from a federally inspected abattoir. Therefore, no Institutional Animal Care and Use Committee approval was necessary.

2.4 Experiments 1 and 2: Hams

2.4.1 Experimental design

Two experiments were conducted to test the effect of 1) brine temperature and 2) brine and meat temperature, on processing yields and ham quality. In the first experiment, 111 pork knuckles (IMPS #403H Pork Leg, Tip) were used in a randomized complete block design, with 2 replicate blocks, to test the effect of brine temperature (ham temperature held constant) on processing yields and quality of hams. In the first block (N = 51, 17 per treatment), knuckles

were collected from pigs slaughtered and fabricated at the University of Illinois Meat Science Laboratory. Following fabrication, all knuckles were sealed in vacuum bags and stored in boxes at -29˚C for approximately 70 d. In the second block (N = 60, 20 per treatment), fresh knuckles were purchased from a commercial abattoir and transported to the University of Illinois Meat Science Laboratory for evaluation and further processing. Two days before processing, knuckles were removed from frozen storage and allowed to thaw at 5.5˚C. Knuckles were assigned identification numbers, netted individually, then weighed, and randomly allotted to 1 of 3 brine temperature treatments: 1) -1˚C (Cold), 2) 7.2˚C (Average), or 3) 15˚C (Warm), such that the mean weight of each treatment group was 1.28 kg.

In the second experiment, 59 pork knuckles were used in a complete randomized design experiment to test the effects of brine in conjunction with meat temperature on processing yields and cured ham quality. Frozen hams were removed from storage and allowed to thaw at 5.5˚C for 48 h, after which knuckles were assigned identification numbers, netted, then individually weighed, and randomly allotted to 1 of 3 temperature treatment groups : 1) Cold-Cold (CC) -1˚C , 2) Average-Average (AA) 7.2˚C, 3) Warm-Warm (WW) 15˚C, such that the mean weight of each treatment group was 1.22 kg. After allotment to treatments, knuckles were allowed to equilibrate to a temperature equal to the targeted brine temperature associated with their respective treatment.

2.4.2 Ham processing

For both ham experiments, a master batch of curing solution, formulated to deliver 6.60% sodium chloride, 1.46% sodium tripolyphosphate, 0.48% sugar (sucrose), 0.22% sodium erythorbate, 0.16% spices, and 0.06% sodium nitrite at a 30% pump uptake (Table 2.1). Cure ingredients, not including nitrite, were mixed approximately 13 h prior to injection. The master

batch was then divided into 3 equal aliquots of cure solution and allowed to equilibrate to their respective temperature treatments (-1˚C, 7.2˚C, and 15˚C) for approximately 13 h and then the temperature was adjusted accordingly by either placing the brine in freezer (-29˚C) or, by placing into the brine solution, a sealed plastic bag containing 82˚C water. Brines were thoroughly agitated during temperature manipulation to ensure representative and accurate temperatures. Immediately before injection, sodium nitrite, in the form of prague powder, was mixed into each aliquot.

Prior to injection for both experiments, knuckles were weighed for an initial weight to account for purge loss, and individual temperature for experiment 2 knuckles were recorded. Knuckles were then pumped with a multi-needle brine injector (Schroder Injector/Marinator model N50, Wolf-Tec Inc., Kingston, NY) to a targeted pump uptake of 30% of initial weight at a pressure of 2.2 Bar and 32 strokes per min using 3 mm needles. In both experiments, the average treatment was injected first. All knuckles were passed through the injector twice, weighed immediately after injection and allowed to drain for 30 min. Cold and then warm treatments were injected following the average treatment, using the same protocol. After the 30 min drain period, knuckles were weighed again to determine final cure pumped weight and pump uptake percentage was calculated: [(pumped weight – initial weight) ÷ initial weight] × 100. After draining, knuckles were hung randomly on a smokehouse cart, and placed in the smokehouse for thermal processing. Knuckles were cooked and smoked in an Alkar smokehouse (Lodi, WI) until they reached an internal temperature of 66.6˚C. Table 2.2 describes the cooking and smoking procedure for the knuckles. After thermal processing, knuckles were showered with cold water and immediately weighed after showering to determine hot cooked weight. Knuckles were then placed in a cooler and chilled at 2.2˚C. When knuckles temperature reached

approximately 7.2˚C they were weighed to determine final cooked-chilled weight. Evaporative chilling loss was calculated using the following equation: [(hot cooked wt – netted chilled wt) ÷ (hot cooked wt)] x 100. Cooked yield was calculated (with netting removed) using the following equation: (chilled cooked wt ÷ initial wt) x 100.

2.4.3 Cured ham color evaluation

Knuckles were placed in numerical order and sliced in half for instrumental color evaluation using a Konica Minolta CR-400 Chroma Meter (Minolta Camera Company, Osaka, Japan; D65 light source, 0˚ observer, 8 mm aperture, white tile for calibration). The knuckles were placed cut surface side up and four measurements were collected working in a clockwise direction starting in the upper left of the knuckles cut surface, and the mean of the 4 readings were reported as cured L*, a*, and b*. Then, two 2.54 cm steaks for experiment 1 were collected from the center of each knuckle. The first 2.54 cm steak was used for texture analysis and proximate composition, and the second 2.54 cm steak was used for sensory evaluation. One 2.54 cm steak for experiment 2 was collected and used for texture analysis and proximate composition. Each sample was individually vacuumed sealed, retaining identification, and stored at -40˚C until further analyses. Sensory evaluation was conducted only on ham steaks from experiment 1, as the 15˚C treatment from experiment 2 may have posed a food safety risk.

2.4.4 Ham texture profile analysis

Ham steaks were removed from refrigeration (4˚C) and four 2.54 cm cores were removed from each sample and compressed using a Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY/ Stable Microsystems, Godalming, UK). A 5.08 cm diameter plate compressed each core in 2 consecutive cycles to 75% of the samples original height with 2 s intervals between cycles. Cycles are labeled as area of work 1 and area of work 2. The cross-

head moved at a constant speed of 5 mm/s. A force-time curve was plotted. Hardness is the absolute peak force on the first down stroke, fracturability is the force at the first peak, springiness is a ratio of the area of work 2 by the area of work 1, cohesiveness is the ratio of the products original height, gumminess is calculated by multiplying hardness by cohesiveness, chewiness is calculated by multiplying gumminess by springiness, and finally resilience is measured on the withdrawal of the first penetration. The values for the 4 cores were averaged and reported as hardness, fracturability, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience of each ham sample.

2.4.5 Ham proximate composition

Proximate composition was determined by homogenizing ham samples, collected from steaks used for texture analysis, in a food processor (Cuisinart model CUI DFP-7BC, Cuisinart, East Windsor, NJ). A 10 gram sample of the homogenate was oven dried at 110˚C for at least 24 h to determine moisture content. Extractable lipid content was determined by washing the dried sample multiple times in an azeotropic mixture of warm chloroform:methanol using the protocol described by Novakofski et al. (1989).

2.4.6 Ham sensory evaluation

Ham samples were thawed for at least 12 h at 4˚C. Eleven panelists participated in training sessions for orientation to scale attributes prior to evaluation. Panelists rated attributes on a 15-cm line scale with anchors at 0, 7.5, and 15 cm, where 0 cm indicated not salty, not juicy, and rubbery texture and where 15 cm indicated very salty, very juicy, and mealy texture. Panelists were presented ham and hot dogs with various attributes prior to evaluation for training. A low sodium ham was used to anchor for saltiness and a ham with natural juices or

water added was used to anchor for juiciness. Low sodium hot dogs and beef hot dogs were assessed for mouthfeel.

For each sensory session, 6 of the 11 trained panelists were selected to participate in sensory evaluations. Panelists were separated in individual booths with ambient temperature (21˚C) and humidity, and red lighting. Panelists were provided apple juice and unsalted crackers as palate cleansers. Vacuum packaged ham steaks were heated in hot water (Hamilton Beach 4 Quart Slow Cooker, Hamilton Beach Brands, Inc., Model 33040Y) for 30 min. Samples were removed at random and cut into 1.75 cm x 2.54 cm pieces, placed on paper plates and served to panelists one at a time. There were 19 sensory sessions with at least 6 samples per session and treatments were balanced within each session. Panelist data was averaged for each sample.

2.5 Experiment 3: Bacon

2.5.1 Experimental design

In experiment three, a randomized complete block design was used to test the effects of brine temperature on processing yields and sensory attributes of bacon. Sixty pork bellies (IMPS #409 Pork Belly, Skinless, left sides) were procured from a commercial abattoir, individually weighed and allotted to 1 of 3 brine temperature treatments: 1) -1˚C (Cold), 2) 7.2˚C (Average), 3) 15˚C (Warm) such that each treatment group had a mean weight of 6.15 kg. Within treatment group, bellies were randomly allotted into 2 blocks. Block was defined as smokehouse cycle.

2.5.2 Bacon processing

A master batch of curing solution was formulated to deliver 16.75% Sodium Chloride, 3.71% sodium tripolyphosphate, 1.24% Sugar, 0.56% sodium erythorbate, 0.41% spices, and 0.15% sodium nitrite at a targeted 10% pump uptake. Cure ingredients, not including nitrite,

were mixed approximately 13 prior to injection. The master batch was divided into 3 equal aliquots of cure solution similar to Experiments 1 and 2.

Bellies were weighed to determine initial weight, then pumped with a multi-needle brine injector (Schroder Injector/Marinator model N50, Wolf-Tec Inc., Kingston, NY) at a pressure of 2.2 Bar and 51 strokes per minutes using 3 mm needles. The Average treatment bellies were injected first. Bellies were weighed immediately after injection to determine pump weight and to calculate pump uptake: [(pumped weight – initial weight) ÷ initial weight] × 100. Bellies were then hung randomly on a smoke cart using stainless steel belly combs. The Cold and Warm treatments were injected following the Average treatment, using the same protocol. Bellies were then placed in an Alkar smokehouse (Lodi, WI) and cooked and smoked until they reached an internal temperature of 52.2˚C (Table 4). After thermal processing, bellies were showered with cold water, then placed in a cooler and chilled at 2.2˚C. When bellies had chilled for at least 24 hours they were weighed to determine final cooked weight. Cooked yield was calculated using the following equation: (chilled wt ÷ initial wt) x 100.

Bacon slabs were sliced using a push-feed style Treif Puma slicer (Treif model 700 F, Oberlahr, Germany) and sliced to 4 mm thickness. Bacon was removed from the slicer and divided into three equal zones (Zones A, B, and C). Two slices from the middle of each zone were collected and stored -4˚C for proximate composition determination. An additional 3 slices were collected from the middle of each zone, vacuumed packaged, and stored at -4˚C for sensory evaluation at a later date.

2.5.3 Bacon proximate composition

Proximate composition was determined by first homogenizing 2 slices from each of the three zones in a food processor (Cuisinart model CUI DFP-7BC, Cuisinart, East Windsor, NJ).

Duplicate 5 g samples of the homogenate were oven dried at 110˚C for at least 24 h to determine moisture content. Extractable lipid content was determined by washing the dried sample multiple times in an azeotropic mixture of warm chloroform:methanol using the protocol described by Novakofski et al. (1989).

2.5.4 Bacon sensory evaluation

Prior to sensory evaluation, bacon samples were thawed for at least 12 h at 4˚C. Eleven panelists participated in training sessions for orientation to scale attributes prior to evaluation. Panelists rated attributes on a 15-cm line scale with anchors at 0, 7.5, and 15 cm, where 0 cm indicated no saltiness, no flavor intensity, or no off-odor associated with lipid oxidation and 15 cm indicated very salty, a very oxidized odor, and a very oxidized flavor. During training, panelists were presented with low sodium ham to assess saltiness and oxidized vegetable oil to assess flavor intensity and oxidized odor intensity prior to evaluation.

For each session, 6 panelists were selected from the pool of 11 available panelists. Panelists were separated in individual booths under ambient temperature, humidity, and under red light. Panelists were provided apple juice and unsalted crackers for palate cleansers and coffee grounds for olfactory cleanser. Eighteen bacon slices (3 from each sample) were placed on baking sheets and cooked at 177˚C for 15 min in a convection oven (Southbend Model V-15, Fuquay-varina, NC). Cooked slices were allowed to cool for approximately 5 min and then cut into 2.54 cm pieces. Each panelist received 3 pieces in a plastic cup covered with a plastic lid. Samples were labeled with a sample code. There were 10 sensory sessions with at least 5 samples per session and treatments were balanced within each session.

2.6 Statistical Analysis

Data from all 3 experiments were analyzed using the MIXED procedure of SAS (SAS Institute, Inc. Cary, NC, USA. Version 9.3, 2011) with individual hams and bellies serving as the experimental unit. Experiment 1 (ham) was analyzed as a randomized complete block design with the fixed effect of brine temperature and block (ham source) serving as a random effect. Experiment 2 (ham) was analyzed as a completely randomized design with the fixed effect of brine/meat temperature. Bacon processing and bacon sensory data (Exp. 3) were analyzed as a randomized complete block design with the fixed effect of brine temperature and block (smokehouse cycle) serving as a random effect. Assumptions of ANOVA were tested with Levene's test for homogeneity of variance in the GLM procedure. Normality of distribution of residuals were tested using the UNIVARIATE procedure of SAS. Least square means were separated using the PDIFF option. Least square means were considered significantly different at $P \leq 0.05$ and trending at $0.05 \geq P \leq 0.10$.

2.7 Results

2.8 Experiment 1: Hams with Different Brine Temperatures

Brine temperature did not affect ($P \geq 0.32$) green weight, pumped weight, drained weight, initial pump uptake percent, drained pump uptake percent, cooked weight, cooked yield, and chilled weight (Table 5). However, the Average hams tended ($P = 0.06$) to have greater evaporative chill loss than Cold hams, with neither different ($P \geq 0.34$) than Warm hams. Warm hams had 1.2 unit greater ($P = 0.02$) L* than Cold hams, but neither were different ($P \geq 0.19$) from Average hams (Table 5). Additionally, Cold hams tended ($P = 0.07$) to have greater a* values than Warm hams, with neither being different ($P \geq 0.42$) from Average hams. There was no effect ($P = 0.25$) of brine temperature on ham b* values, nor on moisture percentage ($P = 0.54$) or the percentage extractable lipid ($P = 0.79$). Moreover, there was no effect ($P \geq 0.40$) of

brine temperature on hardness, fracturability, cohesiveness, chewiness, and resilience; but Cold hams tended ($P = 0.06$) to have greater springiness than Average hams, with neither being different ($P \geq 0.27$) from Warm hams. Similar to the results of the texture profile analysis, there was no effect ($P \geq 0.32$; Table 6) of brine temperature on sensory panelist's evaluations of saltiness, juiciness, or mouthfeel.

2.9 Experiment 2: Tempered Hams with Tempered Brines

Pre-pump and post-pump meat temperature differed ($P \leq 0.0001$) between treatments (Table 7). Brine/meat temperature did not affect ($P \geq 0.57$) netted weight or evaporative chill loss percentage (Table 7). However, CC ham pumped weights were different ($P = 0.01$) than AA and WW. Additionally, CC hams tended ($P = 0.06$) to have a lesser drained pumped weight compared with AA and WW treatments. Initial and drained pumped uptake percentage of CC hams were different ($P \leq 0.0001$) than the AA and WW treatments. Furthermore, CC hams have a 0.12 kg lesser ($P = 0.04$) hot cooked weight than the AA, with neither being different ($P \geq 0.16$) from the WW treatment. CC hams have different ($P \leq 0.0001$) cooked yield percentage than AA and WW treatments. Moreover, CC hams have a 0.13 kg lesser ($P = 0.02$) chilled weight compared to AA, with neither being different ($P \geq 0.13$) than the WW treatment. CC hams tended ($P = 0.10$) to have a 1.1 unit greater L* than the WW, with neither being different ($P \geq 0.24$) than the AA treatment. There was no differences ($P = 0.18$) in a* values between treatments. Additionally, CC hams had an approximately 0.7 unit greater ($P < 0.01$) b* value than the AA and WW treatments. CC hams had almost a 2.0% decrease ($P < 0.0001$) in moisture percentage compared with AA and WW treatments. However, the CC hams tended ($P = 0.06$) to have a 0.81% greater percentage extractable lipid than the WW treatment, with neither different ($P \geq 0.21$) than the AA treatment. Hardness and fracturability values did not differ ($P \geq$

0.21) between treatments. The AA treatment tended ($P = 0.06$) to have a 0.03 greater springiness value than the WW treatment, with neither differing ($P \geq 0.23$) from the CC treatment. Cohesiveness values of AA hams differed ($P = 0.03$) from the CC and WW treatments. However, chewiness values tended ($P = 0.09$) to be lesser in the WW treatment compared to the AA treatment, with neither being different ($P \geq 0.37$) from the CC treatment. The AA had a greater ($P = 0.01$) resilience value compared with the CC and WW treatments.

2.10 Experiment 3: Bacon

Brine and Ham temperature had no effect ($P \geq 0.56$) on green weight, pumped weight, pump uptake percent, chilled weight, and cooked yield percent (Table 4). Additionally, there was no difference ($P = 0.97$) in percent moisture and percent extractable lipid ($P = 0.91$; Table 4). Furthermore, there was no effect ($P \geq 0.14$) on sensory panelist's evaluations of saltiness, oxidized odor, and oxidized flavor (Table 8).

2.11 Discussion

2.12 Experiment 1: Hams with Different Brine Temperatures

Leach (2007) reported similar results for effects of brine temperature with no significant differences detected for initial pump uptake percentage. Furthermore, Leach (2007) reported that brine temperature had a significant difference ($P < 0.05$) in evaporative chill loss, where brine temperature in this experiment on reported a trending difference ($P = 0.07$) for evaporative chill loss percentage. However, Leach (2007) reported a significant difference ($P < 0.05$) for brine temperature having an effect on cook loss percentage where the present data reported conflicting results, with brine temperature having no differences on cook loss percentage.

Instrumental color differed ($P < 0.02$) among treatments with a 1.2 unit greater L* (lighter color) value for warm. A 2 unit difference in L* has been found to be the magnitude of difference for a consumer to notice a change in lightness (Zhu and Brewer, 1999). Based on this information, it can be concluded that a consumer would not be able to detect a visual difference in L* values. With increases in brine temperature above 10˚C, nitrite will rapidly reduce to nitric oxide and may result in poor or no cured color development (Hunt, 2012). When observing cured product, there should be a pink color associated with it. Ultimately, this could be a reason for the lighter color associated with the hot-injected hams. Furthermore, a trending difference ($P = 0.07$) was detected for a* values, with cold having a 0.63 unit greater (redder color) value compared with warm. This difference coincides with the differences in L* values, one would conclude that the greater a* value would indicate a greater cure color development from a brine less than 10˚C. Collectively, there were no differences among treatments for any of the sensory characteristics including saltiness, juiciness, and mouthfeel.

2.13 Experiment 2: Tempered Hams with Tempered Brines

Experiment 2 was conducted as a result of Experiment 1. Data from experiment 1 hams did not differ among processing characteristics. As a result, we hypothesized that hams with differing temperatures which matched the brine temperatures would prove results among treatments.

Pre and post-pump meat temperature was significantly different across the treatments. This was expected and anticipated, due to the fact that meat and brines were held for up to 12 h in different environments with differing temperatures. Meat and brine temperature had no effect on green weight and evaporative chill loss percentage. Initial and drained pump uptake percent

of the average and warm knuckles were 14% and 10% greater than knuckles designated as cold. Cooked yield percentage was 10% less in cold knuckles compared with average and warm hams. It appears that the cause of the cold hams having the lighter weights and lower percentages stem from the meat temperature (-0.32˚C) being close to the freezing temperature of meat (-2.2˚C), in which noticeable ice crystals began to form. Price and Schweigert (1987) report that sarcoplasmic proteins are less soluble after the freezing of muscle tissue, concluding that brine retention could be decreased causing the lighter weights and lower percentages. Cold hams tended ($P = 0.10$) to have 1.10 greater L* (lighter) than warm hams. Even though this was a trending difference between the treatments, consumers would not be able to detect this difference in color. Instrumental yellowness (b*) of cold hams was 0.7 units greater (more yellow, $P < 0.001$) than average and warm hams. These measurements differed from Leach (2007) where b* values for cold hams (-1.7˚C) injected with cold brine (-1.7˚C) had significantly lower b* values compared with hams tempered at 1.4˚C pumped with brine at 3.9˚C and hams tempered at 3.9˚C and pumped with brine at 3.9˚C.

2.14 Experiment 3: Bacon

No differences were detected between any of the processing and sensory characteristics. Future research where bellies of differing temperatures to equal the brine temperatures might produce some differences between processing characteristics.

2.15 Conclusion

The average and warm hams from experiment 2 had a significantly greater pumped weight and drained weight, consequently a greater initial pumped and drained uptake percent compared with the cold hams. This appears to be the beginning of the differences shown in the

data. With the increased pump uptake and the ability to retain more cure after 30 minutes, cooked weight, cooked yield, chilled weight, and percent moisture all had greater values. This can be beneficial for processors interested in increasing their yields, however, a concern with food safety should be noted. Meat that is tempered above 4.4˚C will enter the temperature zone where microbial growth will begin. Future research should focus on microbial growth associated with brine and meat temperature as well as evaluating the effects of a hot tempered brine injected in a cold tempered ham and a cold tempered brine injected in a hot tempered ham. In conclusion, brine temperature has no effect on ham and bacon when meat is tempered to approximately 4˚C.

2.16 Tables

Table 2.1 In-going brine composition (as in basis) for a 30% delivery

Ingredient	Content
Water, %	97.86
Salt, %	1.52
Sugar (sucrose), %	0.11
[1]Sodium phosphate, %	0.33
Sodium erythorbate, %	0.05
[2]Prague powder, %	0.014
Seasoning blend, %	0.12

[1] Sodium tripolyphosphate

[2] Prague Powder consisted of 93.75% sodium chloride and 6.25% nitrite.

Table 2.2. Smokehouse cycle for hams

Step	Step Type	Step Duration (h:min)	Dry Bulb (˚C)	Wet Bulb (˚C)	[1]RH (˚C)	[2]FA/EXH Dampers
1	Cook	1:00	54.4	-17.8	-17.8	Auto
2	Cook	0:30	65.6	-17.8	-17.8	Auto
3	Cook	0:30	65.6	-17.8	-17.8	Auto
4	Smoke Cook	2:00	73.9	-17.8	-17.8	Closed
5	Cook	0:30	73.9	-17.8	-17.8	Auto
6	Cook	1:30	73.9	62.2	62.2	Auto
[3]7	Cook	0:30	76.7	68.9	68.9	Auto
8	Cold Shower	0:15	-17.8	-17.8	-17.8	Open

[1]Relative humidity

[2]Fresh air damper and exhaust damper

[3]If internal temperature is less than 66.7˚C, continue cooking until temperature is greater than 66.7˚C

Table 2.3. Smokehouse cycle for bacon

Step	Step Type	Step Time (h:min)	Dry Bulb (˚C)	Wet Bulb (˚C)	[1]RH (˚C)	[2]FA/Exh Dampers
1	Cook	0:10	48.9	43.3	22.2	Auto
2	Cook	1:30	48.9	-17.8	-17.8	Auto
3	Cook	0:30	48.9	-17.8	-17.8	Auto
4	Smoke Cook	2:00	54.4	-17.8	-17.8	Closed
5	Cook	2:00	60.0	48.9	12.8	Auto
[3]6	Cook	0:02	71.1	62.8	20.0	Auto
7	Cook	0:05	73.9	62.8	15.6	Auto
8	Cold Shower	0:10	-17.8	-17.8	-17.8	Open

[1]Relative humidity

[2]Fresh air damper and exhaust damper

[3]If internal temperature is less than 60.0˚C continue cooking until temperature is greater than 60.0˚C

Table 2.4. Effects of in-going brine temperature on processing characteristics of fresh pork knuckles when meat temperature was 4° C

	In-Going Brine Temperature				
Item	-1^0 C	7.2^0 C	15^0 C	SEM	P-value
Knuckles, n	37	37	37		
Initial wt, kg	1.19	1.20	1.19	0.03	0.32
Pumped wt, kg	1.65	1.67	1.65	0.04	0.55
Drained wt, kg	1.54	1.56	1.55	0.04	0.56
Initial pump uptake, %	38.40	39.46	38.59	1.35	0.45
Drained pump uptake, %	29.86	30.86	30.47	1.02	0.33
Cooked wt, kg	1.32	1.34	1.33	0.03	0.47
[1]Cooked yield, %	108.55	109.39	108.76	1.20	0.52
Chilled wt (net-on), kg	1.29	1.31	1.30	0.03	0.65
[2]Evaporative chill loss, %	2.18^b	2.57^a	2.42^{ab}	0.16	0.07
[3]Instrumental cured color					
L*	59.91^b	60.34^{ab}	61.10^a	0.34	0.03
a*	13.67^a	13.32^{ab}	13.04^b	0.27	0.08
b*	5.05	4.86	5.11	0.14	0.25
Proximate Analysis					
Moisture, %	74.37	74.71	74.67	0.28	0.54
Extractable lipid, %	3.01	2.88	2.96	0.16	0.79
[4]Texture profile analyses					
Hardness	2440.54	2324.76	2413.41	89.51	0.63
Fracturability	2440.95	2312.17	2413.41	89.86	0.57
Springiness	0.758^a	0.740^b	0.752^{ab}	0.006	0.07
Cohesiveness	0.647	0.651	0.655	0.004	0.40
Chewiness	1207.30	1136.36	1208.46	46.57	0.46
Resilience	0.310	0.310	0.315	0.004	0.65

[a-b]Within a row, least squares means lacking a common superscript differ ($P \leq 0.05$).

[1]Cooked yield = (Chilled wt / Green wt) * 100

[2]Evaporative chill loss = ((Cooked wt - Netted chilled wt) / (Cooked wt)) * 100

[3]L* measures darkness to lightness (greater L* value indicates a lighter color); a* measures redness (greater a* value indicates a redder color); b* measures yellowness (greater b* value indicates a more yellow color).

[4]Hardness is the absolute peak force on the first down stroke; Fracturability is the force at the first peak; Springiness is the (Area of Work 2 / Area of Work 1) ; Cohesiveness is the ratio of products original height; Chewiness is Gumminess x Springiness; Resilience is measured on the withdrawal of the first penetration; Gumminess is Hardness x Cohesiveness.

Table 2.5. Effects of in-going brine temperature on sensory characteristics of fresh pork knuckles when meat temperature was 4° C

	In-Going Brine Temperature				
Items	-1^0 C	7.2^0 C	15^0 C	SEM	P-value
Knuckles, n	37	37	37		
Sensory characteristic					
[1]Saltiness	7.64	7.64	7.85	0.15	0.32
[1]Juiciness	8.27	8.20	8.32	0.16	0.81
[1]Mouthfeel	6.88	6.94	6.74	0.14	0.32

[1]Units were assigned by trained panelists using a 15 cm anchored, unstructured line scale where 0 = no salt flavor, not juicy, or rubbery texture and 15 = extreme salt flavor, extreme juiciness, or mealy in texture

Table 2.6. Effects of in-going brine temperature on processing characteristics of fresh pork knuckles when meat temperature was tempered to brine temperature

	In-Going Brine Temperature				
Item	-1^0 C	7.2^0 C	15^0 C	SEM	P-value
Knuckles, n	20	20	19		
Pre-pump temperature, ^{0}C	-0.32^c	4.00^b	14.41^a	0.14	< 0.0001
Post-pump temperature, ^{0}C	0.03^c	5.45^b	15.19^a	0.15	< 0.0001
Initial wt, kg	1.16	1.17	1.15	0.03	0.91
Pumped wt, kg	1.44^b	1.59^a	1.60^a	0.04	0.01
Drained wt, kg	1.38^b	1.50^a	1.50^a	0.04	0.06
Initial pump uptake, %	23.85^b	36.25^a	38.74^a	1.05	< 0.0001
Drained pump uptake, %	19.05^b	28.23^a	30.23^a	0.84	< 0.0001
Cooked wt, kg	1.18^b	1.30^a	1.27^{ab}	0.04	0.04
[1]Cooked yield, %	98.86^b	109.51^a	107.95^a	1.09	< 0.0001
Chilled wt (net-on), kg	1.15^b	1.28^a	1.24^{ab}	0.03	0.02
[2]Evaporative chill loss, %	2.29	1.88	2.00	0.29	0.57
[3]Instrumental cured color					
L*	62.24^a	61.98^{ab}	61.19^b	0.35	0.10
a*	14.31	13.84	13.79	0.22	0.18
b*	6.10^a	5.38^b	5.42^b	0.15	< 0.01
Moisture, %	71.82^b	73.81^a	73.67^a	0.34	< 0.0001
Extractable lipid, %	3.88^a	3.30^{ab}	3.07^b	0.25	0.06
[4]Texture profile analyses					
Hardness	2279.71	2370.35	2076.89	134.74	0.27
Fracturability	2274.11	2370.39	2048.75	134.83	0.21
Springiness	0.73^{ab}	0.74^a	0.71^b	0.01	0.06
Cohesiveness	0.630^b	0.661^a	0.633^b	0.009	0.03
Chewiness	1083.29^{ab}	1164.12^a	942.64^b	74.09	0.09
Resilience	0.282^b	0.312^a	0.291^b	0.007	0.01

[a-b]Within a row, least squares means lacking a common superscript differ ($P \leq 0.05$)

[1]Cooked yield = (Chilled wt / Initial wt) * 100

[2]Evaporative chill loss = ((Cooked wt - Netted chilled wt) / (Cooked wt)) * 100

[3]L* measures darkness to lightness (greater L* value indicates a lighter color); a* measures redness (greater a* value indicates a redder color); b* measures yellowness (greater b* indicates more yellow

[4]Hardness is the absolute peak force on the first down stroke; Fracturability is the force at the first peak; Springiness is the (Area of Work 2 / Area of Work 1); Cohesiveness is the ratio of products original height; Chewiness is Gumminess x Springiness; Resilience is measured on the withdrawal of the first penetration; Gumminess is Hardness x Cohesiveness.

Table 2.7. Effects of in-going brine temperature on processing characteristics of fresh pork bellies

	In-Going Brine Temperatures				
Item	-1^0 C	7.2^0 C	15^0 C	SEM	P-value
Bellies, n	20	20	20		
Initial wt, kg	6.15	6.15	6.16	0.05	0.99
Pumped wt, kg	6.78	6.80	6.81	0.07	0.96
Pump uptake, %	10.41	11.03	10.64	0.39	0.56
Chilled wt, kg	5.98	5.99	5.99	0.07	0.99
Cook yield, %	97.27	97.38	97.26	0.47	0.98
Proximate analyses					
Moisture, %	41.30	41.32	41.57	0.82	0.97
Extractible lipid, %	45.03	45.23	44.59	1.11	0.91
[1]Sensory characteristic					
Saltiness	6.31	6.39	6.42	0.18	0.82
Oxidized odor	1.29	1.23	1.27	0.16	0.88
Oxidized flavor	1.32	1.13	1.44	0.16	0.14

[1]Units were assigned by trained panelists using a 15 cm anchored, unstructured line scale where 0 = no salt flavor, no odor, or no flavor and 15 = extreme salt flavor, extreme oxidized odor, or extreme oxidized flavor

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