ABSTRACT

NOBLES, CURREY ALLEN. Processing Factors Affecting Commercially Produced Pork Bacon. (Under the direction of Dana J. Hanson.)

Three studies were performed to assess the effects of processing and ingredient parameters on the production yields and consumer acceptance of pork bacon. Products were produced at a commercial processing facility and processed under standard plant procedures.

Study 1 was conducted to assess the effect of sodium phosphate reduction on processing yields and consumer sensory perception of bacon. Standard sodium phosphate level bacon (SP) and low sodium phosphate level bacon (LP) were produced at a commercial bacon processing facility. The SP bacon was formulated to 0.05% sodium phosphate in the finished product. LP bacon was formulated to 0.005% sodium phosphate in the finished product. SP bacon trees (N=9; 575 individual pork bellies) and LP bacon trees (N=9; 575 individual pork bellies) were produced. Phosphate reduction had no effect ($p>0.05$) on smokehouse and cooler yields. Phosphate reduction also showed no effect ($p>0.05$) on yield of #1 and #2 bacon slices. At 30 days post processing consumers rated LP bacon higher than SP bacon ($p<0.05$) in the attribute of overall liking, but there was no clear preference ($p>0.05$) of either product among consumers. At 110 days post processing SP bacon was rated higher by consumers ($p<0.05$) than LP bacon in the attribute of overall flavor liking, but there was no clear preference ($p>0.05$) for either product. Sodium phosphate reduction was not detrimental to processing yields and still produced a product that was well received by consumers.

Study 2 was conducted to assess the effect of brine temperature reduction on processing yields and consumer sensory perception of commercially produced bacon. Brines produced with room temperature (23.1^{o}C) water (RTB) and low temperature brines (LTB)

produced with a mixture of ice and water (-6.5°C) were used to process bacon. RTB bacon trees (N=10, approximately 640 individual pork bellies) and LTB bacon trees (N=10, approximately 640 individual pork bellies). Brine temperature reduction showed an effect on smokehouse yield with LTB having a significantly higher ($p<0.05$) yield than RTB (LTB=95.98%; RTB=94.54%). There was no effect on overall yield ($p>0.05$). Brine temperature reduction showed no effects ($p>0.05$) on yield of #1 and #2 bacon slices. At 30 days post processing consumers rated RTB bacon (7.3) higher than LTB bacon (6.8, $p<0.05$) in the attribute of texture liking, and there was a clear preference ($p<0.05$) of consumers towards LTB bacon (59.6%). At 110 days post processing there were no differences ($p>0.05$) in consumer acceptance of bacon. Brine temperature reduction had beneficial effects on smokehouse yield while still producing a product that was well received by consumers.

Study 3 was conducted to assess the effects post injection dwell and smoke time on the processing yields and consumer sensory perception of commercially produced bacon. The experimental design for this study was a 2X2 factorial design with two levels for each variable. The levels of post injection dwell time were 0 and 2 hours and the levels of smoke time were 4 and 6 hours. This experimental design produced 4 treatments: 0 hour post injection dwell, 4 hour smoke (0D4S); 0 hour post injection dwell 6 hour smoke (0D6S); 2 hour post injection dwell, 4 hour smoke (2D4S); and 2 hour post injection dwell 6 hour smoke (2D6S). 0D4S had the highest smoke yield (96.19% $p<0.05$), whereas 2D4S had the highest cooler yield (97.55 $p<0.05$). 2D4S had a significantly higher smoke yield than 2D6S ($p<0.05$), but was not significantly different from 0D6S. Consumers rated 2D4S significantly higher ($p<0.05$) than 2D6S in the attribute of overall flavor, but 2D4S was not significantly different ($p>0.05$) either of the other treatments. There was no difference among treatments ($p<0.05$) for consumer response of purchase intent.

Processing Factors Affecting Commercially Produced Pork Bacon

by
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DEDICATION

This thesis is dedicated to all friends, family, and the wonderful faculty and staff of the NC State University Department of Food Science who devoted hours of their time to teach me so many things and help me succeed.

BIOGRAPHY

Currey Nobles was born to Jeff and Tami Nobles on April 17, 1993 in Asheboro, North Carolina. Currey grew up in Asheboro with his older sister, Caroline. Food Science was unknown to Currey until he came and toured NC State for potential college admission. On this tour, the guide could not stop raving about the awesome class he was enrolled in where the professor brought snacks and you learned the science of food. Through many fortunate circumstances, Currey landed in the NC State Department of FBNS, and was able to find a wonderful place in the meat lab both as an undergraduate worker and graduate student. The 5 years in the FBNS department have been marked by countless exams, projects, and sanitation checks, but it has all been a worthwhile journey.

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I would like to thank my parents, Jeff and Tami, for always supporting and encouraging me through my graduate work. You are the best parents anyone could ask for. Finally, I would like to thank my fiancé, Emily, for always being there for me. You are an amazing woman, and I couldn't have done this without you.

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CHAPTER 1

REVIEW OF LITERATURE

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1.1.History of meat curing

Meat curing technology has been practiced for many centuries. It stemmed from the use of salt as a preservative. Ancient cultures found that meat that was rubbed with salt did not spoil as fast as meat that was not treated with salt. This is due to fact that salt inhibits bacterial growth through a reduction in water activity. This practice was prevalent in many ancient cultures throughout Europe and formed the basis for meat curing technology that is recognized today (Pegg and Shahidi, 2000, Keeton, 2011). While salt was added for a preservative effect, small sodium or potassium nitrate impurities in the salt formed the basis for the curing reaction. These nitrates interacted with the meat, and coupled with time and microbial action produced nitric oxide which reacted with myoglobin to produce crudely cured meat products (Keeton, 2011). The curing of meat products is facilitated by the addition of salt (sodium chloride) and either sodium nitrate or sodium nitrite to the meat matrix (Binkerd and Kolari, 1975, Pegg and Shahindi, 2000, Duncan and Foster 1967). In 1923, the USDA authorized a study by Kerr et al. (1926) to examine the direct use of sodium nitrite in the curing of hams. Based off their results Kerr et al. (1926) found that "One-fourth of an ounce, or less, of sodium nitrite appears to be sufficient to fix the color of 100 pound of meat." These results led to sodium nitrite being approved for use as a curing agent in federally inspected facilities so long as the residual nitrite did not exceed 200 parts per million (Keeton, 2011). The method of delivery of the curing ingredients can vary depending on the application, and other functional ingredients can be added to the curing mix as well.

1.2. Curing Methods

There are multiple methods in which to deliver curing ingredients to a meat system, but all methods generally fall in one of three categories (Pegg, 2004).

1. Dry Curing
2. Immersion Curing
3. Injection Curing

1.2.1 Dry Curing

Dry curing is a curing method in which the curing ingredients are manually applied to the surface of the meat product. This is the most primitive method of curing which was discovered and practiced by ancient civilizations. Dry curing has persisted as a common curing method due to its inherent history and artisan perspective. While many spices, flavors, or sweeteners can be added to the dry cure mixture, salt and nitrite are the main ingredients. Dry curing is not commonly practiced for commercial bacon production due to its time and labor intensive practices. Curing mixtures penetrate the meat system at roughly 1 inch per 7 days, so the meat product must be massaged and curing mixture reapplied to attain an even distribution of curing agents throughout the product. (Scramlin, 2009, Ray, 2012). While dry curing is not commonly used for commercial bacon production, there are markets in which dry cured products dominate (Armenteros et al., 2012). Southeastern United States country ham, Spanish style jamon, and Italian style prosciutto are all examples of dry cured products. The raw materials typically used for dry curing are whole muscle products such as hams or muscles from the pork shoulder. These materials are ideal for dry curing application because their production is typically a long process (at least 4 months) in which the curing agents will have time to distribute throughout the product.

1.2.2 Immersion Curing

Immersion curing is a method in which a curing brine is made and the meat product is submerged in the brine to facilitate distribution of curing ingredients. The ingredients in the curing brine can include water, salt, sodium nitrite, and other flavorings or spices. While immersion curing takes less time than dry curing, it is still a lengthy process that can take upwards of 7-10 days. Due to the time investment immersion curing is not typically used for commercial production of bacon (Scramlin, 1999, Ray, 2012).

1.2.3 Injection Curing

Injection curing is the most common curing method used for commercial bacon production. In injection curing a curing brine is formulated with water, salt, sodium nitrite, sodium erythorbate, and any other functional ingredients or flavorings. After the curing brine is formulated it is delivered to the raw pork bellies through the use of an injection system. The injection system delivers a set amount of brine to the bellies through sets of hollow needles that pierce the belly and distribute the curing brine evenly throughout the product. The amount of curing brine delivered to the product is determined by the pressure of the injection system, how many needles are present in the injection system, and the speed of the conveyor belt on which the raw bellies are carried. This curing method allows quick and even distribution of the curing ingredients which makes it ideal for the high volume commercial bacon production sector (Scramlin, 1999, Ray, 2012).

1.3. Bacon consumption trends

Bacon is a highly valuable pork commodity. Bacon consumption trends have been consistently on the rise due in part to a variety of factors. Chiefly among these consumption factors is the movement of bacon from solely a 'breakfast' item to a highly commoditized and readily available foodservice item (Pellegrini, 2013). Incorporation of bacon as an ingredient into sandwiches, salads, pizza and other readily available food service items has drastically increased demand and consumption since the mid-1990s (Mandigo, 2000). While breakfast still drives bacon consumption, foodservice applications comprise a major market segment. As reported by Pellegrini (2013), 67% of all restaurants include some form of bacon on their menus. In addition, a senior brand manager of a major commercial bacon producer said that "foodservice bacon sales have posted a 3-4% annual growth rate every year since 2007" (Pellegrini, 2013).

Bacon is also increasingly being used in novel or adventurous applications and has been identified as a 'food trend' in recent years. Some of the novel applications for bacon include: bacon infused cocktail type drinks, maple bacon dessert items, and even bacon confectionary products (Ozersky, 2014). In 2005, sales of refrigerated bacon totaled $2 billion which was a 20.5% increase over the past 5 years. This huge increase in sales was driven by the functionality and versatility of bacon as a consumer product (Crews, 2016). The National Pork Board reports that 53% of households always have bacon on hand in the kitchen (National Pork Board, 2007). Consumer demand for bacon has continued to rise since 2005, even in spite of increased prices for the product. In 2013, retail sales of bacon increased 2.5%, to a market value of $3.7 billion. The wholesale value of the belly primal also increased from $39.04/head to $58.07/head. Both the retail and wholesale increase in value is coupled with the 8 cent increase to $4.19 average cost for a retail package of bacon (Pellegrini, 2013). Due to the prevalence of bacon, and its wide consumption, it is an incredibly valuable processed meat commodity.

1.4. Standard of Identity

Bacon, by USDA definition, can only be used to identify the cured belly of a swine carcass (USDA FSIS, 2005). The belly primal of a swine carcass typically comprises approximately 9% of the live weight of the animal, 14% of the chilled carcass weight, but the belly represents around 17% of the total value of the carcass (Stifler, 1975). In addition to the raw material designation to meet the standard of identity for bacon, to be legally labeled bacon, "The weight of cured pork bellies ready for slicing and labeling as ''Bacon'' shall not exceed the weight of the fresh uncured pork bellies." (USDA, 1984) This means that the weight of finished product cannot exceed the weight of raw material due to addition of water and curing ingredients. If a product does not meet these two categories, it cannot be labeled 'bacon' and must be labeled with its starting raw materials. For example, pork jowls are commonly cured and made into a bacon type product, but they must be labeled as 'pork jowl bacon' (USDA FSIS, 2005). Even with the legal labeling restrictions, since the belly is such a valuable portion on the carcass, bacon processing is a highly valued operation.

1.5 Curing Ingredients

1.5.1 Water

Water is a vital ingredient for injection cured products such as bacon. Water constitutes the bulk of the curing brine and serves as the solvent for all curing ingredients formulated into the brine. Water is typically between 70-80% of the curing brine and facilitates proper mixing and solubilization of curing ingredients. Water can be formulated into the curing brine as either liquid water or ice. Reducing the temperature of the brine can serve to alter curing ingredient solubility and affect processing characteristics. No matter the form of water, it is a vital ingredient to any injection cured product as it serves as the solvent medium and insures even distribution of the curing ingredients throughout the brine as well as the product itself. While water is a large percentage of the curing brine injected into pork bellies during bacon production, the weight of product after heat treatment in the smokehouse cannot exceed the raw weight of the bellies, if the product is to be legally labeled as 'bacon'. In essence, all the water that is pumped into the bellies must be removed to call the product bacon. Due to this regulation, commercial bacon processors must manage injecting enough curing brine to facilitate curing, but not so much as to drastically increase smokehouse times and decrease product yield.

In a 2016 study, Peterson et al studied the effects of variable brine temperature on the processing characteristics of bacon and hams. Three different brine temperatures of -1.1°C, 7.2°C and 15.5°C were utilized in the study. All other curing brine components were kept consistent. The brine temperature treatments did not affect ($p>0.18$) cooked yield, chilled weight or evaporative chill loss of hams. There were some color differences of the hams, with the 15.5°C hams being both lighter and redder ($p<0.05$) than both the -1.1°C, 7.2°C hams. From a sensory perspective, 15.5°C hams were saltier ($p<0.10$) than the -1.1°C, 7.2°C hams, but there was no difference between juiciness or mouthfeel between the three treatments ($p>0.05$). Brine temperature did not affect the pump uptake or cooked yield of bacon ($p>0.05$). This study showed some processing effects due to curing brine temperature on hams, but not pork bellies (Peterson, et al., 2016).

Leach (2000) used cold (-1.7°C), intermediate (1.4°C) and warm (3.9°C) curing brine temperatures to examine their effect on ham processing characteristics. The study found that the cold brine temperature had a higher ($p<0.05$) cook loss and chill loss than both the intermediate and warm temperatures. However, the -1.7°C hams cured with the cold brine had significantly higher ($p<0.05$) perceived flavor intensity, juiciness, and overall tenderness when compared to -1.7°C hams cured at intermediate and warm temperatures (Leach, 2000).

Gilchrist (1996) examined the effects of cold (13°C) and hot (38°C) brine on the processing characteristics of cured hams. This study found that cold brine cured hams had lower ($p<0.05$) salt and nitrite contents at 0 hours of ham tumbling than hot brine cured hams, and cold brine cured hams also had a lower ($p<0.05$) concentration of nitrite with 8 hours of ham tumbling (Gilchrist, 1996). This study also showed that the hot brine cured hams had a significantly higher ($p<0.05$) smokehouse yield, as measured by water holding capacity than the cold brine cured hams. The hot brine cured hams had an average of 96% smokehouse yield, compared to 93.5% yield for the cold brine cured hams.

1.5.2 Salt

Salt, in addition with nitrite, is a vital ingredient necessary to produce cured meat products. Salt serves many functions within a cured meat system. Salt is typically the most abundant ingredient present in an injection curing brine (except for water) and therefore contributes a significant flavor to the product (Froehlich et al. 1983). Salt is typically formulated between 12-15% of the curing brine for bacon, and targeted between 1.5-2% of the finished product based on the percent pickup from the injection curing process. In addition to contributing significant flavor to cured meat products, salt functions both independently and in tandem with nitrite to have antimicrobial properties. Salt, on its own, functions osmotically to drive water out of a meat system and lower the water activity of the environment, making it less conducive to microbial growth (Pegg and Shanini, 2000). Salt can have more pronounced antimicrobial effects at higher concentration, but such high salt concentrations would make an undesirable product for consumers. In addition to antimicrobial functions, salt plays a large role in the functionality and acceptability of cured meat products. Salt can function in a water binding capacity which is essential for the functionality of many types of sausages and hams. Aside from water binding, salt serves to enhance the perception of meat flavor and overall acceptability of a product (Pietrasik and Gaudette, 2015). Due to recent health concerns about high levels of sodium intake, there has been much research devoted to the reduction of sodium in processed meats, with a focus on cured meats (Pietrasik and Gaudette, 2015, Tamm et al. 2016, Cluff et al. 2016).

1.5.3 Sweetener

Salt, on its own, would create a product with a harsh, undesirable flavor, so sweeteners are commonly added to cured meat products to alter the flavor profile (Pegg, 2004). The most common sweetener added to cured meats products is sugar (sucrose). However, depending on the product the sweetener could vary from maple syrup to honey to brown sugar. Sugar acts to temper the harsh flavor of the salt and provide a more desirable product. In addition to flavor modification, sweeteners can provide an avenue for Maillard browning to occur (Pegg, 2004). Depending on the chemical structure of the sweetener it can serve as a substrate for Maillard browning either in the course of production or through consumer preparation of the product. The Maillard browning products give bacon a characteristic aroma that could also be influenced by the presence of nitrite. This was shown by Timon et al (2004) when the volitale aromatic compounds associated with bacon (cured) and pork loin (uncured) were captured and identified.

1.5.4 Sodium Nitrite and Sodium Nitrate

Sodium nitrate and sodium nitrite are both curing agents that are used in commercial production of cured meat products. While sodium nitrate and nitrite are commonly used curing ingredients, over the course of the curing reaction they are reduced to nitric oxide which is the active curing ingredient that interacts with myoglobin to 'cure' the product (MacDougall, et al., 1975, Sebranek and Fox, 1985). Nitric oxide interacts with the myoglobin the meat system to form a complex known as nitric oxide myoglobin which is responsible to the color of uncooked cured meats. When the product is exposed to heat, the nitric oxide myoglobin is converted to nitric oxide hemochrome which is responsible for the characteristic pink color of cured meat products (MacDougall et al., 1975, AMSA, 2012). The conversion to nitric oxide myoglobin is assisted either through endogenous or exogenously added nitrifying bacterial cultures, or with the addition of a cure accelerant/reducing agent such as sodium erythorbate or ascorbate. While both sodium nitrate and sodium nitrite can be used as curing agents, sodium nitrite is more commonly used due to the fact that it can be more quickly reduced to nitric oxide. The USDA regulates that the ingoing concentration of sodium nitrite for commercially produced injection cured bacon cannot exceed 120 parts per million and must be used in conjunction with 550 parts per million of sodium erythorbate. (USDA, 1999)

The functions of sodium nitrite in cured meat products are fourfold:

1. Development of cured meat color
2. Development of cured meat flavor
3. Antioxidant functions

4. Antimicrobial functions

Cured meat color is vital to consumer acceptance of a cured meat product. The characteristic pink color associated with ham, frankfurters, and other cured meats is vital to the consumer acceptance and enjoyment of the product (Mancini and Hunt, 2005). Cured meat color is caused by the reduction of sodium nitrite to nitric oxide and the subsequent interaction of nitric oxide with myoglobin (MacDougall et al. 1975, Pegg and Shanidi, 2000). Myoglobin is a prominent protein found in meat and is primarily responsible for meat color. Myoglobin contains 8 α-helices, as well as a heme ring with a centrally located iron atom. This central iron atom can form 6 bonds, with one site available for reversible ligand binding that, in conjunction with the oxidation state of the iron atom determines meat color (Mancini and Hunt, 2005). In the case of cured meat color, the iron is in Fe^{2+} state, and nitric oxide is bound to the myoglobin.

Just as in the development of cured meat color, sodium nitrite functions in a cured meat product to develop cured meat flavor. The mechanism and exact role of nitrite in determining cured meat flavor is still somewhat not understood, but the addition of nitrite does cause detectable flavor differences. This was initially described by Cho and Bratzler (1970) in their study examining pork loin roasts cured with and without nitrite. Through a series of triangle and 2 sample tests, these authors were able to show that consumers could identify the roasts cured with sodium nitrite as having a 'more cured flavor' than those roasts cured without sodium nitrite, even at higher salt levels (Cho and Bratzler, 1970). Dethmers and Rock (1975) also showed that the addition of curing ingredients produced a higher quality product. Thuringer sausages were produced with varying levels of sodium nitrite and subjected to trained sensory panel evaluation. Addition of sodium nitrite at 100 parts per million produced more desirable thuringer that rated higher in appearance and flavor quality scores than thuringer cured with 0 or 50 parts per million sodium nitrite (Dethmers and Rock, 1975). While cured meat flavor is complex, and characterized by more than sodium nitrite alone. Sodium chloride and sodium nitrite with their respective prooxidiant and antioxidant capabilities serve to create a complex flavor system in cured meats (Sebranek and Fox, 1985).

Sodium nitrite, in addition to functioning with cured meat flavor and color, also has antioxidant properties in cured meats. The antioxidant role of sodium nitrite in cured meats is mainly focused on the prevention and/or retardation of lipid oxidation. Lipid oxidation can produce many undesirable flavors and odors, and is of concern in a high fat product such as bacon. Sodium nitrite can function to sequester free radicals and reactive oxygen species to prevent and slow lipid oxidation. MacDonald et al. (1980) evaluated the antioxidant capacities of sodium nitrite both by itself and in the presence of prooxidants such as Fe^{2+} and Fe^{2+}-EDTA as well as beef and pork extracts to simulate a cured meat system. While sodium nitrite showed some prooxidant capabilities on its own, when combined in a model meat system with Fe^{2+} or Fe^{2+}-EDTA, there was a significant (<0.05) reduction in oxidation rates (MacDonald et al., 1980). Sebranek and Fox (1985) reported that nitric oxide produced during the curing reaction could function as a lipid antioxidant due to its nonpolar solubility. This is directly applicable to high fat systems such as bacon. Berardo et al (2016) more recently showed that sodium sodium nitrite alone, and in conjunction with sodium erythorbate can have lipid antioxidant capabilities. The combination of sodium sodium nitrite and sodium erythorbate had the greatest antioxidant effect on dry fermented sausages (27.5% fat) than either ingredient alone (Berardo et al. 2016). Both sodium sodium nitrite and sodium erythorbate are ingredients in commercially produced bacon, so the lipid antioxidant properties of the ingredients is of great value to processors.

In addition to the aforementioned functions, one of the most vital functions of sodium nitrite in cured meats is the antimicrobial properties it provides. Sodium nitrite can provide control of many bacteria present in a meat system, but the most important is the control of *Clostridium botulinum*. This bacterium is a food borne pathogen that produces a toxin that one of the deadliest substances on earth. Christiansen et al. (1974) showed the effects of sodium nitrite in bacon on the growth and survival of *C. botulinum*. In this study bacon was cured with varying concentrations of sodium nitrite (0-340 ppm sodium nitrite), inoculated with *C. botulinum*, and then stored either at 7°C or 27°C. No *C. botulinum* toxin was found in any samples stored at 7°C for up to 84 days. Toxin production was detected in samples stored at 27°C, inoculated with a low level of *C. botulinum* if formulated with 120 µg sodium nitrite/g meat or less (Christiansen et al., 1974). In addition to control of *C. botulinum*, sodium nitrites in cured meat products can also control the outgrowth of *Clostridium perfringens* during typical cooling cycles. Meyers et al (2016) showed that increasing sodium nitrite concentration (0, 50, 100 ppm) was more effective in controlling the outgrowth of a 3 strain *C. perfringens* cocktail broth that was subjected to a representative thermal treatment and cooling process to mimic cured meats processing. Providing control of *C. botulinum* is one of the most important functions of the meat curing process.

With consumers becoming more aware of the method in which their food products are being produced, coupled with the trend of 'all natural' and 'organic' products, the meat industry has had to rely on alternative curing methods. The natural and organic meat sector is one of the fastest growing in the industry, and consumers are willing to pay upwards of 200%

premiums for natural and organically cured meat products (Sebranek and Bacus, 2007). Due to this available market, the meat industry has relied on natural sources of sodium nitrite and nitrate to produce organic and natural products such as bacon, ham, and frankfurters that possess many of the same qualities consumers expect from their conventionally cured counterparts. The most commonly used natural curing ingredients are sea salt, raw (turbinado) sugar, and some form of vegetable juice or powder. The most common sources of vegetable juice or powder were celery, carrot, beet, and spinach, but celery juice and powder have seen the most application within the processed meat industry (Sebrank and Bacus, 2007).

Sindelar (2006) showed that frankfurter styles sausages could be produced using alternative curing methods that were comparable to conventionally cured frankfurters. Alternatively cured product was produced through the incorporation of vegetable juice powder and a nitrate reducing starter culture. These products were compared to a conventionally (sodium sodium nitrite with sodium erythorbate) cured product in the attributes of: color, lipid oxidation, cured pigment and trained sensory evaluation. While there was some variation between the treatment products and the control, all products exhibited cured meat characteristics of color and flavor (Sindelar, 2006).

While it is important to show that alternatively cured meat products exhibit similar color and flavor properties to their conventionally cured counterparts, the safety of the product also has to be taken into account. Since the presence of sodium nitrite can control the outgrowth of *Clostridium spp.,* the safety of naturally or organically cured products must be insured. In a 2011a study, Jackson et al., examined the efficacy of a variety of natural and alternative cure methods for the safety of ham and frankfurter products inoculated with *C. perfringens.*

Six different natural cures each containing either a sodium nitrite/nitrate source, starter culture, and/or antimicrobial were compared to a negative control (truly uncured) and positive control (conventionally cured with sodium sodium nitrite and sodium erythorbate). While there were some similarities, 3 of the naturally cured frankfurters and 2 of the naturally cured ham products had significantly ($p<0.05$) higher growth of *C. perfringens* as compared to the conventionally cured positive control (Jackson et al., 2011a). This indicates that if products were manufactured under the same natural curing procedures as the indicated treatments, consumers could be at an increased risk for food borne illness. The safety of commercially available naturally cured meat products was also assessed by Jackson et al., in 2011b. In this study, Jackson et al. (2011b) obtained commercially available, naturally cured frankfurters (10 samples), hams (7 samples), and bacon (9 samples) and subsequently challenged each sample through inoculation of *C. perfringens*. Each naturally cured product was evaluated against a conventionally cured control. 7 of the naturally cured frankfurter products, 5 of the naturally cured ham products, and 4 of the naturally cured bacon products exhibited significantly ($p<0.05$) higher growth of *C. perfringens* over the 10 day storage period at 20^{o}C, as compared to the conventionally cured positive control products (Jackson et al., 2011b). Once again this shows while alternative curing methods can produce products that exhibit color and flavor characteristics comparable to conventionally cured products, but could possibly be a higher food safety risk for the consumer.

1.5.5 Cure Accelerant

Depending on the product in question, cure accelerants may be added to increase the rate of the curing reaction. This is a common practice in the production of high throughput commercial cured meat products such as frankfurters, luncheon meats, and bacon. Cure accelerants such as sodium erythorbate and sodium ascorbate function as reducing agents to speed the reduction of sodium nitrite to nitric oxide which can interact with myoglobin to form the cured meat pigment (Pegg, 2004). Cure accelerants are not always added to long cured products which rely on nitrifying bacteria for the reduction of sodium nitrite to nitric oxide. The concentration of sodium erythorbate, the most common cure accelerant in bacon production, is monitored and regulated by the USDA. The maximum allowable ingoing concentration of sodium erythorbate in injection cured bacon is 550ppm (USDA, 1999)

1.5.6 Sodium Phosphate

Sodium phosphate is a widely used functional ingredient added to many different types of processed meat products. They can be used in water enhanced, but uncured products such as whole pork loins or beef strip loin steaks. Sodium phosphate, typically in the form of sodium tripolyphosphate, sodium hexametaphosphate, or sodium pyrophosphate are dissolved in water, salt, and sometimes antimicrobial agents such as sodium lactate/acetate and injected into the meat product at 10-15% over the raw weight of the meat (Kilic et al, 2016, Vangnai et al, 2014, Knock et al, 2006). The main function of sodium phosphate in a cured meat system is to increase the water holding capacity (WHC) of the meat system. Sodium phosphate increase the WHC by raising the pH of the meat system away from the isoelectric point of meat. Keller and Acton (1974) identified the minimum WHC of a sausage product occurred at a pH between 5.0-5.2. This pH corresponds to the approximate isoelectric point of actomyosin, which is the major contractile protein in meat. This principle was also demonstrated by Bianchi et al. (2009), in their work on turkey breast meat quality traits.

The increase of WHC has multiple beneficial effects for the processor. An increase in WHC increases the perceived juiciness and moistness, which makes the product more desirable from a consumer perspective (Jensen et al., 2003, Lawrence et al., 2003). In addition to positively affecting sensory characteristics of the product, addition of phosphate to increase WHC helps in protect cooking yields in the production plant. The addition of water allows for greater profit margins due to decreased cooking loss (Baczwaski and Mandigo, 2003). The combined effects of increasing processing yields as well as making the product more desirable to the consumer makes sodium phosphate and ideal functional ingredient in a processed meat system.

However, this is only a tangible benefit to the processor for products that can have a greater than 100% yield after the cooking process such as hams. There is no cooking loss standard of identity similar to that for bacon, for hams. Hams can have upwards of 30% added water and still be labeled as a ham product depending on the amount of added water and native protein (USDA, 1984b). Bacon, however, must meet the green weight stipulation, so the effect of increased WHC on bacon is possibly not a huge benefit to the processor. However, there have been studies that show addition of phosphate can increase the textural properties of cured meat products, which is of great interest to bacon processors from the perspective of slicing yield.

The effects of sodium phosphate on the texture of a variety of meat products has been studied. Roldan et al (2014) found that addition of a 0.2% or 0.4% solution of sodium phosphate to whole lamb loins increased the instrumental texture properties (hardness, cohesiveness, and shear force) of the product after it was cooked sous-vide style to an internal temperature of 72.8^{o}C. The two sodium phosphate treatment products were compared to lamb loins injected with distilled water, and the control loins did not exhibit the same textural properties (Roldan et al., 2014). This same phenomenon was seen in the production of 2 types of Spanish style dry sausages (salchichon and chorizo) formulated with a low and high inclusion of sodium phosphate. For both types of sausage an increase in the sodium phosphate inclusion led to a numerical increase in the textural properties of the products. Hardness, elasticity, cohesiveness, and chewiness were the textural properties measured. While the high level of sodium phosphate inclusion was always significantly different from the low level of inclusion, the chorizo style sausage with a high level of phosphate inclusion had significantly ($p<0.05$) higher hardness, elasticity, and chewiness as compared to a control with no sodium phosphate inclusion (Fonseca et al., 2011).

Keenan et al (2010) found that the reduction of phosphate in a cured beef system from 0.3% to 0.15% had no effect ($p>0.05$) on the cook loss or total yield of two roast beef type products. Hayes et al (2006) reported similar findings on a study examining enhanced pork loins. Loins that were enhanced with a 5.5% salt and 3.3% sodium tripolyphosphate solution showed no significant differences in cook loss or drip loss ($p>0.05$) as compared to non-enhanced pork loins. Detienne and Wicker (1999) showed that pork loins enhanced with a final product concentration of 1.5% salt showed no difference in overall yield (purge and cook yields) between injected phosphate levels of 0.15%, 0.3%, and 0.45%.

1.6. General Bacon Processing

Bacon is a widely consumed cured meat product that is a valuable commodity to pork producers and processors. Due to the widespread popularity of bacon processors are looking for novel approaches to increase or maintain processing yields while still manufacturing a product that is acceptable to consumers (Soladoye et al, 2015, Young, 2008, Person et al, 2005). Processors are looking for areas along the bacon production chain in which adjustments can be made to increase probability. Commercially manufactured bacon is typically produced by implementing the following processing steps. The first step in bacon production is the fabrication of raw materials. Bacon is produced from the belly of a pork carcass which can range anywhere between 5.4kg to upwards of 9.9kg, which represents approximately 14-15% of the total carcass weight (Stiffler, 1975). Once the bellies are procured and outer skin is removed, they are subjected to injection curing in which bellies are pumped with curing brine to typically 112%-115% of their green (raw) weight (Young, 2008). After injection, bellies are hung on combs and placed on trees. Bacon combs have multiple piercing tips that penetrate the belly to secure bellies throughout processing (Beld and Scribner, 2009). The combs are then hung on trees attached to rail systems in the plant that allows the product to flow through production. Some processors incorporate a post injection dwell time ranging from 2-6 hours to facilitate even cure development, but this is not done industry wide.

The next step is the smoking/heat treatment of the bellies. This step serves multiple functions. Smoking provides desirable flavors and colors to the bacon, while the heat treatment ensures enough moisture loss to verify the bacon meets the legal definition of 'bacon'. The time of smoke cycle varies between processors, but typically range between 4-12 hours (Soladoye, 2015, Young, 2008). After smoking, the product is chilled and then tempered to roughly -5.5°C. After tempering, the bacon is decombed and placed in a hydraulic press to ensure consistent product shape. Once the bacon is pressed, it is sliced, graded, and packaged. Bacon can be graded on the lean/fat ratio, or to standard internal or customer product specifications. There are no regulatory guidelines or directive for quality grades of bacon, so this procedure is generally done in plant (Young, 2008). While the grading varies between producers, bacon typically falls into one of three categories. Number 1 (#1) slices are the highest valued slices, have a desirable lean/fat ratio and are relatively free of defects. Number 2 (#2) slices are of lower value than #1 slices, but can be marketed to different demographics at different price points, increasing consumer reach of the product. The final category of bacon grade is ends and pieces (EP). EP are the lowest valued product, but can be further processed into bacon bits by grinding and microwave cooking to add value and reach a wider consumer base. Overall, the ideal distribution of slicing grades is #1: 70-75%, #2: 15-20%, EP: 5-10%, but this can vary based on initial meat quality or size specifications (Person et al, 2005). While this is general production flow for commercially produced bacon, processing can vary based on the facility, the company, or consumer feedback. A detailed flow diagram depicting a general commercial bacon processing operation can be found in appendix 6.1.

Commercial processors are concerned with processing yields throughout production such as: smokehouse yield, cooler yield, press/trim yield, and slicing yield. While these parameters are of huge importance to a high volume commercial bacon processor, they can be impacted by initial raw material quality, preprocessing handling, and size. Belly fat quality, thickness, frozen or fresh storage, and other carcass quality traits have all been explored in their relationship to bacon quality in terms of processing and/or slicing yields (Seman et al, 2013, Scramlin 2009, Robles 2004, Rentfrow et al, 2003). While these studies give various insight into different parameters that affect bacon quality, the goal of this research was to examine processing yields in a true commercial, high volume setting. A high volume commercial processor will have to process bacon out of varying quality raw materials, so it was the goal of this research to understand the impacts of the identified variables on the processing yields and resultant product quality that would represent a typical production shift at the facility.

1.6.1 Smoke and Post Injection Dwell Time

The thermal processing of pork bellies after they have been injected with the curing brine is most commonly performed in a smokehouse during commercial bacon production. Heat treatment of the bellies in a smokehouse accomplishes multiple objectives necessary for the safe production of a high quality product. First and foremost, heat treatment allows the product to meet the legal definition of 'bacon' by removing moisture so that the bacon exits the smokehouse at or under the initial raw (green) weight (USDA, 1984a). In addition to providing the standard of identity, treatment in a smokehouse can provide characteristic flavor and color consumers have come to expect from bacon. Smoke is a complex system that contains many chemical elements that contribute to flavor and color. Yu et al (2008) used solid phase microextraction to examine the flavor compounds associated with traditional Chinese bacon. Yu identified 48 individual flavor compounds in the bacon, many of which were due to the act of smoking. Phenols, methoxyphenols, and furans were all identified in the product and contributed flavor notes of caramel, sweet, smoky, or cresolic notes (Yu et al, 2008).

Post injection dwell time is a processing step that is performed in some commercial bacon production facilities. If performed, the bellies are injected with curing brine, combed, and then hung on trees. After the post injection dwelling step, the trees can post injection dwell from anywhere between 2-6 hours before going into the smokehouse for heat treatment. Post injection dwell time is implemented in some facilities to allow for even dispersion of the curing solution which can improve uniformity of product color as well as reduce ‘pickle pockets’ of brine that can sometimes form in the center of the bellies and lead to reduced slice yield. Scramlin (2009) noted that an extended post injection dwell time (6 hours) resulted in a higher yield of #1 bacon slices ($p<0.05$) when compared to the #1 slice yield of shorter post injection dwell time (2 hours) bacon.

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CHAPTER 2

EFFECT OF SODIUM PHOSPHATE REDUCTION ON COMMERCIALLY PRODUCED PORK BACON

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ABSTRACT

A study was conducted to assess the effect of sodium phosphate reduction in bacon on the processing yields and consumer sensory perception of the bacon. Standard sodium phosphate bacon (SP) and low sodium phosphate bacon (LP) were produced at a commercial bacon processing facility. The SP bacon was formulated to have 0.05% sodium phosphate in the finished product whereas the LP bacon was formulated to have 0.005% sodium phosphate in the finished product. SP bacon trees (N=9; approximately 575 individual pork bellies) and LP bacon trees (N=9; approximately 575 individual pork bellies) were produced at the facility and allowed to progress through normal production procedures. Data was collected on processing yields, slice yields, and samples were taken to perform consumer sensory analysis at 30 and 110 days post processing. Phosphate reduction had no effect ($p>0.05$) on smokehouse and cooler processing yields. Phosphate reduction also showed no effect ($p>0.05$) on yield of #1 and #2 bacon slices. At 30 days post processing consumers rated LP bacon higher than SP bacon ($p<0.05$) in the attribute of overall liking, but there was no clear preference ($p>0.05$) of either product among consumers. At 110 days post processing SP bacon was rated higher by consumers ($p<0.05$) than LP bacon in the attribute of overall flavor liking, but once again there was no clear preference ($p>0.05$) for either product. These data suggest that phosphate reduction is not detrimental to commercial bacon processing facility yields and can still produce a product that is well received by consumers.

2.2 Introduction

Sodium phosphate is a functional ingredient widely used in the processed meat industry to provide a variety of functionalities to a variety of products. Sodium phosphate can be formulated into a meat product in a variety of chemical structures, but the most common are sodium tripolyphosphate, sodium hexametaphosphate, and sodium pyrophosphate (Kilic, et al, 2016). Sodium phosphate function in a meat system to alter pH, increase water holding capacity, protect and improve processing yields, enhance texture of the product, provide antioxidant capabilities, and aid in color stability (Fonseca, et al 2011, Young et al, 2008, Lin and Lin 2002, Puolanne et al, 2001). However, the primary function of sodium phosphate in commercial meat production is protection and improvement of processing yields. The aforementioned studies deal mostly with sausage, ham, or fully cooked processed meat products. Bacon is not a fully cooked product, and must not also contain any added water to be legally labeled as bacon (USDA, 1984). Since bacon has no need for water holding, the reduction or elimination of sodium phosphate as an ingredient could potentially provide large ingredient cost savings for high volume commercial bacon manufacturing plants. The objective of this study was to assess the effects of sodium phosphate reduction on processing yields, slicing yields, color, and consumer acceptance of the product. If the two products performed in a similar fashion, the avenue for potential ingredient cost savings is opened.

2.3. Materials and Methods

2.3.1 Bacon Production

All bacon production was performed at a large, high volume commercial bacon production facility between April 16-18, 2015. Fresh, raw pork bellies (IMPS #409 pork belly, skinless), received from a large commercial pork processing and fabrication plant and ranging between 5.9-6.8 kilograms, were pumped with brine to fill 18 bacon trees. 9 trees were pumped with a low phosphate brine (LP), and 9 trees were pumped with a standard phosphate brine (SP). The LP brine contained approximately 0.05% phosphate and the SP brine contained approximately 0.5% phosphate. The remaining brine ingredients were: water (79.44%), sucrose (4.54%), salt (14.80%), sodium nitrite (120ppm) and sodium erythorbate (547ppm). Bellies were targeted to pump 112% over green weight and allowed to drain down to 110% over green weight to ensure proper delivery of curing ingredients. After pumping, the trees were loaded into a commercial convection smokehouse with LP trees on the right side of the smokehouse and SP trees on the left side of the smokehouse. Trees were thermally processed and smoked to an internal temperature of 49.4°C in accordance with plant procedures for approximately 3.5-4 hours. The smoke was generated from smoldering of hickory wood chips. The trees continued through standard processing and bacon was sliced. Weights for smokehouse yield and cooler yield were collected. Smokehouse and cooler yield were calculated based on pumped weight of trees. Product was sliced on a commercial slicing line with a high speed rotary blade slicer, and amount of #1 slices, #2 slices, ends and pieces, and inedible product were tracked on line and recorded. Slice yield was calculated based on the weight of the tree arriving at the slicing line. One sample box of #1 slices, 24 packages, from each tree was sampled for analytical and sensory analysis. This sample box was transported under refrigeration back to the NC State University Meat Laboratory and stored at 4°C.

2.3.2 Processing Yield Analysis

Data to analyze the smokehouse yield, cooler yield and overall yield were collected through plant monitoring software. Weights of each tree for each treatment were recorded and placed on the plant data logging server to be accessed. Weights were recorded after trees exited the smokehouse, after trees exited the tempering cooler, and directly prior to trees being sliced.

Slice yield data was collected by positioning data collectors at the front and back ends of the slicing line. One the data collector at the front would capture the net weight of the tree before slicing, and the collector at the back end of the slicing line would track and record the amount of #1 and #2 packages produced from that tree. Ends and pieces were tracked and recorded by plant employees. Slice yield was calculated based on the number of packages of #1 slices, #2 slices and ends and pieces produced for each tree. Formulas to calculate smokehouse, cooler, overall and slice yield are as follows:

Smoke yield was calculated as:

$$\text{Net tree weight upon exit of smokehouse} \big/ \text{Net tree weight after brine injection} * 100$$

Cooler yield was calculated as:

$$\text{Net tree weight upon entry to cooler} \big/ \text{Net tree weight upon exit of cooler} * 100$$

Overall yield was calculated as:

$$\text{Net tree weight upon exit of cooler} \big/ \text{Net tree weight after brine injection} * 100$$

Slice yield was calculated as:

$$\text{Weight of parameter (\#1, \#2, or end and pieces)} \big/ \text{Net weight of tree to slicing line} * 100$$

2.3.3 Color Analysis

Color evaluation was performed by first randomly selecting 4, 0.45kg vacuum packaged bacon packages from each box sampled during slicing. From each package, 2 bacon slices from four different locations in the package (top, top-middle, bottom-middle, and bottom) were selected. This made a total of 32 slices per sample box. The color space (L*, a*, b*) was evaluated on both the primary (*Obliquus externus abdominus)* and secondary lean (*Cutaneous trunci*) muscles of each slice using a Konica Minolta CR-410 (Tokyo, Japan) colorimeter using D65 illuminant source and calibrated via manufacturers recommendations to a white tile.

2.3.4 Cook Yield Evaluation

Cook yield evaluation was performed by randomly selecting 2, 0.45kg vacuum packaged bacon packages from each box sampled during slicing. 8 bacon slices from each package were selected for cook loss evaluation. A total of 16 slices per treatment were used from cook yield evaluation. The slices were placed on wire racks and cooked in a Southbend TV convection oven (Fuquay-Varina, NC) oven at 204ºC for 12 minutes based on the procedure outlined by Leick et al (2010). Racks were turned halfway through the cooking procedure to ensure even cooking. Bacon slices were blotted with a paper towel to remove surface fat after the 12-minute cooking period. Pre and post cooking bacon slice weights were measured with a Taylor (Denver, CO) TE10R type gram scale. Final cook yield was calculated as:

$$\text{Post cooking slice weight (g)} \Big/ \text{Pre cooking slice weight (g)} *100$$

2.3.5 Sensory Evaluation

Sensory evaluation by consumer panel was performed at 30 and 110 days post processing. Samples were stored under refrigeration at 2.2°C between sensory evaluations to mimic typical consumer storage conditions and gauge consumer acceptance over the typical shelf life of bacon. Each sensory evaluation was conducted under an 'all-call' procedure in which anyone could participate in the evaluation. Participation in the sensory evaluation resulted in compensation with a $5 Target (Minneapolis, MN) gift card. Sensory evaluations assessed consumer acceptance of product through 9 point hedonic scales, 5 point intensity scales, forced choice preference and 5 point just about right (JAR) scales. The 30 day post processing sensory analysis was conducted on May 20, 2015 with 100 participants, and the 110 day post processing analysis was conducted on August 4, 2015 with 101 participants. The protocol for each analysis was identical. All bacon was cooked in Southbend (Fuquay-Varina, NC) G series convection ovens at 204°C for 12 minutes. Bacon was then held in a Vulcan (Baltimore, MD) VBP-15 warming cabinet at 60°C for up to 30 minutes. If the bacon was not consumed within 30 minutes, it was discarded for quality purposes.

After bacon was prepared participants were randomly given 1 slice of bacon, coded with a random 3-digit treatment identification code, and asked to rate it based on sensory attributes. Sensory attributes were assessed on 9 point hedonic scale (1= dislike extremely and 9=like extremely), 5 point intensity scale (1=low quality/does not meet expectations and 5=high quality/exceeds expectations) and 5 point just about right (JAR) scales (1=too little, 3=JAR, 5=too much). Hedonic scales are widely used in sensory analysis of food products and give insight into how well the consumer liked the product in question. Traditional 9 point hedonic scales, as well as modified 5 or 8 point scales have been used to assess consumer liking of a variety of meat products (O'Quinn et al, 2015, Kallas et al, 2016, Julio et al, 2015). JAR scales are another common scale used in sensory analysis of food products Their use gives better understanding of the consumer experience with the product than hedonic scales alone. JAR scales are used to examine product attributes that influence overall liking of the product. The JAR scale responses can be correlated with overall liking scores to produce a penalty analysis that gives insight into which specific product attributes drive overall liking (Pages et al, 2013, Gacula et al, 2006). JAR scales have been widely used to assess attribute drivers of many meat products (Almeida et al, 2016, Hayes et al, 2014, Saha et al, 2009). Intensity scales, such as the 5 point scale used in sensory analysis are commonly used in sensory analysis of food products and can give insight into purchase intent and quality perceptions about products (Destefanis et al, 2008, Cardoso, et al 2013. Brewer et al, 2002). The combined use of 3 sensory scales enables a wider understanding of the consumer interaction with the bacon.

Attributes rated on the 9 point hedonic scale were: appearance liking, overall liking, overall flavor liking, and texture liking. Attributes rated on the JAR scale were: saltiness, slice thickness, sweetness, smoky flavor, crispiness, and fattiness. Attributes rated on the 5 point intensity scale were: bacon expectations and perceived quality. Participants were then given another slice of bacon, coded with a random 3-digit treatment identification code, and asked the same questions. Finally, the participants were asked to rank which slice of bacon they preferred. The consumers did not know which slice was LP and which slice was SP. Data was collected electronically and analyzed by the NC State University Sensory Service Center through the use of Compusense (Guelph, Ontario, Canada) data collection software. Demographic data for each consumer test are given in appendices 6.2 and 6.3.

2.4 Results and Discussion

Statistical Analysis

All p values were obtained by running a proc mixed analysis in SAS 9.4 (Cary, NC). Values that were found to be $p<0.05$ were considered to be statistically significant.

Processing Yield Analysis

Smoke and cooler yields were tracked throughout processing via in plant software. The data are presented below in table 2.1.

Table 2.1. Smoke, cooler and overall yield (%) of low and standard phosphate bacons

Treatment	Smoke Yield	Cooler Yield	Overall Yield
LP	95.98a	97.24a	93.33a
SP	96.05a	97.01a	93.61a

Means in a column followed by different letters are significantly different ($p<0.05$)

Slice Yield

Slice yield data was collected for #1 slices, #2 slices and ends and pieces. The slice yield data appears in table 2.2.

Table 2.2. Slice yield (%) of low and standard phosphate bacons graded as #1 slices, #2 slices and ends and pieces

Treatment	#1 yield	#2 yield	Ends and Pieces
LP	61.0a	18.2a	8.7a
SP	62.8a	16.2a	12.9b

Means in a column followed by different letters are significantly different ($p<0.05$)

Table 2.1 shows there was no significant difference (p>0.05) in smoke, cooler, or overall yield between LP and SP treatments. All yields were within 0.28 percent of each other. This indicates that there is no significant effect of phosphate level on processing yields. Table 2.1 shows no significance between #1 slice yield for LP versus SP bacon (p>0.05). Yield for #2 slices trended slightly towards significance (p=0.13), but was not significantly different. Ends and pieces yield was found to be significantly different (p<0.05) with LP treatments having a mean of 8.7% and SP treatments having a mean of 12.9% (p<0.05). While this data seems to indicate that phosphate formulation had no significant effect on the overall slice yield of the bacon, data collection methods were not robust, and were subject to a variety of sources of error.

Cook Yield

Table 2.3. Cook yield (%) of low and standard phosphate bacons

Treatment	Cook Yield
LP	35.1a
SP	34.3a

Means in a column followed by different letters are significantly different (p<0.05)

Color Analysis

Table 2.4. Color analysis of primary and secondary lean of low and standard phosphate bacons

	Primary Lean			Secondary Lean		
Treatment	L*	a*	b*	L*	a*	b*
LP	48.37a	20.33a	12.67a	63.83a	9.52a	7.98a
SP	46.92b	22.20a	12.65a	62.43a	10.59a	9.26b

Means in a column followed by different letters are significantly different ($p<0.05$)

No significance was found between the cook yields of each treatment ($p>0.05$) as presented in table 2.3 This indicates that the level of phosphate in the brine did not influence the cooking yields of bacon slices. The color evaluation data presented in table 2.4 shows there are statistically significant differences between measurements. LP bacon had a significantly ($p<0.05$) higher value of L* as compared to SP bacon. No other measurements of primary lean were significantly different ($p>0.05$). In measurement of secondary lean, LP bacon had a significantly lower ($p<0.05$) value of b* as compared to SP bacon. No other measurements of secondary lean were significantly different ($p>0.05$). Whether this statistical difference is practical to a processing and consumer perspective is still to be seen. Appearance of the product was also assessed in the sensory analysis which was conducted at both 30 and 110 days post processing.

Sensory Analysis

Table 2.5. Sensory analysis of 30 day post processing low and standard phosphate bacons

		LP	SP
Appearance Liking		7.3a	6.9b
Overall Liking		7.4a	7.0b
Flavor Liking		7.5a	7.2a
Texture Liking		7.2a	7.1a
Saltiness JAR	Much Too Little	1.0%b	8.0%a
	Just About Right	77.8%a	75.0%a
	Much Too Strong	21.2%a	17.0%a
Thickness JAR	Much Too Thin	27.3%a	25.0%a
	Just About Right	70.7%a	75.0%a
	Much Too Thick	2.0%a	0.0%a
Sweetness JAR	Much Too Little	18.2%a	26.0%a
	Just About Right	78.8%a	72.0%a
	Much Too Strong	3.0%a	2.0%a
Smoky JAR	Much Too Little	19.2%a	26.0%a
	Just About Right	74.7%a	70.0%a
	Much Too Strong	6.1%a	4.0%a
Crispiness JAR	Not Nearly Crispy Enough	37.4%a	21.0%b
	Just About Right	52.5%b	68.0%a
	Much Too Crispy	10.1%a	11.0%a
Fattiness JAR	Not Nearly Fatty Enough	3.0%a	4.0%a
	Just About Right	78.8%a	66.0%a
	Much Too Fatty	18.2%b	30.0%a
Bacon Expectations		4.3a	4.1a
Quality		3.7a	3.5a
Favorite		48.0%a	52.0%a

Data represents 100 consumers
Means in a row followed by different letters are significantly different ($p<0.05$).
5 point scale statistical letterings were obtained from Kruskal-Wallis non-parametric test with Dunn post hoc analysis.

Table 2.6. Penalty analysis of 30 day post processing LP bacon based on JAR and overall liking scores

Variable	Level	Frequency	%	Overall Liking	Mean drops	Std. difference	p
Saltiness JAR	Much Too Little	1	1.0%	7.0	0.55		
	JAR	77	77.8%	7.5			
	Much Too Strong	**21**	**21.2%**	**6.9**	**0.64**	**2.14**	**0.035**
Thickness JAR	**Much Too Thin**	**27**	**27.3%**	**6.8**	**0.89**	**3.42**	**0.001**
	JAR	70	70.7%	7.7			
	Much Too Thick	2	2.0%	6.5	1.17		
Sweetness JAR	Much Too Little	18	18.2%	7.0	0.49		
	JAR	78	78.8%	7.5			
	Much Too Strong	3	3.0%	7.7	-0.18		
Smoky JAR	Much Too Little	19	19.2%	7.6	-0.33		
	JAR	74	74.7%	7.3			
	Much Too Strong	6	6.1%	8.0	-0.70		
Crispiness JAR	Not Nearly Crispy Enough	37	37.4%	7.4	0.16	0.67	0.503
	JAR	52	52.5%	7.6			
	Much Too Crispy	10	10.1%	6.3	1.30		
Fattiness JAR	Not Nearly Fatty Enough	3	3.0%	6.3	1.24		
	JAR	78	78.8%	7.6			
	Much Too Fatty	18	18.2%	6.8	0.74		

Data represents 100 consumers
Bolded rows indicate a significant penalty ($p<0.05$)

Table 2.7. Penalty analysis of 30 day post processing SP bacon based on JAR and overall liking scores

Variable	Level	Frequency	%	Overall Liking	Mean drops	Std. Difference	p
Saltiness JAR	Much Too Little	8	8.0%	6.0	1.19		
	JAR	75	75.0%	7.2			
	Much Too Strong	17	17.0%	6.4	0.83		
Thickness JAR	Much Too Thin	25	25.0%	6.6	0.52	1.43	0.157
	JAR	75	75.0%	7.1			
	Much Too Thick	0	0.0%				
Sweetness JAR	**Much Too Little**	**26**	**26.0%**	**6.3**	**0.90**	**2.71**	**0.008**
	Just About Right	72	72.0%	7.3			
	Much Too Strong	2	2.0%	4.0	3.25		
Smoky JAR	Much Too Little	26	26.0%	6.6	0.48	1.33	0.187
	JAR	70	70.0%	7.1			
	Much Too Strong	4	4.0%	7.5	-0.44		
Crispiness JAR	**Not Nearly Crispy Enough**	**21**	**21.0%**	**6.4**	**0.91**	**2.67**	**0.009**
	JAR	68	68.0%	7.3			
	Much Too Crispy	11	11.0%	5.5	1.79		
Fattiness JAR	Not Nearly Fatty Enough	4	4.0%	4.5	2.89		
	JAR	66	66.0%	7.4			
	Much Too Fatty	**30**	**30.0%**	**6.3**	**1.09**	**3.60**	**0.000**

Data represents 100 consumers
Bolded rows indicate a significant penalty ($p<0.05$)

Table 2.8. Sensory analysis of 110 day post processing low and standard phosphate bacons

		LP	SP
Appearance Liking		7.0b	7.5a
Overall Liking		7.0a	7.3a
Overall Flavor Liking		7.0a	7.4a
Texture Liking		6.9a	7.2a
Saltiness JAR	Not Salty Enough	9.9%a	8.9%a
	JAR	54.5%a	68.3%a
	Too Salty	35.6%a	22.8%b
Slice Thickness JAR	Too Thin	19.8%b	38.6%a
	JAR	73.3%a	59.4%a
	Too Thick	6.9%a	2.0%b
Sweetness JAR	Not Sweet Enough	21.8%a	20.8%a
	JAR	70.3%a	76.2%a
	Too Sweet	7.9%a	3.0%b
Smoky JAR	Not Smoky Enough	23.8%a	23.8%a
	JAR	66.3%a	73.3%a
	Too Smoky	9.9%a	3.0%b
Crispiness JAR	Not Crispy Enough	23.8%a	22.8%a
	JAR	56.4%a	61.4%a
	Too Crispy	19.8%a	15.8%a
Fattiness JAR	Not Fatty Enough	4.0%a	4.0%a
	JAR	67.3%a	75.2%a
	Too Fatty	28.7%a	20.8%a
Bacon Expectations		4.0a	4.2a
Quality		3.6a	3.7a
Preference		43.6%a	56.4%a

Data represents 101 consumers
Means in a row followed by different letters are significantly different ($p<0.05$).
5 point scale statistical letterings were obtained from Kruskal-Wallis non-parametric test with Dunn post hoc analysis.

Table 2.9 Penalty analysis of 110 day post processing LP bacon based on JAR and overall liking scores

Variable	Level	%	Overall Liking	Mean drops	Std. difference	p
Saltiness JAR	Not Salty Enough	9.9%	4.60	2.95		
	JAR	54.5%	7.55			
	Too Salty	35.6%	6.94	0.60	1.90	0.061
Slice Thickness JAR	Too Thin	19.8%	6.35	0.89		
	JAR	73.3%	7.24			
	Too Thick	6.9%	6.86	0.39		
Sweetness JAR	**Not Sweet Enough**	**21.8%**	**6.55**	**0.88**	**2.35**	**0.021**
	JAR	70.3%	7.42			
	Too Sweet	7.9%	5.00	2.42		
Smoky JAR	**Not Smoky Enough**	**23.8%**	**5.83**	**1.78**	**4.80**	**< 0.0001**
	JAR	66.3%	7.61			
	Too Smoky	9.9%	6.10	1.51		
Crispiness JAR	**Not Crispy Enough**	**23.8%**	**6.25**	**1.42**	**3.99**	**0.000**
	JAR	56.4%	7.67			
	Too Crispy	19.8%	6.20	1.47		
Fattiness JAR	Not Fatty Enough	4.0%	6.50	1.06		
	JAR	67.3%	7.56			
	Too Fatty	**28.7%**	**5.90**	**1.66**	**4.58**	**< 0.0001**

Data represents 101 consumers
Bolded rows indicate a significant penalty ($p<0.05$)

Table 2.10 Penalty analysis of 110 day post processing SP bacon based on JAR and overall liking scores

Variable	Level	%	Overall Liking	Mean drops	Std. difference	p
Saltiness JAR	Not Salty Enough	8.9%	6.22	1.31		
	JAR	68.3%	7.54			
	Too Salty	22.8%	7.17	0.36	1.28	0.205
Slice Thickness JAR	**Too Thin**	**38.6%**	**6.97**	**0.63**	**2.27**	**0.025**
	JAR	59.4%	7.60			
	Too Thick	2.0%	6.50	1.10		
Sweetness JAR	Not Sweet Enough	20.8%	6.95	0.53	1.61	0.110
	JAR	76.2%	7.48			
	Too Sweet	3.0%	6.33	1.15		
Smoky JAR	**Not Smoky Enough**	**23.8%**	**6.54**	**1.04**	**3.40**	**0.001**
	JAR	73.3%	7.58			
	Too Smoky	3.0%	7.67	-0.09		
Crispiness JAR	**Not Crispy Enough**	**22.8%**	**6.74**	**1.10**	**4.59**	**< 0.0001**
	JAR	61.4%	7.84			
	Too Crispy	15.8%	6.25	1.59		
Fattiness JAR	Not Fatty Enough	4.0%	7.25	0.26		
	JAR	75.2%	7.51			
	Too Fatty	**20.8%**	**6.71**	**0.80**	**2.44**	**0.017**

Data represents 101 consumers
Bolded rows indicate a significant penalty ($p<0.05$)

Table 2.5 shows there were significant ($p<0.05$) differences between the appearance and overall liking of LP and SP samples at 30 days post processing. LP had a higher appearance score and overall liking score than SP, and none of the other 9 point hedonic attributes were significantly different ($p>0.05$). JAR scores were used to perform a penalty analysis for each attribute. The only significant penalties for LP bacon were ‘too salty’, which accounted for 0.64 mean drops and ‘too thin’ which accounted for 0.89 mean drops.

SP bacon had penalties assessed on the attributes of: not sweet enough (0.90), not crispy enough (0.91), and too fatty (1.09). The full penalty analysis for 30 day post processing LP and SP bacon are shown in tables 2.6 and 2.7, respectively.

Table 2.6 shows that SP had a significantly ($p<0.05$) higher appearance liking score than LP at 110 days post processing. None of the other hedonic attributes were significantly different. All products met consumer expectations for bacon, and were perceived as a high quality product, and there were no differences among quality perceptions and expectations. There was no consumer preference for either of the products. Penalty analysis for LP produced the following results and associated mean drops for significant penalties: not sweet enough (0.88), not smoky enough (1.78), not crispy enough (1.42), and too fatty (1.66). Penalty analysis of JAR scores for SP produced the following results and associated mean drops: too thin (0.63), not smoky enough (1.04), not crispy enough (1.10), and too fatty (0.80). Full penalty analysis for 110 day post processing LP and SP bacon are shown in tables 2.9 and 2.10, respectively.

2.5 Conclusions

Overall processing yield data indicates that there is no statistical significance between LP and SP treatment groups. This supports the conclusions of Poulanne et al. (2001) that showed WHC and cooking yield of sausage products was more a function of initial pH of the meat and salt level in the product, not the level of sodium phosphate inclusion. Neither smoke, cooler, nor overall yield was affected by the amount of phosphate in the brine. This is important from a processing standpoint because it shows that reduction in phosphate does not harm overall processing yield. This could potentially represent substantial ingredient cost savings.

Slice yield data showed some potential for significance, but was heavily influenced by data collection methods, machinery, and employees. All product was sliced on a single line that was prone to mechanical issues on the day of slicing which impacted data collection. In addition to mechanical issues, the amount of rework generated was large and hard to keep track of. Also, since slice grading is not standardized, and data collection occurred over the course of 2 production shifts, different graders were used which could have influenced the distribution of #1 and #2 slices. Since there were so many contributing factors in this data collection and analysis, conclusions cannot be drawn about the effect of phosphate level on slice yields.

Color analysis showed some significant differences between LP and SP. L* values of primary lean were significantly greater in LP bacon than SP bacon. A* values trended towards significance for both primary and secondary lean, with SP exhibiting a slightly redder color. L* and a* values are of higher priority in bacon because they deal with relative darkness and red color. The data indicates that incorporation of a higher concentration of phosphate results in a more pronounced red color. This could be an area of future sensory analysis to see if consumers are more influenced by taste or appearance of LP versus SP bacon.

Consumer performance attributes of the LP and SP bacon showed varying degrees of significance. Cook yield was not affected by treatment. This indicates that consumers would see that LP and SP bacon behaved the same way when cooked at home.

Sensory analysis showed no overall preference for on treatment over another, however specific attributes between LP and SP were found to be significant. One sensory attribute that was significant from a penalty analysis between both treatments was 'not smoky enough'. This could indicate that consumers expect a more intense smoky flavor from bacon, and could be a topic of future sensory research. However, all products were highly liked overall, and all possessed high quality and expectation scores from consumers. The other penalty analysis results such as too thin, not crispy, or not sweet enough could have been due to individual consumer preference. Since all product was produced with the same processing parameters (slice thickness, sugar content in brine) LP and SP products should have behaved the same. All products were also cooked under an identical protocol before serving to the consumer. While there is inherent biological variation within a bacon system, individual preference also plays a large role in acceptability.

Overall, processing yields and consumer acceptance of LP and SP bacon was not significantly different. While some data collected showed differences, processing yields, cook loss, and the majority of sensory attributes were not significantly different. Further research, with stricter processing controls is needed to strengthen the true relationship between the effects of phosphate formulation on slice yield and performance characteristics of bacon.

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CHAPTER 3

EFFECT OF BRINE TEMERPATURE REDUCTION ON COMMERCIALLY PROCESSED PORK BACON

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ABSTRACT

A study was conducted to assess the effect of brine temperature reduction on the processing yields and consumer sensory perception of commercially produced bacon. Standard brines (RTB) produced with room temperature (23.1°C) water and low temperature brines (LTB) produced with a mixture of ice and water (-6.5°C) were used to process bacon. RTB bacon trees (N=10) and LTB bacon trees (N=10) were produced at the commercial facility and allowed to progress through normal production procedures. Data was collected on processing yields, slice yields, and samples were taken to perform consumer sensory analysis at 30 and 110 days post processing. Brine temperature reduction showed an effect on smokehouse yield with LTB having a significantly higher ($p<0.05$) yield than RTB. There was no effect on overall yield ($p>0.05$). Brine temperature reduction showed no effects ($p>0.05$) on yield of #1 and #2 bacon slices. At 30 days post processing consumers rated RTB bacon higher than LTB bacon ($p<0.05$) in the attribute of texture liking, and there was a clear preference ($p<0.05$) of consumers towards LTB bacon.. At 110 days post processing there were no differences ($p>0.05$) in consumer acceptance of bacon. These data suggest that brine temperature reduction could have beneficial effects on smokehouse yield while still producing a product that is well received by consumers.

3.2 Introduction

The temperature of the curing brine used to cure products is an easily controllable processing factor that has been of some interest to cured meat processors. Variation of brine temperature either with ice or applied heat can potentially impart varied processing and/or flavor characteristics to the product in question. While this processing characteristic is of interest to processors, the true effects of brine temperature are still not fully understood (Keenan et al., 2016, Peterson et al., 2016). In a 2016 study, Peterson et al., examined the effect of three brine temperatures (-1.1°C, 7.2°C, and 15.5°C) on the processing yields, color, and sensory evaluation of ham and bacon. Hams and bacon were cured with the same curing brine formulation, save for brine temperature, and were processed in a method similar to commercial production. Brine temperature did not have any effect ($p>0.05$) on the processing yields (pumped weight, drained weight, initial pump uptake, drained pump uptake, cooked yield, chilled weight, or evaporative chill loss) of either the hams or bacon. Hams cured with 15.5°C brine were saltier ($p<0.05$) than hams cured with -1.1°C or 7.2°C brine, but there were no ($p>0.05$) textural differences among the products.

Keenan et al. (2016) examined the effect of brine temperature on the processing yields and eating quality of cured beef products. Two different beef muscles were cured with a low temperature brine ranging from 1.6°C-3.9°C or an elevated temperature brine ranging from 15°C-17.2°C. This study found no significant ($p>0.05$) effects of brine temperature on brine uptake, cook loss, or any other processing yields. These results support the results of Boles and Swan (1997) in which a range of brine temperatures from 0°C -12.2°C showed no effects ($p>0.05$) on cook yields of roast beef. Keenan et al., (2016) showed significant ($p<0.05$) effects on tenderness, juiciness, saltiness, overall flavor, overall texture and overall acceptability with the product cured with the low temperature brine scoring higher than the product cured with the elevated temperature brine (Keenan et al., 2016).

Overall, this study was performed to generate data about the true effect of brine temperature on the processing yields and consumer evaluation of bacon. Since there is still a lot of unknown information about the effects of brine temperature, it is important to identify how this variable impacts bacon production on the commercial scale.

3.3 Materials and Methods

3.3.1 Bacon Production

All bacon production was performed at a large, high volume commercial bacon production facility between September 30-October 1, 2015. Fresh, raw pork bellies (IMPS #409 pork belly, skinless), received from a large commercial pork processing and fabrication plant and ranging between 6.8-7.7 kilograms, were pumped with brine to fill 20 bacon trees. 10 trees were pumped with a brine prepared with a mixture of ice and water (LTB), and 10 trees were pumped with a brine prepared with room temperature water (RTB). The ice and water brine mixture was at a temperature of -6.5°C, and the room temperature water was at 23.1°C. The ice/water mixture and room temperature water comprised 79.44% of the weight of the brine. The remaining curing ingredients were identical and present at the following concentrations in the brine: sucrose (4.54%), salt (14.80%), sodium phosphate (0.50%), sodium nitrite (120ppm) and sodium erythorbate (547ppm). Bellies were targeted to pump 112% over green weight and allowed to drain down to 110% over green weight to ensure proper delivery of curing ingredients. The temperature of the LTB was targeted at 4.4°C, but the first attempt to produce the mixture resulted in a brine that was greater than 4.4°C. Therefore, for the next attempt, enough ice was added to ensure that the 4.4°C temperature threshold was reached. After brines were prepared, enough bellies were pumped to fill 10 trees per treatment. Trees were thermally processed and smoked to an internal temperature of 49.4°C in accordance with plant procedures for approximately 3.5-4 hours. The smoke was generated from smoldering of hickory wood chips. The trees continued through standard processing and bacon was sliced. Weights for smokehouse yield and cooler yield were collected. Smokehouse and cooler yield were calculated based on pumped weight of trees. Product was sliced on a commercial slicing line with a high speed rotary blade slicer, and amount of #1 slices and #2 slices were tracked on line and recorded. Slice yield was calculated based on the weight of the tree arriving at the slicing line. One sample box of #1 slices, 24 packages, from each tree was sampled for analytical and sensory analysis. These sample boxes were transported under refrigeration back to the NC State University Meat Laboratory and stored at 4°C.

3.3.2 Processing Yield Analysis

Data to analyze the smokehouse yield, cooler yield and overall yield were collected through plant monitoring software. Weights of each tree for each treatment were recorded and placed on the plant data logging server to be accessed. Weights were recorded after trees exited the smokehouse, after trees exited the tempering cooler, and directly prior to trees being sliced.

Slice yield data was collected by positioning data collectors at the front and back ends of the slicing line. One the data collector at the front would capture the net weight of the tree before slicing, and the collector at the back end of the slicing line would track and record the amount of #1 and #2 packages produced from that tree. Ends and pieces were tracked and recorded by plant employees. Slice yield was calculated based on the number of packages of #1 slices, #2 slices and ends and pieces produced for each tree. Formulas to calculate smokehouse, cooler, overall and slice yield are as follows:

Smoke yield was calculated as:

$$\text{Net tree weight upon exit of smokehouse} \big/ \text{Net tree weight after brine injection} *100$$

Cooler yield was calculated as:

$$\text{Net tree weight upon entry to cooler} \big/ \text{Net tree weight upon exit of cooler} *100$$

Overall yield was calculated as:

$$\text{Net tree weight upon exit of cooler} \big/ \text{Net tree weight after brine injection} *100$$

Slice yield was calculated as:

$$\text{Weight of parameter (\#1, \#2, or end and pieces)} \big/ \text{Net weight of tree to slicing line} *100$$

3.3.3 Color Analysis

Color evaluation was performed by first randomly selecting 4, 0.45kg vacuum packaged bacon packages from each box sampled during slicing. From each package, 2 bacon slices from four different locations in the package (top, top-middle, bottom-middle, and bottom) were selected. This made a total of 32 slices per sample box. The color space (L*, a*, b*) was evaluated on both the primary (*Obliquus externus abdominus)* and secondary lean (*Cutaneous trunci*) muscles of each slice using a Konica Minolta CR-410 (Tokyo, Japan) colorimeter using D65 illuminant source and calibrated via manufacturers recommendations to a white tile.

3.3.4 Cook Yield Evaluation

Cook yield evaluation was performed by randomly selecting 2, 0.45kg vacuum packaged bacon packages from each box sampled during slicing. 8 bacon slices from each package were selected for cook loss evaluation. A total of 16 slices per sampled box were used for cook yield evaluation. The slices were placed on wire racks and cooked in a Southbend TV convection oven (Fuquay-Varina, NC) oven at 204°C for 12 minutes based on the procedure outlined by Leick et al (2010). Racks were turned halfway through the cooking procedure to ensure even cooking. Bacon slices were blotted with a paper towel to remove surface fat after the 12-minute cooking period. Pre and post cooking bacon slice weights were measured with a Taylor (Denver, CO) TE10R type gram scale. Final cook yield was calculated as:

$$\text{Post cooking slice weight (g)} \Big/ \text{Pre cooking slice weight (g)} * 100$$

3.3.5 Sensory Evaluation

Sensory evaluation by consumer panel was performed at 30 and 110 days post processing. Samples were stored under refrigeration at 2.2°C between sensory evaluations to mimic typical consumer storage conditions and gauge consumer acceptance over the typical shelf life of bacon. Each sensory evaluation was conducted under an ‘all-call’ procedure in which anyone could participate in the evaluation. Participation in the sensory evaluation resulted in compensation with a $5 Target (Minneapolis, MN) gift card. Sensory evaluations assessed consumer acceptance of product through 9 point hedonic scales, 5 point intensity scales, forced choice preference and 5 point just about right (JAR) scales. The 30 day post processing sensory analysis was conducted on November 4, 2015 with 104 participants, and the 110 day post processing analysis was conducted on January 15, 2016 with 105 participants. The protocol for each analysis was identical. All bacon was cooked in Southbend (Fuquay-Varina, NC) G series convection ovens at 204°C for 12 minutes. Bacon was then held in a Vulcan (Baltimore, MD) VBP-15 warming cabinet at 60°C for up to 30 minutes. If the bacon was not consumed within 30 minutes, it was discarded for quality purposes.

After bacon was prepared participants were randomly given 1 slice of bacon, coded with a random 3-digit treatment identification code, and asked to rate it based on sensory attributes. Sensory attributes were assessed on 9 point hedonic scale (1= dislike extremely and 9=like extremely), 5 point intensity scale (1=low quality/does not meet expectations and 5=high quality/exceeds expectations) and 5 point just about right (JAR) scales (1=too little, 3=JAR, 5=too much).

Attributes rated on the 9 point hedonic scale were: appearance liking, overall liking, overall flavor liking, and texture liking. Attributes rated on the JAR scale were: saltiness, slice thickness, sweetness, smoky flavor, crispiness, and fattiness. Attributes rated on the 5 point intensity scale were: bacon expectations and perceived quality. Participants were then given another slice of bacon, coded with a random 3-digit treatment identification code, and asked the same questions. Finally, the participants were asked to rank which slice of bacon they preferred. The consumers did not know which slice was LTB and which slice was RTB. Data was collected electronically and analyzed by the NC State University Sensory Service Center through the use of Compusense (Guelph, Ontario, Canada) data collection software. Demographic data for each consumer evaluation are given in appendices 6.4 and 6.5.

3.4 Results and Discussion

Statistical Analysis

All p values were obtained by running a proc mixed analysis in SAS 9.4 (Cary, NC). Values that were found to be $p<0.05$ were considered to be statistically significant.

Smoke and Cooler yields

Smoke and cooler yields were tracked throughout processing via in plant software. The data are presented below in table 3.1.

Table 3.1. Smoke, cooler, and overall yield (%) of bacons prepared with ice/water brine and room temperature water brine

Treatment	Smoke Yield	Cooler Yield	Overall Yield
LTB	95.98a	96.47a	92.59a
RTB	94.54b	97.31a	92.00a

Means in a column followed by different letters are significantly different ($p<0.05$)

Slice yield

Slice yield was calculated based on the number of packages of #1 slices and #2 slices produced for each tree. Data is presented in table 3.2.

Table 3.2. Slice yield (%) of bacons prepared with ice/water brine and room temperature water brine graded as either #1 or #2 slices

Treatment	#1 Yield	#2 Yield
LTB	78.18a	12.13a
RTB	72.50a	13.11a

Means in a column followed by different letters are significantly different ($p<0.05$)

Table 3.1 shows that the LTB had a significantly ($p<0.05$) higher smoke yield of almost 96%, compared to 94.54% for RTB. The cooler yield comparison was not statistically significant ($p>0.05$), but the RTB had a numerically higher cooler yield of 97.3% as compared to 96.5% for LTB. The overall yield was not statistically significant ($p>0.05$), LTB had a higher numerical overall yield of 92.6% as compared to 92.0% for RTB.

Table 3.2 shows yield for #1 graded bacon slices could possibly be trending towards significance ($p=0.0785$). Yield for #2 slices was not significantly different between treatments ($p>0.05$). Ends and pieces yield was not tracked for this study. Based on the difficulty of tracking ends and pieces yield during the previous study, the decision was made with the input of plant personnel to focus solely on slice yield of #1 and #2 graded slices. This data indicates that using an ice water brine could potentially increase the yield of #1 slices. While the data suggests an increase yield for #1 slices, there was no significant effect on yield of #2 slices. While the data may suggest this, the method for slice yield data collection was not robust, so this data was not presented or used in any further analysis. Since a significant ($p<0.05$) difference was found in #1 slice yield, it would follow that an impact would be seen in #2 slice yield as well, because all slices are being fabricated from a fixed population. However, this was not the case. The apparent impact on #1 slices was not translated to #2 slices. As was the case for the reduced phosphate study mechanical issues, grading discrepancies, and the large volume of rework interfered with slice yield data collection. The fact that only #1 and #2 slice yield data was collected was in direct response to the difficulty collecting data from the reduced phosphate trial, instead of collecting #1, #2, ends and pieces, and inedible product, however collection of #1 and #2 slices still proved to be a difficult task.

Cook Yield

Cook yield data is presented in table 3.3.

Table 3.3. Cook yield (%) of bacons prepared with ice/water brine and room temperature brine

Treatment	Cook Yield
LTB	36.09a
RTB	33.22a

Means in a column followed by different letters are significantly different ($p<0.05$)

Color Analysis

Color analysis of primary and secondary lean is presented in table 3.4.

Table 3.4. Color analysis of primary and secondary lean of bacons prepared with ice/water brine and room temperature water brine

	Primary Lean			Secondary Lean		
Treatment	L*	a*	b*	L*	a*	b*
LTB	51.34a	21.31a	10.86a	67.14a	10.70a	9.31a
RTB	54.32b	19.85b	10.46a	69.55b	10.10a	9.72a

Means in a column followed by different letters are significantly different ($p<0.05$)

Table 3.3 shows cook yield evaluation trended towards significance between treatments ($p=0.074$). LTB bacon slices had an average yield of approximately 36%, whereas RTB bacon slices had an average yield of approximately 33%. The data indicate that on average, the LTB treatment trended towards having a higher overall cook yield than RTB.

The data in table 3.4 show a significant difference some of the color measurements. RTB product displayed a lighter color based on the significantly higher ($p<0.05$) L* values seen in primary lean muscle. While RTB was lighter overall, LTB bacon showed more red character in the primary lean based off the significantly higher ($p<0.05$) a* value. There was no significant ($p>0.05$) difference seen in the b* values of primary lean. The secondary lean of the RTB product was also significantly ($p<0.05$) lighter in color than LTB with a L* value of 69.55 compared to 67.14 for LTB. Neither the a* or b* values of the secondary lean were significantly different ($p>0.05$). While there are statistically significant differences in color, whether those differences are practically evident to the consumer remains to be seen. Assessing product appearance through consumer sensory analysis, or a more subjective method would give more useful data about color perceptions of the products.

Sensory Evaluation

Table 3.5. 30 Day post processing sensory evaluation of bacons prepared with ice/water brine and room temperature water brine

		RTB	LTB
Appearance Liking		7a	7a
Overall Liking		7.5a	7.3a
Overall Flavor Liking		7.5a	7.3a
Texture Liking		7.3a	6.8b
Saltiness JAR	Not Salty Enough	10.6%a	13.5%a
	JAR	64.4%a	69.2%a
	Too Salty	25%a	17.3%a
Slice Thickness JAR	Too Thin	25%a	32.7%a
	JAR	73.1%a	62.5%a
	Too Thick	1.9%a	4.8%a
Sweetness JAR	Not Sweet Enough	17.3%a	19.2%a
	JAR	77.9%a	79.8%a
	Too Sweet	4.8%a	1%a
Smoky JAR	Not Smoky Enough	25%a	28.8%a
	JAR	75%a	70.2%a
	Too Smoky	0%a	1%a
Crispiness JAR	Not Crispy Enough	30.8%a	40.4%a
	JAR	67.3%a	47.1%b
	Too Crispy	1.9%b	12.5%a
Fattiness JAR	Not Fatty Enough	1.9%a	3.8%a
	JAR	67.3%a	72.1%a
	Too Fatty	30.8%a	24%a
Bacon Expectations		4.3a	4.1a
Quality		3.7a	3.6a
Preference		40.4%b	59.6%a

Data represents 104 consumers
Means in a row followed by different letters are significantly different ($p<0.05$).
5 point scale statistical letterings were obtained from Kruskal-Wallis non-parametric test with Dunn post hoc analysis.

Table 3.6 Penalty analysis of 30 day post processing LTB bacon based on JAR and overall liking scores

Variable	Level	%	Overall Liking	Mean drops	Std. difference	p
Saltiness JAR	Not Salty Enough	10.5	7.4	0.172		
	JAR	64.4	7.6			
	Too Salty	**25.0**	**7.0**	**0.627**	**2.222**	**0.029**
Slice Thickness JAR	Too Thin	25.0	7.5	-0.026	-0.097	0.923
	JAR	73.0	7.5			
	Too Thick	1.9	6.0	1.474		
Sweetness JAR	Not Sweet Enough	17.3	6.8	0.827		
	JAR	77.8	7.6			
	Too Sweet	4.8	7.4	0.205		
Smoky JAR	Not Smoky Enough	25.0	7.2	0.346	1.280	0.203
	JAR	75.0	7.5			
	Too Smoky	0.0				
Crispiness JAR	**Not Crispy Enough**	**30.7**	**6.9**	**0.794**	**3.220**	**0.002**
	JAR	67.3	7.7			
	Too Crispy	1.9	7.5	0.200		
Fattiness JAR	Not Fatty Enough	1.9	8.0	-0.171		
	JAR	67.3	7.8			
	Too Fatty	**30.7**	**6.6**	**1.235**	**5.476**	**< 0.0001**

Data represents 104 consumers
Bolded rows indicate a significant penalty ($p<0.05$)

Table 3.7 Penalty analysis of 30 day post processing RTB bacon based on JAR and overall liking scores

Variable	Level	%	Overall Liking	Mean drops	Std. difference	p
Saltiness JAR	Not Salty Enough	13.4	6.357	1.060		
	JAR	69.2	7.417			
	Too Salty	17.3	7.278	0.139		
Slice Thickness JAR	**Too Thin**	**32.6**	**6.912**	**0.596**	**2.480**	**0.015**
	JAR	62.5	7.508			
	Too Thick	4.8	6.200	1.308		
Sweetness JAR	Not Sweet Enough	19.2	6.550	0.860		
	JAR	79.8	7.410			
	Too Sweet	0.9	8.000	-0.590		
Smoky JAR	Not Smoky Enough	28.8	6.933	0.450	1.769	0.080
	JAR	70.1	7.384			
	Too Smoky	0.9	7.000	0.384		
Crispiness JAR	**Not Crispy Enough**	**40.3**	**6.929**	**0.724**	**3.101**	**0.003**
	JAR	47.1	7.653			
	Too Crispy	12.5	6.769	0.884		
Fattiness JAR	Not Fatty Enough	3.8	6.500	0.887		
	JAR	72.1	7.387			
	Too Fatty	24.0	6.960	0.427	1.638	0.105

Data represents 104 consumers
Bolded rows indicate a significant penalty ($p<0.05$)

Table 3.8. 110 Day post processing sensory evaluation of bacons prepared with ice/water brine and room temperature water brine

		RTB	LTB
Appearance Liking		7.3a	7.2a
Overall Liking		7.5a	7.3a
Overall Flavor Liking		7.6a	7.3a
Texture Liking		7.1a	7.0a
	Not Salty Enough	6.7%a	11.4%a
Saltiness JAR	JAR	64.8%a	70.5%a
	Too Salty	28.6%a	18.1%a
	Too Thin	24.8%a	32.4%a
Slice Thickness JAR	JAR	74.3%a	66.7%a
	Too Thick	1.0%a	1.0%a
	Not Sweet Enough	18.1%a	22.9%a
	JAR	75.2%a	76.2%a
	Too Sweet	6.7%b	1.0%a
	Not Smoky Enough	23.8%a	22.9%a
Smoky JAR	JAR	70.5%a	73.3%a
	Too Smoky	5.7%a	3.8%a
	Not Crispy Enough	23.8%a	19.0%a
Crispiness JAR	JAR	63.8%a	62.9%a
	Too Crispy	12.4%a	18.1%a
	Not Fatty Enough	3.8%a	3.8%a
Fattiness JAR	JAR	73.3%a	73.3%a
	Too Fatty	22.9%a	22.9%a
Bacon Expectations		4.3a	4.2a
Quality		3.7a	3.6a
Preference		56.2%a	43.8%a

Data represents 105 consumers
Means in a row followed by different letters are significantly different ($p<0.05$).
5 point scale statistical letterings were obtained from Kruskal-Wallis non-parametric test with Dunn post hoc analysis.

Table 3.9 Penalty analysis of 110 day post processing LTB bacon based on JAR and overall liking scores

Variable	Level	%	Overall Liking	Mean drops	Std. difference	p
Salty Strength JAR	Not Salty Enough	6.7%	5.9	2.0		
	JAR	64.8%	7.8			
	Too Salty	**28.6%**	**7.2**	**0.6**	**3.0**	**0.0**
Thickness JAR	**Too Thin**	**24.8%**	**6.9**	**0.8**	**3.4**	**0.0**
	JAR	74.3%	7.7			
	Too Thick	1.0%	8.0	-0.3		
Sweetness JAR	Not Sweet Enough	18.1%	6.6	1.1		
	JAR	75.2%	7.7			
	Too Sweet	6.7%	7.7	0.0		
Smoky JAR	**Not Smoky Enough**	**23.8%**	**7.2**	**0.5**	**2.0**	**0.0**
	JAR	70.5%	7.7			
	Too Smoky	5.7%	7.0	0.7		
Crispiness JAR	**Not Crispy Enough**	**23.8%**	**7.2**	**0.6**	**2.4**	**0.0**
	JAR	63.8%	7.8			
	Too Crispy	12.4%	6.9	0.8		
Fattiness JAR	Not Fatty Enough	3.8%	6.5	1.3		
	JAR	73.3%	7.8			
	Too Fatty	**22.9%**	**6.8**	**0.9**	**3.9**	**0.0**

Data represents 105 consumers
Bolded rows indicate a significant penalty ($p<0.05$)

Table 3.10 Penalty analysis of 110 day post processing RTB bacon based on JAR and overall liking scores

Variable	Level	%	Overall Liking	Mean drops	Std. difference	p
Salty Strength JAR	Not Salty Enough	11.4%	6.7	1.0		
	JAR	70.5%	7.6			
	Too Salty	18.1%	6.3	1.4		
Thickness JAR	Too Thin	32.4%	7.1	0.4	1.3	0.2
	JAR	66.7%	7.4			
	Too Thick	1.0%	5.0	2.4		
Sweetness JAR	**Not Sweet Enough**	**22.9%**	**6.8**	**0.7**	**2.3**	**0.0**
	JAR	76.2%	7.5			
	Too Sweet	1.0%	3.0	4.5		
Smoky JAR	Not Smoky Enough	22.9%	7.3	0.1	0.3	0.8
	JAR	73.3%	7.4			
	Too Smoky	3.8%	4.3	3.2		
Crispiness JAR	Not Crispy Enough	19.0%	7.0	0.8		
	JAR	62.9%	7.7			
	Too Crispy	18.1%	6.1	1.6		
Fattiness JAR	Not Fatty Enough	3.8%	5.5	2.0		
	JAR	73.3%	7.5			
	Too Fatty	**22.9%**	**6.8**	**0.7**	**2.3**	**0.0**

Data represents 105 consumers
Bolded rows indicate a significant penalty ($p<0.05$)

Table 3.5 shows the 30 day post processing sensory evaluation in which there was no difference in appearance liking, overall liking, or overall flavor liking ($p>0.05$), but there was a significant difference in texture liking ($p<0.05$). For the texture liking, RTB bacon was rated 7.3 whereas LTB bacon was rated 6.8. While there was no significant difference between overall appearance, or flavor liking, the preference for specific treatments was significantly different ($p<0.05$). 59.6% of consumers preferred LTB bacon while only 40.4%

of consumers preferred RTB bacon ($p<0.05$). This indicates that although consumers could not detect any flavor differences between treatments, the consumer's overall preference leaned towards LTB bacon. Penalty analysis for RTB bacon showed the following penalties and associated mean drops: too salty (0.63), not crispy enough (0.79), and too fatty (1.24). Penalty analysis for LTB bacon showed the following penalties and associated mean drops: too thin (0.60), and not crispy enough (0.72). Full penalty analysis is seen in tables 3.6 and 3.7.

Table 3.8 shows the 110 day post processing sensory evaluation in which there were no significant differences between any of the attributes in question. The overall liking scores and quality perception scores were identical to those scores from the 30 day post processing analysis. This data suggests that there is no organoleptic degradation over the typical shelf life of the product. While there were no differences in hedonic or intensity attributes both the RTB and LTB product incurred some penalties on the JAR scale. Penalty analysis for RTB bacon showed the following penalties and associated mean drops: too salty (0.6), too thin (0.8), not smoky enough (0.5), not crispy enough (0.6), and too fatty (0.9). Penalty analysis for LTB bacon showed the following penalties and associated mean drops: not sweet enough (0.7), and too fatty (0.7). Full penalty analysis is seen in table 3.9 and 3.10.

3.5 Conclusions

Brine temperature seemed to have an effect on processing yields. There was a significant difference in smoke yield, with LTB having a smoke yield approximately 1.45% greater than RTB. However, this trend was reversed when examining cooler yield. Cooler yield trended towards significance ($p=0.0623$) with RTB having an approximately 0.8%

greater yield than LTB. However, even with a significant difference in smokehouse yield, the overall yield was not significantly different ($p>0.05$). These results show mixed support with current research. Peterson et al. (2016), showed that different brine temperatures had no effect on processing yields. Keenan et al. (2016) and Boyles and Swan (1997) also showed that variation in brine temperature did not have significant effects on the processing yields of cured products. This data suggests that reduction in brine temperature could improve smoke yield, but would not impact overall yield of the bacon production process.

Brine temperature did not have any significant effects on slicing yield. While the yield of #1 slices was numerically higher in LTB (78.2%) as compared to RTB (72.5%), the two were not statistically different. There was no effect of brine temperature reduction on the slicing yield of #2 graded slices. LTB (12.1%) and RTB (13.1%) were separated by 1 percentage point. Conclusions about the true impacts of brine temperature reduction are difficult to draw because data collection was very difficult. Attempting to keep pace with the speed of production while still collecting accurate data proved to be challenging. Data collection methods were highly influenced by processing parameters, machinery and employees. Additional slicing yield tests with stricter controls are needed to determine the true impact of brine temperature reduction on slicing yield.

Color analysis revealed some differences between LTB and RTB bacon. Color analysis showed significant differences between primary lean measurements of L* and a*, whereas analysis of secondary lean showed significant differences in only L* values. For both primary and secondary lean, RTB bacon slices had a significantly higher L* value indicating that these slices were lighter in color than LTB bacon. While there was a significant difference measured qualitatively, consumers did not prefer one product over another when color and appearance was assessed through sensory evaluation. While the objective color measurements are beneficial to have, whether the slight differences in measured parameters impact consumer interaction with the product would be a more telling measure of product color.

Cook yield evaluation of the treatments showed LTB having a roughly 3% higher numerical average cook yield. While LTB was higher numerically, the two products were not significantly different ($p>0.05$). Since the difference was not significant, it is very unlikely that the typical consumer will be able to notice a 3% difference in cooking yield. However, since consumers have specific preferences for bacon consumption, they will most likely cook bacon to their desired level of doneness regardless of yield. Even so, the data indicate that LTB bacon did not lose as much water and fat throughout the cooking process.

Sensory analysis showed no significant differences between LTB and RTB bacon when rated on appearance, overall liking, and overall flavor liking. However, consumers showed significant differences on the texture and overall preference of the bacon treatments. RTB bacon was given a higher texture rating (7.3) but was less preferred overall by consumers (40.4%). In addition to overall liking and preference questions, RTB bacon was perceived by some consumers as too salty, too fatty and not crispy enough as assessed through penalty analysis. LTB bacon was perceived by some consumers as too thin and not crispy enough. There should be no difference in the salt content of the two treatments, as both bacon samples were prepared with the same brine formulation (other than water/ice temperature). The fat content of the bacon does vary, so the 'too fatty' penalty for RTB bacon could be due to consumers receiving bacon slices with a higher fat content. However, on the whole, the fat content of the bacon should vary consistently between treatments. The ‘not crispy enough’ penalty could be due to either personal preference of bacon crispness or cooking method. Both samples were cooked according to the same protocol used for cook yield evaluation. Since both treatments were rated as not crispy enough, the cooking method might need to be revised, or this panel was composed of consumers who preferred more crispy bacon slices. For the ‘too thin’ penalty, there should be no realistic difference between treatments because all bacon was processed on slicing lines set to identical specifications.

Overall, sensory analysis showed no difference in overall acceptability, indicating that brine temperature did not have an effect on consumer acceptance of bacon. The preference question for the sensory evaluation was a forced preference question as the concluding question of the survey. This preference question could have been subject to recall bias, or been biased by the order in which samples were presented. Since there was no significant difference between overall acceptability and overall flavor, it is counterintuitive that there would be a significant difference in preference. Both the discrepancy in preference between samples and the penalty analysis could be due to normal variation with using human subjects for a subjective sensory evaluation.

Overall, brine temperature did have effects on processing and performance characteristics of bacon. Bacon produced with an ice water brine had an approximately 1.45% greater smoke yield and 0.6% greater overall yield than bacon produced with room temperature brine. LTB bacon also showed an approximately 3% greater cook yield as compared to RTB bacon. Sensory evaluation of RTB and LTB bacon showed no differences in overall liking, flavor and acceptability, and the samples only varied on consumer driven preferences such as crispiness and saltiness. There were also some significant color differences as RTB bacon was lighter in color, as measured by L* values, and possessed less red color in the primary lean as measured by a* values.

While these observed differences could be accredited solely to brine temperature, production, processing, and storage conditions could have made an impact. Based solely on the processing yields and sensory evaluation data, it seems feasible that using ice brine could provide economic benefit, while still maintaining acceptable consumer quality. However, to accurately confirm these preliminary observations, more production trials with tighter temperature control need to be performed. This trial was run with ice brine at approximately -6.6°C, which is likely outside the range of typical processing conditions. Therefore, more trials that would more accurately simulate typical processing need to be conducted. However, the preliminary data show that reducing brine temperature can favorably impact processing yields while maintain consumer acceptability.

3.6 References

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CHAPTER 4

THE EFFECTS OF POST INJECTION DWELL AND SMOKE TIME ON COMMERCIALLY PROCESSED PORK BACON

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ABSTRACT

A study was conducted to assess the effects post injection dwell and smoke time on the processing yields and consumer sensory perception of commercially produced bacon. The experimental design for this study was arranged in a 2X2 factorial design with two levels each of post injection dwell time and smoke time. The levels of post injection dwell time were 0 and 2 hours and the levels of smoke time were 4 and 6 hours. This experimental design produced 4 treatments: 0 hour post injection dwell, 4 hour smoke (0D4S); 0 hour post injection dwell 6 hour smoke (0D6S); 2 hour post injection dwell, 4 hour smoke (2D4S); and 2 hour post injection dwell 6 hour smoke (2D6S). All bacon was produced in a high volume commercial facility. Each treatment had N=20 trees (approximately 1,200 individual pork bellies). Data was collected on processing yields, and samples were taken to perform consumer sensory analysis and descriptive analysis (DA). 0D4S had the highest smoke yield ($p<0.05$), whereas 2D4S had the highest ($p<0.05$) cooler yield. 2D4S had a significantly higher smoke yield than 2D6S ($p<0.05$), but was not significantly different from 0D6S. Consumers rated 2D4S significantly higher ($p<0.05$) than 2D6S in the attribute of overall flavor, but 2D4S was not significantly different ($p>0.05$) either of the other treatments. This trend was seen throughout the hedonic responses of the sensory evaluation. Competitor products O and M consistently fell between 2D4S and 2D6S in hedonic responses. There was no difference among treatments ($p<0.05$) for consumer response of purchase intent. Overall these data suggest that increasing smoke time can have detrimental effects on commercial smoke yield of bacon. The data also suggest that consumers consistently rated the 2D4S higher on the hedonic scale than 2D6S.

4.2 Introduction

Bacon is a complex flavor system in which many physical and chemical components contribute to the overall flavor, aroma, and consumer sensory experience with the product. Cured meat flavor, smoky, sweet, salt, and fat are all examples of potential flavor and aroma attributes that can contribute to the overall flavor of bacon (Gatlin, et al, 2006, Jeremiah, et al, 1996). Yu et al (2006) identified 48 individual chemical compounds that contributed to the overall flavor profile of bacon. Many of these compounds were generated through hard wood smoking of the product. Smoke flavor has been identified in this work previously as a driver of overall consumer liking of reduced phosphate and reduced brine temperature bacon. Consumer sensory analysis revealed, through penalty analysis of just about right (JAR) and overall liking scores, that the JAR rating of 'not smoky enough' resulted in a significant penalty in 3 out of 6 consumer evaluations. Responses of 'too smoky' did not results in any significant penalties. It was hypothesized in this experiment that increasing the amount of time commercially processed bacon is exposed to smoking, a more desirable consumer product could be produced while still maintaining commercial processing yields.

In many commercial bacon manufacturing facilities, after curing, bellies are allowed to experience a post injection dwell time in which they are held under refrigeration prior to treatment in a smokehouse. There is thought in the bacon processing industry that including a post injection dwell time in processing aids in flavor development and produces a higher quality product (Young, 2008). However, in the commercial facility in which this research was conducted, there was no post injection dwell time step employed in processing (Appendix 6.1). There has been previous research done on a commercial scale to suggest that increasing product post injection dwell time could improve slice yield of #1 graded slices

(Scramlin, 2009). However, this study did not singly isolate increased post injection dwell time as a variable; it was combined with increased smoking time. Therefore, the objective of this study was to examine the effects of post injection dwell time, in combination with smoke time on processing characteristics and consumer evaluations of the products.

4.3 Materials and Methods

4.3.1 Experimental design

For this experiment a more complex, 2x2 factorial was designed. The factors of post injection dwell time and smoke time each had 2 levels to which experimental units were randomly assigned to form 4 unique treatments. With the 2 factors and 2 levels, the experimental design was as follows:

Table 4.1. Experimental design for testing varying levels of post injection dwell time and smoke time

Treatment	Post injection dwell Time (hours)	Smoke Time (hours)
0D4S*	0	4
0D6S	0	6
2D4S	2	4
2D6S	2	6

*Standard plant procedures

4.3.2 Bacon Production

All bacon production was performed at a large, high volume commercial bacon production facility between September 30-October 1, 2015. Fresh, raw pork bellies, received from a large commercial pork processing and fabrication plant and ranging between 6.8-7.7

kilograms, were pumped with enough brine to fill 80 trees that were loaded into 4 large convection smokehouses. The brine formulation for all 80 trees was identical and contained: water (79.44%), sucrose (4.54%), salt (14.80%), sodium phosphate (0.50%), sodium nitrite (120ppm) and sodium erythorbate (547ppm). Bellies were targeted to inject 112% over green weight and allowed to drain down to 110% over green weight to ensure proper delivery of curing ingredients. Bellies were injected using a conveyor fed, multi-needle brine injection system. After injecting half (N=40) of the trees were randomly assigned to an extended post injection dwell treatment and the other half (N=40) were loaded into 2 separate convection smokehouses. From there, one smokehouse was randomly assigned to the standard smoke treatment of 4 hours, whereas the other smokehouse was given an extended smoke treatment of 6 hours. The same procedure was followed for the trees assigned to an extended post injection dwell treatment after the 2 hour post injection dwell time had elapsed. Half of the extended post injection dwell trees received a standard smoke treatment while the other half received an extended smoke treatment. This experimental design produced N=20 trees worth of product for each of the four treatments. After thermally processing to an internal temperature of 49.4°C, and smoking with smoldering hickory wood chips for the designated smoking time, trees continued through standard processing and were sliced. Product was sliced on four separate high speed slicing lines equipped with rotary blade slicers. Each treatment was sliced on a designated slicing line. Samples from each treatment were randomly collected throughout the slicing operation. 6 boxes of #1 slices, each containing 24, 0.45kg, packages, from each treatment were sampled for analytical and sensory analysis. Sampled boxes were transported under refrigeration back to the NC State University Meat Laboratory and stored at 4°C.

4.3.3 Processing Yield Analysis

Data to analyze the smokehouse yield and cooler yield were collected through plant monitoring software. Weights of each tree for each treatment were recorded and placed on the plant data logging server to be accessed. Weights were recorded after trees exited the smokehouse, after trees exited the tempering cooler, and directly prior to trees being sliced.

Slice yield data was collected by positioning data collectors at the front and back ends of the slicing line. The data collector at the front of the line would capture the net weight of the tree before slicing, and the collector at the back end of the slicing line would track and record the amount of #1 packages produced from that tree. Slice yield was calculated based on the number of packages of #1 slices, #2 slices and ends and pieces produced for each tree. Formulas to calculate smokehouse, cooler, and slice yield are as follows:

Smokehouse yield was calculated as:

$$\text{Net tree weight upon exit of smokehouse} \big/ \text{Net tree weight after brine injection} * 100$$

Cooler yield was calculated as:

$$\text{Net tree weight upon entry to cooler} \big/ \text{Net tree weight upon exit of cooler} * 100$$

Slice yield was calculated as:

$$\text{Weight of parameter (\#1, \#2, or end and pieces)} \big/ \text{Net weight of tree to slicing line} * 100$$

4.3.4 Color Analysis

Color evaluation was performed by first randomly selecting 4, 0.45kg vacuum packaged bacon packages from each box sampled during slicing. From each package, 2 bacon slices from four different locations in the package (top, top-middle, bottom-middle, and bottom) were selected. This made a total of 32 slices per sample box. The color space (L^*, a^*, b^*) was evaluated on both the primary (*Obliquus externus abdominus)* and secondary lean (*Cutaneous trunci*) muscles of each slice using a Konica Minolta CR-410 (Tokyo, Japan) colorimeter using D65 illuminant source and calibrated via manufacturers recommendations to a white tile.

4.3.5 Cook Yield Evaluation

Cook yield evaluation was performed by randomly selecting 2, 0.45kg vacuum packaged bacon packages from each box sampled during slicing. 8 bacon slices from each package were selected for cook loss evaluation. A total of 16 slices per sampled box were used for cook yield evaluation. The slices were placed on wire racks and cooked in a Southbend TV convection oven (Fuquay-Varina, NC) oven at 204°C for 12 minutes based on the procedure outlined by Leick et al (2010). Racks were turned halfway through the cooking procedure to ensure even cooking. Bacon slices were blotted with a paper towel to remove surface fat after the 12-minute cooking period. Pre and post cooking bacon slice weights were measured with a Taylor (Denver, CO) TE10R type gram scale. Final cook yield was calculated as:

$$\text{Post cooking slice weight}\,\big/_{\text{Pre cooking slice weight}} * 100$$

4.3.6 Sensory Evaluation: Consumer Evaluation

For this experiment, 2 separate sensory evaluations were conducted. A consumer evaluation was conducted under different protocols than used for the reduced phosphate and reduced brine temperature experiments. In addition to the consumer evaluation, a descriptive analysis by trained panel was also conducted. For the consumer evaluation 150 consumers were recruited through an online screening procedure accessed through the NC State Sensory Service Center. This consumer evaluation was not conducted under the 'all call' protocol, and recruited consumers were compensated with a $20 Target (Minneapolis, MN) gift card. The consumer evaluation occurred over 2 days, and in conjunction with the 4 treatment bacon products, 2 competitor products (O and H) were included in the consumer evaluation. Consumers were first asked to evaluate the appearance and give purchase intent of each (raw) product by being presented with an unlabeled/unbranded image of a retail vacuum package of the product in question. After assessing appearance and purchase intent, consumers were given cooked samples and asked to rate the product on 9 point hedonic attributes, JAR scales, as well as a post consumption purchase intent. Overall the 3 scales were used to evaluate a variety of product attributes. A 5 point intensity scale was used to evaluate the attributes of: pre-consumption purchase intent (based on appearance of raw product in unlabeled vacuum package), expectations, perceived quality and post consumption purchase intent. A 9 point hedonic scale was used to evaluate the attributes of: appearance liking of the raw product in an unlabeled vacuum package, overall liking, flavor liking, texture liking, crispiness liking, and fattiness liking. A JAR scale was used to evaluate the attributes of: sweet taste, saltiness, hickory smoked flavor, and smoky taste.

All 6 bacon products were coded with a unique, random 3 digit code. All bacon was cooked in Southbend (Fuquay-Varina, NC) G series convection ovens at 204^{o}C for 12 minutes. Bacon was then held in a Vulcan (Baltimore, MD) VBP-15 warming cabinet at 60^{o}C for up to 30 minutes. If the bacon was not consumed within 30 minutes, it was discarded for quality purposes. This sensory evaluation occurred over the course of 2 days, with each consumer evaluating half of the products each day. Delivery of products to each consumer was randomized over the 2 day period. The test occurred over 2 days to limit consumer fatigue and increase the reliability of the results. All data was collected electronically by the NC State University Sensory Service Center through the use of Compusense (Guelph, Ontario, Canada) software.

4.3.7 Sensory Evaluation: Descriptive Analysis

In addition to the consumer sensory analysis, descriptive analysis (DA) by a trained sensory panel was performed on all 4 treatment bacon products as well as 2 competitor products (O and H). The DA panel quantatively assessed the presence and/or intensity of aroma, flavor, and texture attributes of all bacon products. The DA panel was comprised of 6 panelists trained in the Spectrum™ method of DA. A 0-15 point universal intensity scale was used to assess intensity of aromatics and basis tastes where 0=no intensity and 15=maximum intensity. Texture attributes were evaluated on a 0-15 point, product specific intensity scale. Edge color of the product was scored based on a 1-4 scale where 1=no difference in edge color and 4=very dark edge color. Lexicons for flavor and texture attributes were developed during preliminary training or adapted from previous work (Gatlin, et al 2006). Each panelist evaluated each bacon treatment in triplicate. References for basic tastes with known intensities were used as calibration techniques; water and unsalted, Nabisco, saltine crackers (East Hanover, NJ) were used for palate cleansing between sample evaluation.

The panelists on the DA panel were highly qualified and trained, with hundreds of hours of experience on a wide range of products. Bacon samples for DA were received and stored under refrigeration at 3.3°C until panelists were ready to evaluate samples. Bacon samples were cooked in a Southbend (Fuquay-Varina, NC) G series convection ovens at 204°C for 12 minutes and were lightly blotted with paper towels after cooking procedure. After cooking, bacon slices were presented to panelists coded with random 3-digit identifying codes. Samples were presented to panelists one at a time to ensure temperature integrity of the product. Panelists evaluated appearance, texture, and flavor on each sample in the same presentation window. Bacon samples were evaluated over three separate sessions. Complete appearance, flavor, and texture lexicons used by the DA panel are given in appendix 6.6.

4.4 Results and Discussion

Statistical Analysis

All p values were obtained by running a proc mixed analysis in SAS 9.4 (Cary, NC). Values that were found to be $p<0.05$ were considered to be statistically significant.

Smoke and Cooler yields

Smoke and cooler yields were tracked throughout processing via in plant software. The data are presented below in table 4.2.

Table 4.2. Smoke and cooler yield (%) of bacon processed with varying post injection dwell and smoke times

	0 Hour Post injection dwell		2 Hour Post injection dwell		P Values		
	4 Hour Smoke	6 Hour Smoke	4 Hour Smoke	6 Hour Smoke	Post injection dwell	Smoke	Post injection dwell*Smoke
Smoke Yield	96.19[a]	94.62[b,c]	95.17[b]	94.19[c]	0.0006	<0.0001	0.1517
Cooler Yield	96.45[a]	96.88[a,b]	97.55[b]	96.84[a,b]	0.0457	0.5875	0.0333

Means in a row followed by different letters are significantly different ($p<0.05$)
P values represent main effects and interaction effect

Slice Yield

The raw data that was collected for #1 slice yield is presented in table 4.3.

Table 4.3. Raw #1 slice yield (%) data of bacon processed with varying post injection dwell and smoke times

Treatment	Line	Yield
0D4S	6	76.7
0D6S	7	66.5
2D4S	8	68.4
2D6S	9	67.8

The results in table 4.2 indicate that the 0D4S treatment had the significantly highest smoke yield. 0D6S and 2D6S had the lowest smoke yields, but were not significantly different. This is expected due to the longer heat treatment. From the p values given, there was no interaction effect on smoke yield, but both post injection dwell and smoke time affected smoke yield. Smoke had the smallest p value, which makes sense that it would be mostly responsible for changes seen in smoke yield. The only significant differences in cooler yield were seen between treatments 2D4S and 0D4S, with 2D4S being significantly higher. Both post injection dwell time and the interaction between post injection dwell and smoke had an effect on cooler yield. Smoke time did not have a significant effect on cooler yield.

Raw #1 slice yield data is given in table 4.3. This data was not statistically analyzed because data collection methods were altered midway through slicing and were not consistent across slicing line. The data was initially set to be collected through plant inventory software, but it was apparent this data was not accurate. Data was then collected manually on line, but the collection protocol was not consistent between the 4 slicing lines. Therefore, while the raw data is presented, no statistical analysis was conducted.

Cook Yield

The estimates for cook yield for each treatment, as well as main and interaction effect p values are given in table 4.4.

Table 4.4. Cook yield (%) of bacon processed with varying post injection dwell and smoke times

	0 Hour Post injection dwell		2 Hour Post injection dwell		P Values		
	4 Hour Smoke	6 Hour Smoke	4 Hour Smoke	6 Hour Smoke	Post injection dwell	Smoke	Post injection dwell*Smoke
Cook Yield	30.42a	30.30a	27.10b	31.97a	0.1774	0.0001	<0.0001

Means in a row followed by different letters are significantly different (p<0.05)
P values represent main effects and interaction effect

Color Analysis

Estimates for L*, a*, and b* values of primary and secondary lean, as well as main and interaction effect p values are given in table 4.5.

Table 4.5. Color analysis of primary and secondary lean of bacon processed with varying post injection dwell and smoke times

	0 Hour Post injection dwell		2 Hour Post injection dwell		P Values		
	4 Hour Smoke	6 Hour Smoke	4 Hour Smoke	6 Hour Smoke	Post injection dwell	Smoke	Post injection dwell*Smoke
L*_1	51.34a	49.72c	50.53b,c	51.15a,b	0.2423	0.0287	<0.0001
a*_1	23.46b	24.17a,b	24.51a	21.58c	0.0005	<0.0001	<0.0001
b*_1	14.32a	12.99b	14.36a	11.88c	0.0002	<0.0001	<0.0001
L*_2	65.87a	66.51a	62.49b	65.46a	<0.0001	<0.0001	0.0008
a*_2	11.96c	12.54b	13.08a	12.27b,c	0.0024	0.4148	<0.0001
b*_2	10.96b	10.40c	11.35a	9.22d	0.0001	<0.0001	<0.0001

Means in a row followed by different letters are significantly different ($p<0.05$)
P values represent main effects and interaction effect

Table 4.4 shows that treatment 2D4S had a significantly lower slice cook yield than the other three treatments. The significance between the treatments is due to the smoke and post injection dwell*smoke interaction variables. Treatments 0D4S, 0D6S and 2D6S were not significantly different from each other. The reason behind the lower cook yield of 2D4S is not fully understood but could be due to cooking equipment variation, even though steps were taken to mitigate this influence.

Table 4.5 shows there were significant differences between many of the color measurements, with significant p values for post injection dwell, smoke, and interaction variables. While the data did show significant differences between treatments, whether these differences are practical to the consumer is difficult to determine. The effect of color on consumer perception of bacon was more effectively assessed through sensory evaluation. However, it is evident that post injection dwell time, smoke time, and their interaction did affect the color of the product.

Sensory Evaluation: Consumer Evaluation

Table 4.6. Nine point hedonic scale scores of sensory attributes of bacon processed with varying post injection dwell and smoke times as well as 2 competitors bacon

	0 Hour Post injection dwell		2 Hour Post injection dwell		Competitor	
	4Smoke	6Smoke	4Smoke	6Smoke	O	H
Appearance	7.2ab	7.0ab	7.3a	6.9b	7.2ab	7.3a
Aroma	7.2a	7.2a	7.2a	7.3a	7.2a	7.1a
Overall	6.9ab	7.0ab	7.2a	6.8b	7.2ab	7.2a
Flavor	6.9bc	7.0abc	7.3a	6.8c	7.2ab	7.2ab
Texture	7.0ab	7.2ab	7.4a	6.8b	7.0ab	7.1ab
Crispness	7.0ab	7.0ab	7.3a	6.8b	6.8b	7.1ab
Fattiness	6.5ab	6.3b	6.7a	6.4ab	6.6ab	6.7ab

Data represents 150 consumers
Means in a row followed by different letters are significantly different ($p<0.05$)

Table 4.7. Five point intensity scale scores of sensory attributes of bacon processed with varying post injection dwell and smoke times as well as 2 competitors bacon

	0 Hour Post injection dwell		2 Hour Post injection dwell		Competitor	
	4Smoke	6Smoke	4Smoke	6Smoke	O	H
Pre PI	4.1a	4.2a	4.2a	4.1a	4.1a	4.3a
Meets Expectations	3.6a	3.6a	3.9a	3.6a	3.8a	3.6a
Quality	3.5bc	3.4b	3.7a	3.4bc	3.7bc	3.6bc
Post PI	3.6a	3.6a	3.8a	3.5a	3.8a	3.6a

Data represents 150 consumers
Means in a row followed by different letters are significantly different ($p<0.05$)

Table 4.8. Pre-consumption purchase intent of bacon processed with varying post injection dwell and smoke times as well as 2 competitors' bacon

	0D4S	0D6S	2D4S	2D6S	OM	H
n	124	134	131	123	124	135
%	83	89	87	82	83	90

N represents 150 consumers

Table 4.9. Post-consumption purchase intent of bacon processed with varying post injection dwell and smoke times as well as 2 competitors' bacon

	0D4S	0D6S	2D4S	2D6S	OM	H
n	87	88	99	78	98	87
%	58	59	66	52	65	58

N represents 150 consumers

Sensory Evaluation: Descriptive Analysis

Table 4.10. Key descriptive analysis findings of bacon processed with varying post injection dwell and smoke times as well as 2 competitors' bacon

Attribute	0D4S	0D6S	2D4S	2D6S	OM	H
Smoke	2.0c	1.8d	2.4b	2.9a	1.9cd	1.7d
Salt	5.3c	5.3c	7.0b	5.3c	5.4c	7.8a

Means in a row followed by different letters are significantly different ($p<0.05$)

Table 4.6 shows that treatment 2D4S and H product had the highest overall liking scores and were significantly different than treatment 2D6S. However, all overall liking scores ranged from 6.9-7.2. In all attributes assessed on the 9 point hedonic scale (overall, flavor, texture, crispiness, and fattiness liking) treatment 2D4S had the highest score, and in all attributes except fattiness liking treatment 2D6S had the lowest score. Treatments 0D4S and 0D6S were not significantly different in any attributes.

Table 4.7 shows there was no significant difference in pre-consumption purchase intent based off unlabeled pictures of retail packages of each product. Purchase intent scores ranged from 4.1-4.3. Treatment 2D4S and the H product had the highest appearance liking scores and were significantly higher than appearance liking score of treatment 2D6S. However, all appearance liking scores ranged from 6.9-7.3. There was no significant difference in the products meeting consumer expectations for bacon. All scores for products ranged from 3.6-3.9, with treatment 2D4S having the highest score. Treatment 2D4S had the highest score for perceived quality of product, and was significantly different than all other products. Scores for this question ranged from 3.4-3.7. There was no difference in post consumption purchase intent, however treatment 2D4S had the highest score. Scores for this question ranged from 3.5-3.8.

Tables 4.8 and 4.9 show the top 2 box analysis for pre-consumption and post-consumption purchase intent, respectively. This analysis shows what percentage of consumers scored these questions as 4 or 5 (top 2 box). Detailing this percentage shows how many consumers would definitely purchase the product in the future. Scoring a 4 or 5 means that the consumer probably would by the product in question. Table 8 purchase intent is generated from viewing unlabeled retail packages, and table 9 purchase intent is generated after consumption of all samples. While all samples were relatively close in table 8, table 9 shows that treatment 2D4S and O had the highest percentage of 4/5 scores while treatment 2D6S had the lowest.

In addition to the consumer sensory analysis, a descriptive analysis (DA) was performed by a highly trained panel to quantitatively assess the intensity of specific attributes in the 4 experimental products as well as 2 competitor products. The panel evaluated the 6 products on attributes ranging from flavor, to basic tastes, to texture and mouthfeel properties. The key differences of the DA panel were concerned with smoke flavor and salty basic taste.

Table 4.10 shows that 2D6S had the most intense smoke flavor, and was significantly higher than all other products. The 0D6S product had the least intense smoke flavor and was significantly different than all products except H. For the salt basic taste, H had the highest intensity salt flavor followed by 2D4S. These two products were bother significantly different from each other as well as all other products. The remaining four products had a significantly lower salt perception and were not significantly different from each other. The difference in smoke flavor intensity in the 2D6S product could be due to evaporative drying of the surface of the product during the post injection dwell time that would allow for greater smoke adherence to the product during the extended smoke cycle. This trend was also seen when comparing the 0D4S and 2D4S treatments. The high salt intensity for the 2D4S product was surprising considering all treatment products were produced with the same salt level in the brine. Also, the other extended post injection dwell treatment, 2D6S, did not display such high salt intensity. Full DA results are given in appendix 6.7.

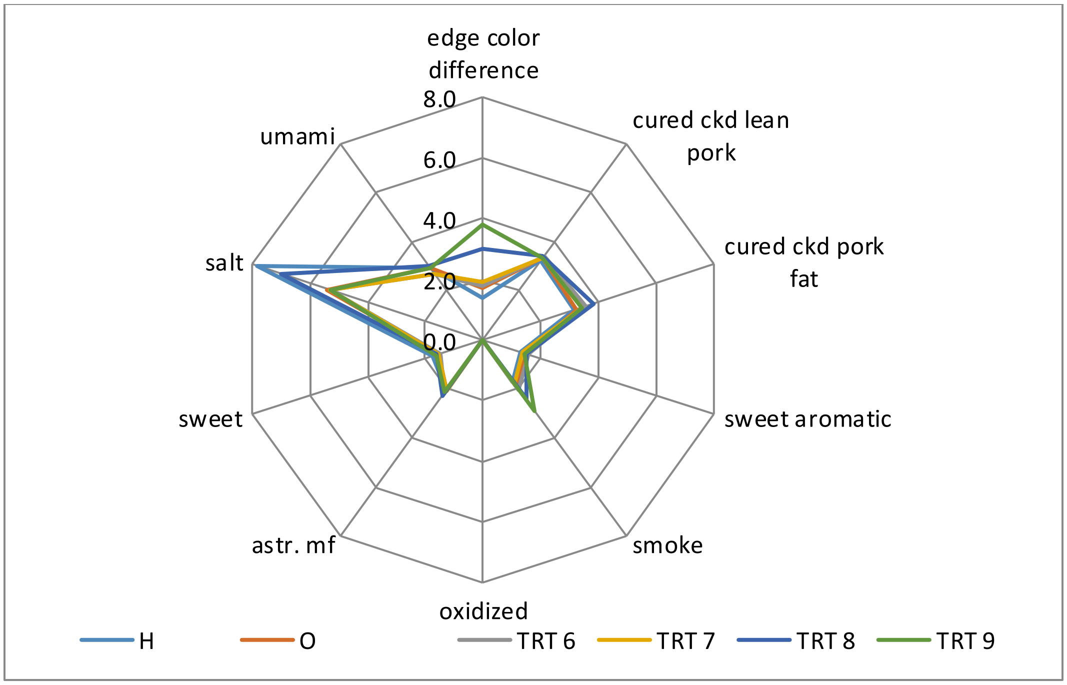

Figure 4.1. Key flavor attribute spider plot of bacon processed with varying post injection dwell and smoke times as well as 2 competitors' bacon

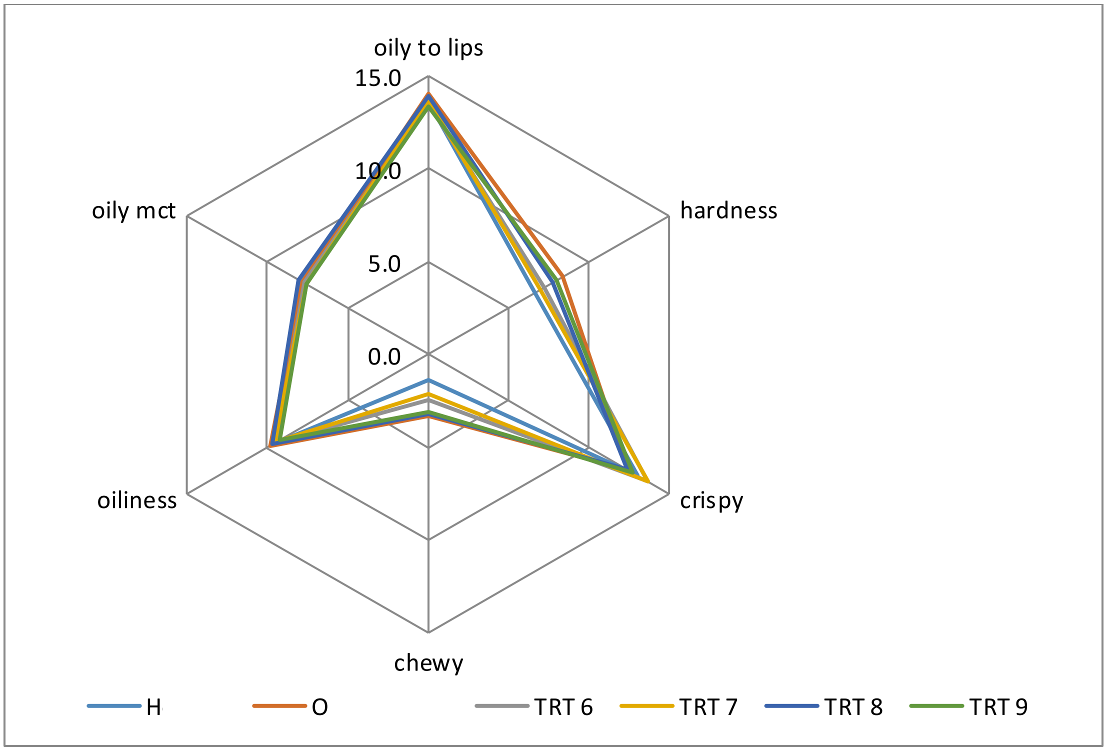

Figure 4.2. Key texture attribute spider plot of bacon processed with varying post injection dwell and smoke times as well as 2 competitors' bacon

For figures 1 and 2: TRT 6 is treatment 0D4S, TRT 7 is treatment 0D6S, TRT 8 is treatment 2D4S, and TRT 9 is treatment 2D6S

4.5 Conclusions

The different combinations of post injection dwell and smoke time did have an impact on the smoke yield of the 4 treatments. Treatment 0D4S had the highest smoke yield and treatment 2D6S had the lowest yield, and they were significantly different ($p<0.05$). As a trend, the treatments with a longer smoke time (2D4S, 2D6S) had lower average smoke yield compared to treatments with shorter smoke times. There were also significant differences in cooler yield between treatments. Treatment 2D4S had the highest cooler yield and was significantly higher than treatment 0D4S. Treatment 2D4S was not significantly different from any other treatments.

The treatment effect on slice yield was difficult to determine due to difficulty in data collection. However, based on solely the raw data treatment 1 had a higher average yield, roughly 10% greater than the other 3 treatments. However, this is simply the raw data which is based off a different sample size for each treatment. Scramlin (2009) did show that increased post injection dwell time could improve yield of #1 graded slices, but unfortunately the data was not collected to support this finding. However, with stricter data collection methods, the impacts of post injection dwell and smoke time on slicing yields could be of interest for future research. Color measurements showed differences between treatments depending on which value of L*, a*, or b* was compared across primary or secondary lean. While there were statistical differences detected, true consumer perception of product appearance was assessed through sensory evaluation.

Cook yield of the treatments also showed difference with treatment 2D4S having the lowest yield and treatment 2D6S having the highest yield. Again, while there were statistical differences, whether the differences are practical to the consumer remains to be seen.

From a consumer sensory perspective, treatment 2D4S consistently had the highest scores both in hedonic attributes and 5 point intensity attributes. Treatment 2D6S was consistently on the low end of consumer acceptance scores, and the other 4 products fell in the middle depending on the attribute in question. A top 2 box analysis of post-consumption purchase intent showed that treatment 2D4S had the highest percentage of consumers responding that they would probably purchase the product. Descriptive analysis of the four experimental products as well as two competitors showed that 2D6S had the most intense smoke flavor and was significantly higher than all other products. DA also showed that 0D6S and H products had significantly higher salty taste than the other four products.

While there were significant differences in consumer responses to products, hedonic scores for all attributes were greater than 6.3 and all 5 point intensity scores for attributes were greater than 3.4. This can be taken to mean that all products were liked by consumers, treatment 3 was just liked to a greater extent. Overall, post injection dwell and smoke time did have effects on both processing yields as well as consumer perceptions of the products. However, to more effectively determine the true effects due to each variable as well as their interaction, additional research is necessary.

The DA results generated from the 6 bacon samples differ somewhat from those results presented by Gatlin et al. (2006). The values for smoke generated by this DA panel were numerically lower than those presented by Gatlin et al. (2006). The for smoke in the 2006 panel had an average of 5.7 while the highest value of smoke in this study was 2.9. However, this is probably due to the fact that the bacon in the 2006 study was smoked for 24 hours, while the longest smoke treatment experienced by the treatment bacons was 6 hours. The smoke treatment for the competitor products is unknown. However, this trend indicates that bacon can show an increase in smoke flavor with an increase in smoking time, up to 24 hours. However, this might not be practical from many high volume processors standpoints, and the product that received the longest smoke treatment in this study (2D6S), was consistently rated lower than the other products by consumers in hedonic attributes and purchase intent. Overall, there is still research needed into what factors drive consumer liking of bacon and how processing factors and DA attributes relate to attribute liking.

4.6 References

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CHAPTER 5

FINAL SUMMARY

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5.1 Overall Conclusions

Through the course of this project, processing effects were seen due to adjustment of processing parameters. Reduction in phosphate did not result in decreased yields or an undesirable product. Reduction of brine temperature showed some promise in increasing smoke and overall yields while maintaining product quality. The interaction of post injection dwell and smoke time produced products that were as highly rated in consumer acceptability as two competitor products. While the data presented in this thesis was collected in the best available manner, research conducted in a commercial plant is very different from that conducted on the lab or even pilot scale. Balancing the needs of production with the need to collect data was a chief challenge of this project. In addition, the experiments conducted represent a very small percentage of the capacity of the commercial facility in which research was conducted. To accurately gauge the true effectiveness of the processing or ingredient parameters targeted in these three experiments, larger scale production runs are necessary. Taking a shift, or days', or weeks' worth of production as the sample size would give much better insight into the effects on processing and slicing yields due to the experimental condition. While this was not feasible for this research, it could be an area of future research. Overall, while there is still much research that needs to be done, this work will hopefully provide a positive impact to the bacon production industry.

5.2 Economic Implications

The goals of this research were to examine how processing and ingredient variables impacted the processing yields and consumer evaluation of bacon. However, since this research was conducted on the commercial scale, it is important to take note of the potential economic implications, both to the processor and consumers, brought about by this research. Whether through reduced ingredient cost, improved yield, or improved consumer acceptance of the product, this data could be used to support economic decisions. For the reduced sodium phosphate study, there is a definite opportunity for reduced ingredient cost without compromising yield, quality, or consumer acceptance of the product. Based on estimates provided, the current usage cost of sodium phosphate in the commercial facility is \$0.0075/kg. This is calculated based on the standard 0.50% sodium phosphate in the brine. However, if the formulation of sodium phosphate is dropped to 0.05% (as it was in study 1), the usage cost for the ingredient becomes \$0.000705/kg. This is a difference of \$0.00635/kg. Since the facility processes in such high volumes, even a small difference of \$0.00635/kg applied to a daily production of 226,790kg equates to \$1,440 savings per day. Across 4,535,9237kg of product this translates into a cost savings of \$290,000. Since the facility operates in such large volumes, fractions of pennies saved in ingredient cost can have a big economic impact.

While there is no ingredient savings for brine temperature reduction, if reduction of brine temperature could consistently produce a higher yield of #1 slices (which was noted in study 2), there are possible economic impacts. On average, #1 slices wholesale for \$3.97/kg, #2 slices wholesale for \$1.76/kg, and ends and pieces wholesale for \$1.54/kg. With a difference of \$2.21/kg between #1 and #2 slices, it is in the best economic interest of both the processor and consumer to produce the highest amount of #1 slices to overcome a raw material cost of \$2.65/kg. Improving yield of #1 slices would improve the profit margin for the processors, and could serve to keep the retail price of #1 slices more reasonable for the consumer. However, the potential profit generated from increased yield of #1 slices would have to be weighed against the cost of installation and maintenance of a brine chilling system in the commercial facility.

In addition to ingredient cost savings and possible increased yield of #1 slices the processing steps addressed in study 3 (post injection dwell time and smoke time) have definite economic impacts on overall processing. The faster the commercial facility can raw pork bellies into bacon, the more inventory they have to sell, and therefore higher profits. However, the facility is limited by the space available for post injection dwelling as well as the batch process nature of the smokehouse convention ovens. Therefore, the increased post injection dwell time and smoke time slow production down by tying up valuable space and equipment in the commercial facility. However increasing these parameters over standard plant procedures (no post injection dwell, 4 hour smoke) does not produce a product that is more significantly well liked by consumers than bacon processed under standard plant procedures. Therefore, it is up to the processor to weigh the potential benefits to the consumer against the slowing of production and throughput of product (Personal communication).

Overall, since this research was conducted in a commercial facility, it is important to understand the economic implications of changes in processing and/or ingredient factors. Whether by reducing ingredient usage cost in the case of sodium phosphate, or increasing yield of #1 slices, the potential for economic benefits for both the processor and consumer are available.

5.3 Future Research

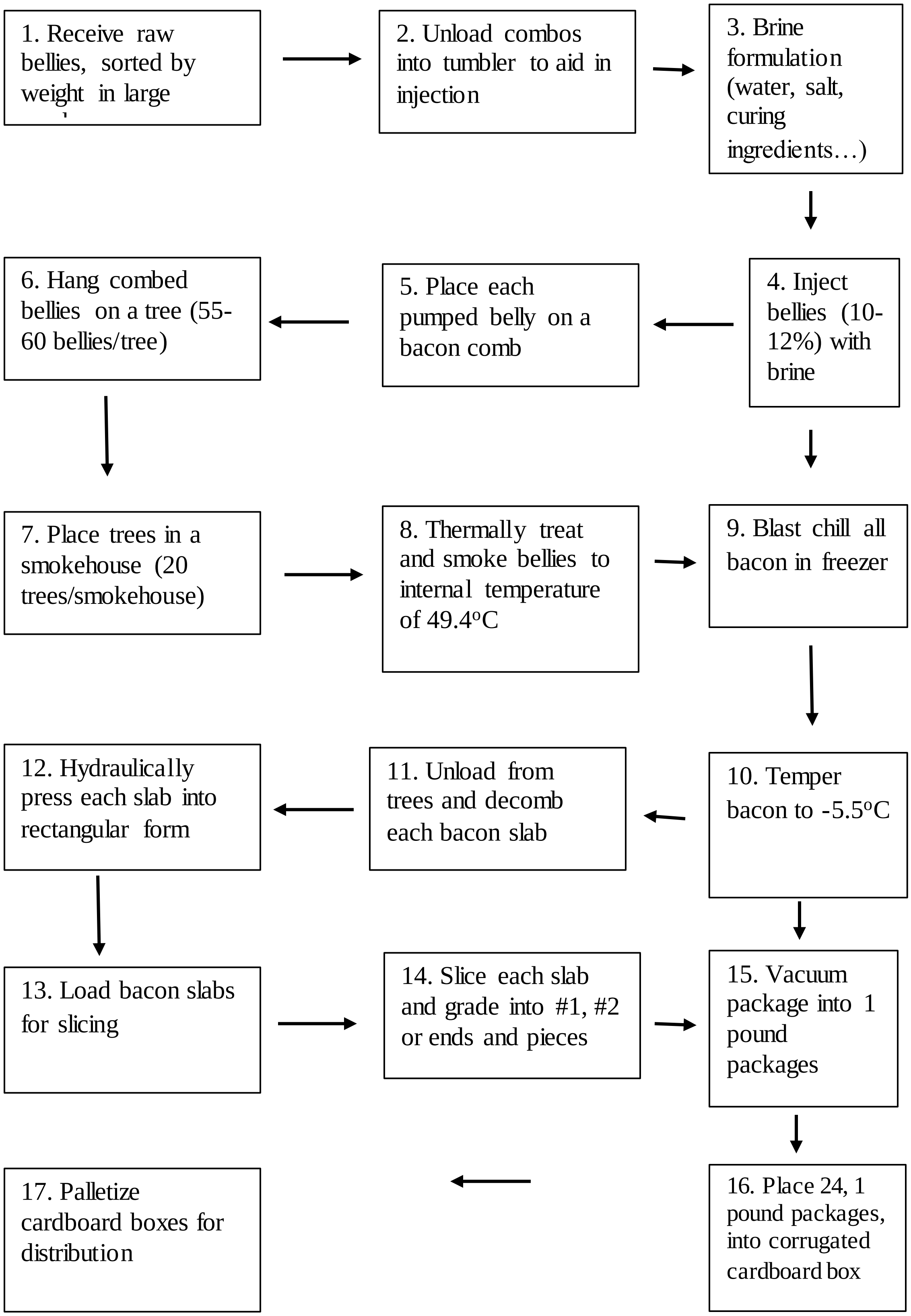
Based off the experience of this research, and the overall goal of the goal of the project to assess bacon production on a commercial scale, future research should focus on data collection on a commercial scale. Instead of designing experiments like the ones conducted in this work in which a smokehouse composed of roughly 20 trees was the treatment population, research should be conducted to increase the reach of the assigned treatments. Allowing an entire production shift, day, or even week to operate under the give test protocols would give a much better indication as to the true effects of sodium phosphate reduction, brine temperature reduction, or the interaction between post injection dwell and smoke time. Also, conducting research in this method would eliminate data collection errors since all processing yields, and especially slicing yield could be tracked through the electronic systems already in place in the plant. This method of research would also not interfere with the production schedule since the entire shift would be running under the same protocol. While this may not be practical from the processor's standpoint, to truly understand the effects of changing the identified processing variable on commercially produced bacon, they need to be tested under true commercial conditions.

5.4 References

Personal communication. Re: Bacon Questions. Message to Currey Nobles. November 20, 2016. Email.

APPENDICES

Appendix 6.1 General production flow for commercial bacon processing



Appendix 6.2. Demographic information for 30 day post processing sensory evaluation of reduced phosphate bacon

Gender	Male	28%
	Female	72%
Age Range	18-24 years old	19%
	25-29 years old	16%
	30-39 years old	23%
	40-49 years old	19%
	50-64 years old	23%
	65 years old and older	0%
Household Income	Under $20,000	13%
	$20,000-$40,000	28%
	$40,000-$70,000	35%
	Over $80,000	24%
Bacon Consumption	Never	0%
	A few times per year	3%
	At least once per month	31%
	At least 2-3 times per month	32%
	At least once per week	22%
	Two or more times per week	12%
Cook Method	Stove top	49%
	Microwave	10%
	Oven	35%
	Deep fat fried	3%
	Prepared fully cooked	3%
	I do not consume bacon	0%
Bacon Purchase Intent Factors	Price	67%
	Flavoring	57%
	Thickness	64%
	All Natural Labeling	16%
	Reduced Sodium	23%
	Low or Reduced fat	20%
	No Sodium nitrites, Uncured	12%
	Center cut	30%
	Sustainably raised	9%
	No Hormones	21%
	No Antibiotics	15%
	Other	5%

Data represents 100 consumers

Appendix 6.3 Demographic information for 110 day post processing sensory evaluation of reduced phosphate bacon

Gender	Male	43.6%
	Female	56.4%
Age Range	18-24 years old	16.8%
	25-29 years old	21.8%
	30-39 years old	23.8%
	40-49 years old	10.9%
	50-64 years old	23.8%
	65 years old and older	3.0%
Household Income	Under $20,000	6.9%
	$20,000-$40,000	26.7%
	$40,000-$70,000	40.6%
	Over $80,000	25.7%
Bacon Consumption	Never	0.0%
	A few times per year	5.9%
	At least once per month	18.8%
	At least 2-3 times per month	42.6%
	At least once per week	20.8%
	Two or more times per week	11.9%
Cook Method	Stove top	60.4%
	Microwave	5.0%
	Oven	29.7%
	Deep fat fried	3.0%
	Prepared fully cooked	2.0%
	I do not consume bacon	0.0%
Bacon Purchase Intent Factors	Price	71.3%
	Flavoring	69.3%
	Thickness	67.3%
	All Natural Labeling	18.8%
	Reduced Sodium	19.8%
	Low or Reduced fat	13.9%
	No Sodium nitrites, Uncured	9.9%
	Center cut	20.8%
	Sustainably raised	10.9%
	No Hormones	15.8%
	No Antibiotics	16.8%
	Other	4.0%

Data represents 101 consumers

Appendix 6.4. Demographic information for 30 day post processing sensory evaluation of reduced brine temperature bacon

Gender	Male	37.5%
	Female	62.5%
Age Range	18-24 years old	37.5%
	25-29 years old	17.3%
	30-39 years old	17.3%
	40-49 years old	8.7%
	50-64 years old	18.3%
	65 years old and older	1.0%
Household Income	Under $20,000	13.5%
	$20,000-$40,000	26.0%
	$40,000-$70,000	40.4%
	Over $80,000	20.2%
Bacon Consumption	Never	0.0%
	A few times per year	15.4%
	At least once per month	23.1%
	At least 2-3 times per month	26.0%
	At least once per week	24.0%
	Two or more times per week	11.5%
Cook Method	Stove top	62.5%
	Microwave	6.7%
	Oven	23.1%
	Deep fat fried	3.8%
	Prepared fully cooked	3.8%
	I do not consume bacon	62.5%
Bacon Purchase Intent Factors	Price	77.9%
	Flavoring	72.1%
	Thickness	67.3%
	All Natural Labeling	13.5%
	Reduced Sodium	25.0%
	Low or Reduced fat	22.1%
	No Sodium nitrites, Uncured	7.7%
	Center cut	24.0%
	Sustainably raised	10.6%
	No Hormones	14.4%
	No Antibiotics	15.4%
	Other	6.7%

Data represents 104 consumers

Appendix 6.5 Demographic information for 110 day post processing sensory evaluation of reduced brine temperature bacon

Gender	Male	40.0%
	Female	60.0%
Age Range	18-24 years old	37.1%
	25-29 years old	24.8%
	30-39 years old	12.4%
	40-49 years old	9.5%
	50-64 years old	16.2%
	65 years old and older	0.0%
Household Income	Under $20,000	13.3%
	$20,000-$40,000	21.9%
	$40,000-$70,000	35.2%
	Over $80,000	29.5%
Bacon Consumption	Never	0.0%
	A few times per year	7.6%
	At least once per month	21.9%
	At least 2-3 times per month	42.9%
	At least once per week	16.2%
	Two or more times per week	11.4%
Cook Method	Stove top	62.9%
	Microwave	3.8%
	Oven	21.0%
	Deep fat fried	4.8%
	Prepared fully cooked	6.7%
	I do not consume bacon	1.0%
Bacon Purchase Intent Factors	Price	65.7%
	Flavoring	70.5%
	Thickness	70.5%
	All Natural Labeling	16.2%
	Reduced Sodium	12.4%
	Low or Reduced fat	15.2%
	No Sodium nitrites, Uncured	11.4%
	Center cut	15.2%
	Sustainably raised	10.5%
	No Hormones	11.4%
	No Antibiotics	10.5%
	Other	4.8%

Data represents 105 consumers

Appendix 6.6 Appearance, flavor and texture lexicons used in descriptive analysis of bacons

Flavor and Appearance Lexicon		
Attribute	Definition	Example or Reference
Orthonasal Aromatics		
Aroma description	describe the aromatics detected orthonasally	
Visual Observations		
lean color	color of the cooked lean portion	PR (pink/red), RB (red/brown), B (brown), DB (dark brown)
fat color	color of the cooked fat portion	W (white), B (beige), T (tan), Y (yellow)
edge color	color of the edge of the bacon slices, ranging from no difference to very dark	ND (not distinguishable), SD (slightly darker), D (dark), VD (very dark)
Retronasal Aromatics		
cooked cured lean pork	aromatics of cooked, lean cured pork muscle that includes any browned note	cooked Hormel bacon = 3 to 3.5
cooked cured pork fat	aromatics of cooked cured pork fat	cooked Hormel bacon = 3.3
sweet aromatic	aroma of sweet substances such as brown sugar, molasses	Hormel cooked bacon = 1.2, pork loin = 1.8
smoke	aromatics of slow burned hardwoods (non specific)	smoked sausage, campfire coals
oxidized	any oxidized flavor; cardboardy, stale, rancid	stale or rancid meat fats
Feeling Factors		
astringent mouthfeel	drying, drawing or puckering of any mouth surfaces, tooth etching	0.02% alum solution = 2
Basic Tastes		
sweet	basic taste elicited by sugars & high potency sweeteners	2% sucrose solution = 2
salty	basic taste elicited by salts	0.7% NaCl solution = 5.5
umami	basic taste elicited by glutamates; fullness, savoriness	0.5 % msg solution = 3

Texture Lexicon		
Attribute	Definition	Example or Reference
Initial: Place the bacon slice against the lips.		
oiliness to lips	Degree to which the sample surface feels oily.	Hormel cooked bacon = 14
First Bite: Place 1/2 inch to 3/4 inch of the slice from the narrow end into the mouth and bite.		
hardness	amount of force required to bring the front teeth together	Hormel cooked bacon = 7, Oscar Mayer beef hot dogs = 4
crispy	degree to which the sample fractures apart easily, usually with sound	Hormel cooked bacon = 12.5
chewy	degree to which the sample is slightly resistant to breaking apart	Hormel cooked bacon = 1 to 1.5
Mastication: Chew a 1/2 inch to 3/4 inch sample bite at a rate of one chew per second.		
oiliness	degree to which oil is perceived during mastication	Hormel cooked bacon = 9.5
# chews to swallow	number of chews required to prepare the sample for swallowing	Hormel cooked bacon = 24
Residual: Evaluate after swallowing or expectorating.		
oily mouthcoating	degree to which oil is coating any of the mouth surfaces	Hormel cooked bacon = 7.5

Appendix 6.7. Complete descriptive analysis results of bacons produced with varying post injection dwell and smoke times as well as 2 competitors' bacon

	H	O	0D4S	0D6S	2D4S	2D6S
lean color	RB	RB / DB	PR /RB	PR /RB	RB	PR / RB
fat color	Y / T	T	B / T / Y	Y	Y / T	Y / T
edge color	1.4 d	1.7 cd	1.8 cd	1.9 c	3.0 b	3.8 a
cured cooked lean pork	3.2	3.3	3.4	3.3	3.4	3.3
cured cooked pork fat	3.2	3.2	3.6	3.4	3.8	3.4
sweet aromatic	1.3 b	1.5 ab	1.6 a	1.4 ab	1.5 ab	1.4 ab
smoke	1.7 d	1.9 cd	2.0 c	1.8 d	2.4 b	2.9 a
oxidized	ND	ND	ND	ND	ND	ND
astringency. mouthfeel	2.1	2.0	2.2	2.1	2.3	2.1
sweet	1.7	1.6	1.5	1.6	1.6	1.6
salt	7.8 a	5.4 c	5.3 c	5.3 c	7.0 b	5.3 c
umami	2.9	2.9	2.7	2.7	3.0	2.9
oily to lips	13.6	14.0	13.5	13.7	13.9	13.4
hardness	6.7 d	8.3 a	7.2 c	7.0 c	7.8 b	8.0 b
crispy	13.0	12.4	13.7	13.7	12.4	12.7
chewy	1.4 c	3.3 a	2.4 b	2.1 b	3.2 a	3.1 a
oiliness	9.6	9.8	9.4	9.5	9.7	9.2
chews to swallow	23.3	28.7	25.9	23.8	25.3	31.4
oily mouthcoating	7.9	7.9	7.7	7.6	8.0	7.6
comments	smoky aftertaste	breaks up easily in mouth	tastes like fat back but less so than 2D6S	late smoky flavor		tastes like fat back, dark edge very noticeable

Means in a row with different letters are significantly different ($p<0.05$)

Appendix 6.8. Additional data from Study 1

Low Sodium Phosphate Bacon			**Standard Sodium Phosphate Bacon**		
Smoke Yield (%)	*Cooler Yield (%)*	*Overall Yield (%)*	*Smoke Yield (%)*	*Cooler Yield (%)*	*Overall Yield (%)*
96.13	97.46	93.69	97.53	94.5	92.16
95.71	97.13	92.97	95.3	97.33	92.76
95.99	97.16	93.26	95.68	100.9	96.54
95	97.24	92.38	95.82	93.11	93.11
96.32	97.16	93.59	96.07	97.35	93.53
95.91	97.48	93.49	95.92	97.6	93.62
97.12	97.29	94.49	95.95	97.37	93.43
95.44	97.21	92.77	96.05	97.42	93.57
96.16	97.05	93.33	96.17	97.54	93.80
#1 Slice yield (%)	*#2 Slice Yield (%)*	*Ends and Pieces Yield (%)*	*#1 Slice yield (%)*	*#2 Slice Yield (%)*	*Ends and Pieces Yield (%)*
66.8	15.7	7.4	59.0	14.9	21.0
61.5	20.2	8.4	67.0	19.1	12.0
63.7	17.2	8.4	59.3	16.2	15.9
52.7	14.7	7.8	63.2	17.7	14.3
62.5	20.6	9.1	69.4	11.9	7.9
62.8	19.0	10.4	74.3	23.7	17.0
57.2	20.3	9.4	60.1	17.8	10.0
			61.5	15.8	9.1
Primary Lean Color			*Primary Lean Color*		
*L**	*a**	*b**	*L**	*a**	*b**
52.48	15.79	23.27	44.88	24.50	12.97
49.75	19.54	10.63	47.69	20.09	12.44
47.48	20.84	10.32	46.18	21.64	12.20
48.81	20.71	11.12	48.19	22.14	13.01
45.97	22.26	11.26	46.68	22.69	11.78
46.19	22.47	12.22	46.71	22.30	12.80
47.91	20.69	9.87	45.84	22.01	13.32
Secondary Lean Color			45.20	22.26	12.71
*L**	*a**	*b**	*Secondary Lean Color*		
66.26	7.86	6.57	*L**	*a**	*b**
60.42	11.02	7.89	64.12	10.06	9.12
64.06	8.49	8.10	64.15	9.75	8.96
62.03	11.02	9.35	61.92	11.31	9.41
63.58	9.00	7.80	58.50	13.91	9.63
64.01	10.54	9.08	66.82	9.26	8.83
66.44	8.70	7.05	61.07	11.49	9.16
			58.64	10.57	10.07
			64.19	10.43	8.90

Appendix 6.9. Additional data from Study 2

Low Temperature Brine Bacon			**Room Temperature Brine Bacon**		
Smoke Yield (%)	*Cooler Yield (%)*	*Overall Yield (%)*	*Smoke Yield (%)*	*Cooler Yield (%)*	*Overall Yield (%)*
95.05	96.55	91.77	93.88	97.96	91.97
96.64	95.33	92.13	95.77	96.68	92.58
96.60	96.25	92.97	94.59	97.30	92.03
96.01	96.37	92.53	94.54	97.76	92.42
95.74	96.74	92.63	94.20	97.02	91.39
95.06	99.31	94.40	94.79	97.93	92.83
95.70	96.68	92.52	94.54	96.66	91.38
95.70	95.02	90.93	93.44	98.42	91.97
97.16	95.72	93.01	95.14	96.80	92.10
96.10	96.73	92.96	94.49	96.60	91.28
#1 Slice yield (%)	*#2 Slice Yield (%)*		*#1 Slice yield (%)*	*#2 Slice Yield (%)*	
80.88	12.44		78.05	12.85	
80.74	13.64		74.98	12.99	
73.85	12.84		70.13	14.79	
90.39	13.15		84.10	9.60	
82.28	12.06		65.46	17.94	
82.51	13.48		67.97	13.59	
79.49	11.74		66.03	13.59	
57.81	8.04		75.81	15.38	
84.02	11.87		72.73	8.44	
80.72	12.07		69.75	11.97	
80.88	12.44				
Primary Lean Color			*Primary Lean Color*		
*L**	*a**	*b**	*L**	*a**	*b**
50.14	22.94	10.71	58.28	18.00	10.49
49.28	23.56	12.55	50.90	22.20	11.65
52.10	20.59	11.33	57.07	19.25	9.70
53.02	20.91	10.01	54.64	19.77	10.14
49.27	22.89	11.20	53.53	19.31	11.46
53.26	19.97	10.47	51.16	19.72	9.70
51.49	20.08	10.03	56.13	19.42	10.55
51.65	20.39	10.09	50.76	21.86	9.73
50.57	21.44	11.38	52.87	21.31	11.97
52.68	20.30	10.87	57.82	17.65	9.24
Secondary Lean Color			*Secondary Lean Color*		
*L**	*a**	*b**	*L**	*a**	*b**
67.95	11.55	9.50	70.87	9.53	8.71
66.37	10.35	9.52	65.82	12.70	9.35
68.16	10.17	9.14	73.83	9.53	8.29
70.59	8.77	9.96	68.88	10.46	10.76
65.55	11.72	10.46	67.07	8.55	9.99
66.07	10.77	8.05	68.81	10.08	9.03
66.17	9.32	7.58	72.07	9.13	8.96
66.23	11.58	9.30	68.23	10.86	9.58
67.69	12.18	10.12	69.94	9.79	11.69
66.62	10.63	9.43	69.95	10.36	10.85

Appendix 6.10. Additional data from Study 3

0D4S		0D6S		2D4S		2D6S	
Smoke Yield (%)	*Cooler Yield (%)*	*Smoke Yield (%)*	*Cooler Yield (%)*	*Smoke Yield (%)*	*Cooler Yield (%)*	*Smoke Yield (%)*	*Cooler Yield (%)*
95.93	96.75	94.46	97.55	95.40	95.78	94.12	97.52
96.75	95.94	93.47	98.19	95.88	96.47	92.68	99.27
96.82	96.12	93.40	98.23	95.51	97.48	94.46	98.17
96.75	96.12	94.54	96.32	96.05	98.20	95.08	97.08
96.69	95.27	94.75	94.12	94.56	96.55	92.89	96.77
96.42	96.55	95.26	96.96	94.99	98.10	94.86	94.97
96.48	96.79	94.97	97.14	95.33	98.14	94.50	96.81
96.24	96.70	94.86	96.92	97.16	97.58	94.85	96.83
94.55	98.11	95.68	97.55	95.38	98.01	92.86	98.64
95.13	97.82	94.95	96.30	94.16	98.25	93.04	95.53
95.47	96.08	94.66	97.60	95.26	95.11	94.50	95.45
95.83	96.87	94.97	96.50	95.20	98.09	94.40	97.48
96.75	96.23	94.66	96.87	94.04	98.06	92.61	95.78
96.64	96.36	95.01	95.37	95.39	97.00	94.63	95.50
95.30	96.05	93.28	97.17	95.02	99.30	93.70	99.66
95.96	97.07	94.97	97.00	95.20	97.91	96.16	95.37
96.69	95.87	94.66	97.09			95.81	95.44
96.96	95.38						
93.35	98.34						

0D4S			0D6S			2D4S			2D6S		
Primary Lean Color			*Primary Lean Color*			*Primary Lean Color*			*Primary Lean Color*		
*L**	*a**	*b**	*L**	*a**	*b**	*L**	*a**	*b**	*L**	*a**	*b**
49.38	23.44	13.58	48.20	25.09	12.68	48.33	26.87	13.88	49.98	22.52	12.85
54.09	20.47	14.37	52.60	21.93	12.62	50.86	24.85	15.32	49.97	21.95	11.13
52.85	22.67	14.03	50.46	23.26	11.97	49.87	23.43	13.25	54.13	19.71	10.28
51.70	25.06	15.04	48.83	25.87	13.48	52.60	21.55	13.01	50.95	21.50	12.34
50.12	22.96	13.33	48.49	24.66	14.18	51.68	25.37	15.21	48.88	24.40	13.96
50.24	26.13	15.58				49.84	24.98	15.52	52.97	19.39	10.70
Secondary Lean Color			*Secondary Lean Color*			*Secondary Lean Color*			*Secondary Lean Color*		
*L**	*a**	*b**	*L**	*a**	*b**	*L**	*a**	*b**	*L**	*a**	*b**
63.16	13.12	10.66	65.48	13.08	10.52	63.27	13.49	12.75	66.43	12.05	9.34
66.52	11.41	10.41	65.70	12.88	10.06	62.49	13.62	10.72	64.02	13.71	9.31
69.24	10.42	10.29	68.98	11.51	9.71	64.22	12.46	11.40	65.12	12.94	8.50
68.44	11.69	12.23	68.34	12.14	10.76	63.69	12.90	11.36	65.26	11.24	10.10
66.85	10.76	10.44	64.05	13.11	10.96	63.04	12.22	10.73	64.91	13.09	9.70
61.11	14.37	11.70				58.26	13.78	11.11	67.00	10.58	8.34