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Physical and chemical effects of citrus fiber as a natural alternative to sodium tripolyphosphate in uncured all-pork bologna and oven-roasted turkey breast

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Physical and chemical effects of citrus fiber as a natural alternative to sodium tripolyphosphate in uncured all-pork bologna and oven-roasted turkey breast

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The student author and the program of study committee are solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

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DEDICATION

This thesis is in memory of my grandparents, Gerald & Bernadette Coyle and Robert & Arla Powell. Your love and passion for school and encouragement growing up impacted me more than I was ever able to thank you for. Thank you for instilling in me such confidence, the importance of taking chances, and teaching me I can achieve anything. You continue to shine as my inspirations. I would not be where I am today without you.

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NOMENCLATURE

DSP	Disodium phosphate
HSP	Hemisodium phosphate
MSP	Monosodium phosphate
SAPP	Sodium acid pyrophosphate
SHMP	Sodium hexametaphosphate
SPG	Sucrose phosphate glutamate
STMP	Sodium trimetaphosphate
STPP	Sodium tripolyphosphate
TSPP	Tetrasodium pyrophosphate
TSP	Trisodium phosphate

ABSTRACT

"Clean label" has become the normality in the food industry. Many consumers have become increasingly concerned with the added ingredients in their food products and the meat industry is not exempt from these concerns. Consequently, processed meat products could benefit from the elimination of synthetic non-meat additives. Citrus fiber has the potential to serve as a natural alternative to sodium tripolyphosphate in processed meat and minimize changes in sensory characteristics associated with an acceptable product. The objective of this study was to evaluate the functionality of citrus fiber as a natural alternative to sodium tripolyphosphate in an uncured all-pork bologna and an oven-roasted turkey breast.

Five bologna treatments were produced using the following sodium tripolyphosphate replacement formulations: 1) sodium tripolyphosphate control (STPP), 2) no sodium tripolyphosphate control (No STPP), 3) 0.50% citrus fiber (0.50% CF), 4) 0.75% citrus fiber (0.75% CF), and 1.00% citrus fiber (1.00% CF). The treatments all maintained acceptable quality throughout a 98-day shelf life. Citrus fiber treatments resulted in bologna with acceptable technological parameters, as indicated by similar cook/chill yields and emulsion stability compared with the STPP control. Lipid oxidation across all treatments was maintained for the entirety of the 98-day shelf life period. There were slight differences among sensory evaluation scores for texture and moistness, with the citrus fiber treatments perceived as being softer and less moist; however, these contradicted the TPA measurement data showing the citrus fiber treatments as harder than the sodium tripolyphosphate control. The citrus fiber treatments were harder, less

resilient, less cohesive, and less springy compared to the sodium tripolyphosphate control. Sensory evaluation of color showed no difference in lightness throughout the 98-day shelf life. While there were instrumental color differences, they were slight and did not result in a product that was visually different or unappealing compared to the sodium tripolyphosphate control.

Four oven-roasted turkey treatments were produced using the following: 1) sodium tripolyphosphate control (STPP), 2) no sodium tripolyphosphate control (No STPP), 3) 0.25% citrus fiber (0.25% CF), and 4) 0.50% citrus fiber (0.50% CF). The treatments all maintained acceptable quality throughout an 84-day shelf life. Citrus fiber treatments resulted in turkey with acceptable technological parameters, as indicated by similar cook/chill yields compared to the STPP control. Lipid oxidation across all treatments was maintained for the entirety of the 84-day shelf life period. There were slight differences among sensory evaluation scores for moistness, with the citrus fiber treatments perceived as being less moist. Sensory evaluation of color showed no difference of lightness throughout the 84-day shelf life. While there were instrumental color differences, they were slight and did not result in a product that was visually different or unappealing compared to the sodium tripolyphosphate control. In conclusion, citrus fiber has the potential to produce an uncured all-pork bologna and oven-roasted turkey breast with similar technological attributes, texture characteristics, color values, lipid oxidation, and sensory properties as those made with sodium tripolyphosphate.

CHAPTER 1. GENERAL INTRODUCTION

Food additives have been utilized in processed meat products for centuries. Processed meat is a generic term defining meat products that have been modified in some manner to improve quality characteristics. Modification can include curing, salting, fermentation, smoking, or the addition of various functional ingredients, commonly referred to as food additives. Food additives contribute to improved quality characteristics, safety, and preservation. However, in the past decade, the trend of removing additives from food has become a popular option across much of the food industry. Consumers have become more critical of the ingredients in their processed food products and are increasingly skeptical of ingredients whose name and functions they do not understand or are perceived as unsafe for consumption. It is because of this trend and the consumer demand for more transparency that the food industry has worked to reformulate their products.

The meat industry is under constant criticism for its use of food additives, especially in processed meat, which has the reputation of being unhealthy due to high sodium and fat contents and the presence of supposed carcinogens. This has pushed the industry to comply with consumer requests to remove conventional ingredients from their products and replace them with natural alternatives. Sodium tripolyphosphate is a food additive used in meat products for its contribution to higher yields and for acting as a buffering agent. It functions to improve sensory characteristics, specifically texture. Without the application of phosphate products may experience decreased cook/chill yield, water holding capacity, and unacceptable texture. The complete elimination of

phosphate is not always plausible, so finding alternatives has been at the forefront of recent research in the meat industry. Several different forms and combinations of binders have been researched to serve as potential alternatives to phosphate. One alternative that has shown popularity in various industries is citrus fiber. Citrus fiber is produced from orange pulp, core, and peel, and due to its high surface area and fiber content, it functions to improve water retention, texture, and gelation. This functionality shows promise to produce a successful processed meat product in replacement of phosphate.

The objective of this research was to evaluate the physical and chemical effects of citrus fiber as a natural alternative to sodium tripolyphosphate in uncured all-pork bologna and oven-roasted turkey breast. It was hypothesized that citrus fiber as a sodium tripolyphosphate replacer would produce bologna and oven-roasted turkey with acceptable color, oxidative stability, texture, and sensory characteristics throughout a 98- and 84-d shelf-life, respectively. If successful, citrus fiber could find a permanent home in the meat industry as a natural additive that can result in a successful product with improved sensory characteristics that previous phosphate alternatives could not produce.

CHAPTER 2. REVIEW OF LITERATURE

Introduction

In the last decade, consumers have started demanding "clean labels" and the elimination of ingredients that are perceived as "unnatural" or "unhealthy" from further processed foods. The meat industry is not exempt from these growing trends and is one of the major industries trying to apply changes to their products in an attempt to meet consumer requests. The majority of focus has been on eliminating nitrite/nitrate, ascorbate/erythorbate and phosphates from processed meat and poultry products and replacing them with natural sources to provide a "clean label." It is well established that cultured celery juice powder and cherry powder/acerola are acceptable natural alternatives for nitrite and ascorbate/erythorbate in cured meat products, respectively (J. G. Sebranek & Bacus, 2007). However, little research has been published on successful natural alternatives to phosphate in processed meat products.

Phosphates serve as a very functional ingredient in processed meat. They provide increased water binding, and therefore help maintain cook/chill yields (Pearson & Gillett, 1996) and in many cases their complete elimination is not plausible for a successful and profitable product. The use of phosphates in meat products is of concern to some consumers, therefore, a natural alternative to phosphates will allow for greater acceptance among these consumers. However, there are challenges associated with this. These include maintaining phosphate effects by using other nonmeat ingredients without altering the integrity or palatability of the overall product. Successful manufacturing of such products could find a common place in the meat industry as the negative perceptions

surrounding the health of processed meat and current consumer concerns about the addition of nonmeat ingredients continues to grow.

Food Additives

A food additive is any ingredient added to a food that serves a functional purpose. Chemical substances have been added to foods since prehistoric times to perform a function or provide a desired characteristic. While some foods contain no additives, with technological advancements, more than 3000 substances are added to food to produce desired properties. There are six major categories of additives: preservatives, nutritional additives, flavoring agents, coloring agents, texturizing agents, and miscellaneous additives (Branen et al., 2001). Preservatives include antimicrobials to prevent growth of microorganisms and extend shelf life, antioxidants to prevent lipid oxidation, and anti-browning agents to prevent enzymatic and non-enzymatic browning. Nutritional additives have grown in popularity as consumers become more concerned with their nutritional intake. Some examples of nutritional additives are amino acids, minerals, vitamins, and fibers. There are three major categories of flavoring additives: sweeteners, natural and synthetic flavors, and flavor enhancers. Coloring agents are used to improve overall visual appearance. There are quite a few different natural and synthetic ingredients that are used as coloring agents. Texturizing agents include emulsifiers, stabilizers, phosphates, and dough enhancers. And finally, miscellaneous additives include various processing aids.

Many additives are multifunctional when added individually and often work in combination with each other. The use of food additives may result in safer and more

nutritious food through the use of antimicrobials, antioxidants, and vitamins; greater food choices stemming from the development of convenient, health-promoting, and low-calorie foods; and lower priced foods (Branen et al., 2001). Food additives are regulated in the United States by the Food and Drug Administration and the Department of Agriculture. The risks associated with the inclusion of food additives are minimal because of the labeling requirements and regulations that are set in place to avoid any adverse effects of long- or short term consumption and the possibility of any toxicological risks.

Food additives are not only added to improve the physical or chemical characteristics of the food, but to benefit the producer and processor by improving or adding quality, safety, and variety to products. Also, they benefit the consumer, whether they deem them beneficial or not, because they can provide desired sensory characteristics, improved nutritional content, and simplicity or convenience of food preparation. Concern for food additives by consumers stems from a fear of chemicals and is directed more towards synthetic additives than natural additives (Baines & Seal, 2012). Many consumers believe chemicals are harmful to their health; synthetic additives are chemicals and for that reason are deemed to be detrimental. Whether these beliefs are based on science or not, these consumer concerns are what is driving the push towards elimination of chemical sounding ingredients from processed foods. The importance of this trend is further confirmed by the selection of “clean label” as Food Business News’ Trend of the Year for 2015. The food industry is moving to remove artificial ingredients from products and major brand names in all spectrums of the food industry, including

meat, are changing formulations and menus to comply with consumers demands and concerns related to food additives (Watrous, 2015).

Basic Phosphate Chemistry

Phosphorus (P) is essential to all life and is present in every organism. After calcium, P is the second most abundant component of bone and teeth. It is an important regulator of energy metabolism in organs and generates energy in every living cell (Branen et al., 2001). Phosphorus is absorbed into all living organisms in the form of phosphate ions, which no organism is capable of synthesizing; therefore, it must be obtained from food (Ellinger, 1972). It is impossible to eat anything that was once a living organism and avoid phosphate (Ellinger, 1972). Phosphorus is available in combination with other minerals as calcium phosphate, calcium pyrophosphate, calcium glycerophosphate, ferric phosphate, ferric pyrophosphate, magnesium phosphate, manganese glycerophosphate, potassium glycerophosphate, sodium phosphate, sodium ferric pyrophosphate, and sodium pyrophosphate (Institute of Medicine, 1996).

Phosphorus is involved in energy transfer mechanisms where chemical bonds are transformed into other bonds or other forms of energy. It has a central role in the muscle contraction of animals and rigor mortis through adenosine triphosphate (ATP) and has roles in other metabolic pathways in animals, plants, and microorganisms. The synthesis and breakdown of carbohydrates, proteins, and lipids are all P dependent (Molins, 1991). Phosphates are defined as salts of phosphoric acid made of positively charged metal ions and negatively charged phosphate ions, and are widely used as additives in the meat industry bound to sodium or potassium (Feiner, 2006). Phosphates are distinguished from

other P-containing molecules by four oxygen atoms bound to a central P atom (Branen et al., 2001). The oxygens atoms at the four corners resemble a tetrahedron structure. This organization forms the basis of phosphate nomenclature and allows for the formation of diphosphates (pyrophosphates), triphosphates (tripolyphosphates), tetraphosphates, etc., collectively known as condensed phosphates. Orthophosphates are the simplest phosphate tetrahedron structure. Metaphosphates are cyclic ring structures formed by combining multiple orthophosphates together, however, they are not used in food applications. Ortho- and polyphosphates serve as functional food additives serving as buffers, metal ion sequesters, and microbial inhibitors.

Phosphate Functionality in Meat and Poultry

The use of phosphate in processed meat and poultry offers numerous functional benefits. These include, but are not limited to reduced requirement for salt, reduced development of warmed over flavor (WOF), color protection, color development in cured products, reduced cook-cool loss, reduced thaw-drip loss, inhibition of lipid oxidation, stabilization of emulsions, gelation of myosin, and enhanced tenderness and juiciness of cooked product (Strack & Oetker, 1992). Phosphates are important additives in comminuted meat products (Molins, 1991). They offer multiple functionalities in meat during the manufacture of restricted or low-sodium products, as antimicrobials, and through pigment protection (Bolin et al., 1976; Brotsky et al., 1973; Merkenich, 1977; Steinhauer, 1983). Compared to other nonmeat ingredients used in processed meat products, phosphates offer unique benefits which differ with the multiple forms that can be used individually or in combination (Sebranek, 2015). Ring phosphates, chain

phosphates, and a combination of ring and chain phosphates are the three basic forms (Feiner, 2006). These different forms vary in solubility and pH.

Phosphates are used in meat products for several reasons. They break the actin-myosin bond formed in the conversion of muscle to meat during rigor mortis. The functionality of phosphates to separate this bond is one of the primary uses worldwide. Phosphates work synergistically with salt to activate meat protein, an important step in emulsification of fat in processed meats. The alkalinity of many phosphates and phosphate blends used in the meat industry increases the water-binding ability of meat and reduces shrinkage during processing by raising the pH. Phosphates also reduce the development of oxidative rancidity due to their ability to chelate metal ions (Schwartz & Mandigo, 1976)

The use of phosphate blends is very common in the meat industry. These blends contain combinations of monophosphates, pyrophosphates, or tripolyphosphates. The desired functionality of using phosphates determines the best form of the phosphate or blend. Phosphates can increase color development, particularly in small diameter products (Aberle, Forrest, Gerrard, & Mills, 2012). Many different forms of phosphates are allowed in meat products and are approved for use at levels not exceed 0.5% in the finished product; however, it has been shown that amounts greater than 0.3% are not any more beneficial or effective (Wierbicki & Howker, 1976). In cured products, specifically, phosphates work hand in hand with the curing agent. The ability of phosphates to change ionic strength can reduce water loss during processing and make for a juicier and more tender product. The buffering effect of alkaline phosphates allows for more protein available to bind water due to the breaking of the actomyosin cross-bridges. Phosphates

influence development and stability of cured meat color and flavor through the reduction of pigment oxidation. Therefore, muscles reflect less light with highly hydrated proteins allowing for a darker and more acceptable product color. Phosphate offers protection against browning during storage and acts with ascorbates to protect against oxidative rancidity (Aberle et al., 2012). The combination of phosphate and other compounds, such as salt, curing agents, ascorbate, and other nonmeat ingredients, offers greater beneficial results compared to each ingredient working by itself. Ruusunen and others (2003a) found that when creating low-salt, no-phosphate frankfurters, it is necessary to use other non-meat ingredients to improve water and fat binding. In this study, the addition of modified tapioca starch and sodium citrate with or without salt and phosphate helped to decrease frying loss and improve water and fat binding abilities compared to salt alone without the addition of phosphate with or without other binders (Ruusunen et al., 2003a). Schwartz and Mandigo (1976) found that salt in combination with STP offered the most acceptable product. The synergistic effects of salt and STP were significantly better for cooking loss, raw color, TBA value, cooked color, aroma, flavor, texture, and juiciness (Schwartz & Mandigo, 1976).

While examples of phosphates and phosphate blends have been given above, there are numerous combinations that have different specific properties and functions (Branen et al., 2001). Alkaline phosphates are the most common form used in meat products. The addition of an alkaline phosphate to meat raises the pH. When this shift takes place, larger gaps form between actin and myosin in the protein portion, creating more space for water to be bound. An increase in ionic strength also leads to muscle fiber swelling, allowing for the emulsification of fat and immobilization of water. Phosphates, however,

cannot activate the proteins alone, they can only break the actin-myosin link, making the addition of salt necessary to activate those proteins to allow for immobilization of water and emulsification of fat. Frankfurters usually contain short-chain phosphates because they can withstand and become activated by the high energy produced from the bowl chopper during manufacture. Longer chain phosphates produce softer emulsions and can be used for applications where the emulsions are pumped. Long chain phosphates also are best for brines since they tend to be more soluble in cold water (Feiner, 2006).

One of the functional properties of phosphates is sequestration of metal ions, which are naturally occurring in meat. The ability of phosphates to bind to Ca^{2+} and Mg^{2+} specifically act to separate actin and myosin, allowing for increased water holding capacity, and, as a result, increased tenderness. The ability of phosphates to bind metal ions has the possibility to reduce oxidative rancidity of processed meats (Branen et al., 2001; Ellinger, 1972; Feiner, 2006; Fernandez et al., 2004; Inklaar, 1967; Ricardo A. Molins, 1991). (Akamittath et al., 1990) evaluated the effects of salt with and without polyphosphates on lipid oxidation in restructured beef, pork, and turkey and found that polyphosphates were effective in delaying the onset of lipid oxidation in beef, pork, and turkey by 4, 8, and 6 weeks, respectively.

pH and Water Binding

Increased pH and water retention are correlated (Branen et al., 2001). When phosphates are used, there is less water and purge loss during cooking, allowing for an increase in juiciness and tenderness (Aberle et al., 2012). As polyelectrolytes, phosphates can change ionic charge distributions, thus increasing ionic strength. This leads to an

increase in muscle fiber swelling and activation of protein which supports the immobilization of water and the emulsification of fat (Feiner, 2006; Li, Liu, Guo, Li, & Shu, 2002; Offer & Trinick, 1983; Siegel & Schmidt, 1979; Trout & Schmidt, 1986; Xu et al., 2009). Phosphates differ in pH and solubility, which is why blends are so commonly used in food to achieve desired results (Lampila & Godber, 2001). Alkaline phosphates are commonly used in the meat industry because of their ability to create larger gaps between actin and myosin, allowing for greater water binding ability (Anjaneyulu et al., 1990; Feiner, 2006; Lampila & Godber, 2001; Puolanne et al., 2001; Young et al., 2005). This leads to repulsion of meat proteins by dissociation of the actomyosin cross bridges (Aberle et al., 2012). Orthophosphates have essentially no effect on water binding and are not commonly used in meat products (Lampila & Godber, 2001).

Protein solubility in water is affected by ionic strength, pH, and temperature. The pH dependence is related to the net charge on the proteins. Phosphates act on proteins by influencing the pH and altering their net charge, therefore, leading to an increase in ionic strength (Molins, 1991). As the ion concentration is increased, the binding of the ions to ionized groups on oppositely charged proteins increases, decreasing electrostatic attractions and increasing protein solubility. Ions attached to the protein molecules allow for more interactions with water, which increases protein-water interactions and protein solubilization (Molins, 1991). In buffalo meat patties, the addition of pyrophosphate and sodium tripolyphosphate increased pH, water holding capacity, emulsifying capacity, extractability of salt-soluble proteins, and moisture retention after cooking when compared to salt and additive-free controls (Anjaneyulu et al., 1989). Beef rolls had

increased protein solubilization and improved beef muscle binding with the addition of polyphosphates during manufacture (Trout & Schmidt, 1986). Addition of phosphate can cause an increase in water holding capacity of cooked sausages and sectioned and formed hams (Puolanne et al., 2001; Siegel et al., 1978). Meat pH needs to be compensated for by other means when trying to achieve the same water holding capacity without the addition of phosphate (Ruusunen et al., 2005). There is a direct relationship between phosphate-induced increases in ionic strength, pH, and water binding by meat proteins. Polyphosphates are effective in promoting water binding by muscle proteins, but only to the extent they are hydrolyzed to diphosphates, the active form (Tsai & Ockerman, 1981).

The solubility of phosphates is another consideration that needs to be taken when choosing a phosphate or phosphate blend. Phosphates have been found to increase the solubility of salt-soluble proteins by increasing pH (Molins, 1991). While diphosphates generally have a high pH value and act directly on actomyosin bonds of meat proteins, their solubility is very low, which is one reason blends are more commonly used in meat products (Lampila & Godber, 2001). Longer-chain phosphates are not as effective at buffering compared to shorter-chain phosphates, which is one reason why long-chain forms are predominately used in blends as opposed to individually (Offer & Trinick, 1983). Short-chain phosphates are used for emulsion-type sausages for desired water holding capacity and stability (Feiner, 2006).

Phosphate works synergistically with salt (NaCl) to solubilize proteins. Salts on their own do not solubilize proteins, but have an effect on ionic strength and consequently extract myosin (Knight & Parsons, 1988; Ranken, 2000). Phosphates alone do not act on myosin, but can only remove the link between actin and myosin (Feiner,

2006). Therefore, NaCl and phosphate can work together to activate proteins, immobilize water and emulsify fat (Bendall, 1954; Fernandez-Lopez et al., 2004; Huffman et al., 1981; Lampila & Godber, 2001; Moore et al., 1976; Shults & Wierbicki, 1973; Zayas, 1997). An evaluation of 0.5% TSPP, STPP, SHMP, and two blends of STPP and SHMP, with and without NaCl, on beef Longissimus dorsi, biceps femoris, and semimembranosus concluded that TSP and NaCl yielded the greatest effect on pH rise in all three muscle types (Shults et al., 1972). Muscle fiber swelling was greatest and shrink lowest when pyrophosphates were used in combination with NaCl, as opposed to phosphate alone. After evaluation of 20 different combinations of NaCl and STPP, there was a synergistic effect on TBA values, thaw-drip loss, improved cooked color, aroma, flavor, eating texture, cook–cool loss, raw color, and improved juiciness of the restructured chops (Schwartz & Mandigo, 1976). When NaCl and STPP were added in combination to a comminuted beef product, cook-cool losses were decreased when compared to treatments with NaCl alone (Clarke et al., 1987). In pork and beef, small amounts of NaCl and pyrophosphate have shown effectiveness in extracting the A-band of beef myofibrils (Offer & Trinick, 1983; Voyle et al., 1984). In reduced-salt turkey frankfurters, SAPP, SHMP, or STPP improved emulsion stability and yields (Barbut, 1988). In a study where treatments consisted of NaCl and polyphosphate, emulsion capacity and emulsion stability were increased, cook-chill losses and shrink were decreased, and cook yield and WHC of buffalo meat patties were increased (Anjaneyulu et al., 1990).

Antioxidant and antimicrobial-like activity

Sequestering metal ions naturally found in meat, Ca^{2+}, Mg^{2+}, Fe^{2+}, and Fe^{3+} is an important function of phosphate in food applications (Lampila & Godber, 2001) and the binding of these could prevent or slow oxidative rancidity (Feiner, 2006; Fernandez-Lopez et al., 2004; Inklaar, 1967; Lampila & Godber, 2001; Molins, 1991). As early as 1958, phosphates STPP, TSPP, SPG, but not orthophosphates, were found to delay lipid oxidation in cooked meats and to act synergistically with ascorbic acid (Tims & Watts, 1958). Lipid oxidation was inhibited by di- or triphosphate and neutralized the oxidative effects of NaCl in frozen beef patties (Mikkelsen et al., 1991). STPP and SAMP in ground turkey inhibited the development of rancid flavor and worked with salt to decrease cook-cool losses and provide a juicier product (Craig et al., 1991). Phosphates' ability to sequester metal ions relates to their ability to prevent lipid oxidation and, therefore, rancidity in cooked cured meat products (Love & Pearson, 1974).

The ability of polyphosphates to prevent lipid oxidation decreases as their chain length increases, which was shown when TSPP and STPP exhibited some synergism on prevention of ground pork lipid oxidation compared to SPG, which exhibited little activity (Shahidi et al., 1986). Sodium pyrophosphate and sodium tripolyphosphate, minimally, lower fat oxidation and improve sensory characteristics in cooked pork (Shahidi et al., 1986). Pyro-, tripoly-, and hexametaphosphates, but not orthophosphates, are capable of preventing lipid oxidation (Sato & Hegarty, 1971). Phosphates work best as antioxidants and lipid oxidation preventers in combination with other antioxidant additives (Labuza, 1971). Sodium tripolyphosphate and sodium pyrophosphate, with or without encapsulation, are effective in reducing lipid oxidation in both raw and cooked

ground chicken and beef (Kilic et al., 2014). Sodium tripolyphosphate, alone and in combination with rosemary, resulted in significantly lower TBA values in cooked and stored ground beef when compared to spices with known antioxidant properties (Vasavada, Dwivedi, & Cornforth, 2006). Phosphates, acting with ascorbates, offer protection against browning and rancidity during storage. This antioxidant activity is due to lipid oxidation inhibition by the phosphates creating high pH conditions and sequestering metal catalysts (Aberle et al., 2012).

Sodium acid pyrophosphate, tetrasodium pyrophosphate, sodium tri-polyphosphate, sodium tetrapolyphosphate, sodium hexametaphosphate, and trisodium phosphate have all demonstrated some level of antimicrobial effect in meat (Branen et al., 2001). They can inhibit or slow the growth of gram positive bacteria (Bunkova et al., 2008; Dickson et al., 1994; Feiner, 2006; Lampila & Godber, 2001; Molins, 1991; Molins et al., 1985; Sofos, 1986; Tompkin, 1984). Working synergistically with pH, salt, and nitrite, SAPP, SHMP, or polyphosphates have shown increased effects in preventing growth of *Clostridium botulinum* (Ivey & Robach, 1978; Nelson et al., 1980; Roberts et al., 1981; Wagner et al., 1983). In poultry, trisodium phosphate at levels ranging from 8-12% showed decreased growth of *Salmonella* (Giese, 1992), *Salmonella Typhimurium* (Kim & Slavik, 1994; Kim et al., 1994; Wang, Li, Slavik, & Xiong, 1997) and *Campylobacter jejuni* (Slavik et al., 1994). In beef, TSP was also shown to decrease *E. coli* O157:H7 and *Salmonella Typhimurium* (Kim & Slavik, 1994; Pohlman et al., 2002).

Sensory Characteristics

Phosphates affect the sensory characteristics of processed meat, specifically flavor, texture, and color. The use of phosphate in meat products is limited to 0.5% of the finished product (USDA). However, phosphates are self-limiting due to the negative flavor impact they have when added in amounts higher than 0.3-0.5%, sometimes described as a soapy flavor (Chambers et al., 1992; Craig et al., 1991; Ranken, 2000). Phosphates decrease cooking loss and achieve increased firmness in low-sodium, high-fat ground meat patties (Ruusunen et al., 2005). Sodium tripolyphosphate decreases lightness due to the increased water holding capacity and stabilizes oxymyoglobin in ground pork (Fernandez-Lopez et al., 2004). Phosphate also influences cured meat color and flavor. Cured meat color is more stable and uniform because of the reduction of pigment oxidation by phosphates and less light being reflected by muscles with highly hydrated proteins caused by the increased water binding (Aberle et al., 2012). In restructured beef steaks, phosphate and salt addition improved texture and had no negative effects on color over time (Lamkey et al., 1986). Hams without phosphate had greater drip and cook losses and received lower palatability scores than hams containing phosphate (Vollmar & Melton, 1981). The function of phosphate to chelate iron has been observed to improve cured color development. SAPP acts as a cure accelerator, when added directly either in the form of pyrophosphates or from hydrolysis of STPP (Molins, 1991). Improved instrumental and sensory texture was observed in frankfurters formulated with SAPP, due to its acidity (Hargett et al., 1980). Addition of 0.5% STPP increased firmness in frankfurters compared to those formulated with nonmeat protein binders (Keeton et al., 1984).

Varying concentrations of STPP, SHMP, TSPP, and salt were injected into beef and color, quality, and sensory characteristics were observed (Baublits et al., 2005a, 2005b). STPP was the most effective in maintaining beef color (Baublits et al., 2005b) while STPP, SHMP, and TSPP were all effective in creating increased sensory tenderness and juiciness compared to salt alone; STPP or TSPP improved sensory characteristics without decreasing yields (Baublits et al., 2005a). Phosphates alone without the addition of NaCl did not improve sensory tenderness, juiciness, water holding, or cook yields (Baublits et al., 2006).

Clean Label

"Clean label" is a term that has been coined to represent foods that do not contain chemical sounding ingredients on their labels (Baines & Seal, 2012). "Clean label" foods have a simpler ingredient statement which is perceived as more consumer-friendly than those of traditional products. Most food has been processed in some way through a cooking or preservation processes. However, some consumers have are suspicious of processed food manufacturing. This skepticism has created a demand for more transparency of food companies by some consumer groups.

Food additives must meet three conditions to be added to meat products: they must be necessary for product quality, must not be a threat to human health, and must not mislead the consumer (Feiner, 2006). However, over the past twenty years, consumers have become overwhelmingly more concerned with the ingredients and processing procedures associated with their food. The main concern has been in relation to food additives and preservatives (Brewer & Prestat, 2002; Brewer & Russon, 1994; Rojas &

Brewer, 2008). Recently there has been an increase in consumer preference for clean labeling and for food ingredients and additives with common names, which are perceived to be healthier than their synthetic counterparts (Hillmann, 2006; Joppen, 2006). Not only is there a growing preference for natural ingredients, but for sustainable agriculture and environmentally friendly production practices as well (Berger, 2009). Consumer perceptions of which ingredients and food products are natural do not always coincide with manufacturer guidelines. There is no consensus in this area among consumers, making what is perceived as "natural" or "clean label" ingredients inconsistent (Williams et al., 2009). It is estimated that consumers will pay a premium price for organic fresh produce for their increased antioxidant content and perceived health-promoting benefits (Defrancesco, 2008). Less processing of food products is also associated with a more natural and clean label product among consumers (Evans et al., 2010).

Phosphate Alternatives

With the push for clean labels, it is essential for the meat industry to find alternatives to phosphates for their products without losing the important functional properties they provide. Some of that functionality can be replicated by modified food starches, fibers, and different processing techniques. Ruusunen and others (2003b) researched different levels of modified tapioca starch, sodium citrate, and wheat bran as alternatives to phosphates in a low-salt frankfurter. Modified tapioca starch performed well in decreasing frying loss and increasing firmness of the product in combination with low salt. Sodium citrate also was acceptable in decreasing frying loss, but overall the modified tapioca starch performed the best in comparison to a no-phosphate, low-salt

frankfurter (Ruusunen, et al., 2003b). Strip loins injected with acid-solubilized proteins performed comparably to phosphate injected loins for overall acceptability and discoloration; however, phosphate-injected loins outperformed solubilized-protein injected loins in lean color, fat color, aerobic plate count, lipid oxidation, percent purge, cook yield, and shear force (Vann & Dewitt, 2007). In beef rolls, NaOH and salt, in combination, had higher cohesiveness and bind strength than the controls and were comparable to sodium tripolyphosphate controls for overall acceptability (Moiseev, 1997). Chicken marinated with sodium bicarbonate in a salt solution had improved water holding capacity, pH, cooking yield, and sensory attributes similar to tetrasodium pyrophosphate (Sen et al., 2005). In frankfurters that evaluated porcine plasma as an alternative to polyphosphate and caseinate, the plasma treatment did not have a negative effect on composition, water holding capacity, cooking losses, instrumental texture, or sensory texture. While there were off-flavors and odor associated with the plasma treatments, these could be masked with different spices and seasonings (Hurtado et al., 2012). Sodium bicarbonate and potassium lactate used in a poultry marinade resulted in higher marinade pick-up, lower purge loss, and higher cook yield than no-phosphate added chicken products (Lee et al., 2015).

Citrus Fiber

Dietary fibers have been described as "the remnants of plant cells resistant to digestion by human enzymes…whose components are hemicellulose, cellulose, pectin, lignin, oligosaccharides, gums, and waxes" (Trowell et al., 1985). Fibers have been added to meat products to increase cook yields and improve texture (Cofrades et al., 2000) and

have been studied alone or in combination with other ingredients in reduced-fat meat products (Chang & Carpenter, 1997; Claus & Hunt, 1991; Desmond & Troy, 2003; Grigelmo-Miguel & Martin-Belloso, 1998; Mansour & Khalil, 1999).

Oat bran was added to fat-free frankfurters and low-fat bologna and resulted in products with greater yields, reduced red color, and decreased purge (Steenblock et al., 2001). In another study, oat bran and oat fiber were reported to provide the mouthfeel of fat in reduced-fat dry fermented sausages (Garcia et al., 2002). Inner pea fiber was added at different amounts to low-fat ground beef and improved tenderness and cooking yields with no detrimental effects on juiciness or flavor (Anderson & Berry, 2000). In another study, citrus fiber was added to bologna to observe its effect on quality and storage characteristics. There was increased nutritional fiber content, decreased residual nitrite levels, and only TBA and redness were influenced by light storage conditions, but these effects were minimized by citrus fiber. Citrus fiber treatments were harder, less springy, and less chewy (Fernandez-Lopez, Fernandez-Gines, et al., 2004). In low-fat frankfurters, citrus fiber exhibited improved water binding and decreased cook losses (Song et al., 2016). The addition of citrus fiber to reduced-fat, Lyon style sausages and liver sausages offered the potential to increase consumer acceptability of a lower-fat product when compared to full-fat controls (Tomaschunas et al., 2013). In reduced-fat, dry-fermented sausages, orange fiber had the best results compared to other cereal and fruit fibers with sensory scores similar to those of conventional sausages (Garcia et al., 2002; Tomaschunas et al., 2013).

Recently citrus fiber has gained some attention as a potential phosphate alternative in processed meat products. As a byproduct from the juicing industry that

would otherwise go unused, citrus fiber offers promising advantages in the creation of a phosphate-free meat product. Citrus fiber is obtained from orange (*Citrus sinensis*) pulp or juice vesicles and has a high internal surface area, water holding capacity, and apparent viscosity, making it fundamentally similar to conventional phosphates (Lundberg, 2005). In a recent study, pectin and cellulose were reported to be the most predominant polysaccharides in citrus fiber (Lundberg et al., 2014). Pectin's inherent viscous properties and its predominance in citrus fiber contributes to citrus fiber's functionality. Hemicellulose, another important component of citrus fiber, has viscous properties when hydrated. The properties and structure of hemicellulose, due in part to its branched form, contribute to citrus fiber's water holding capacity and viscosity.

Pectin found in citrus fiber is primarily made of galacturonic acid, which is acidic, or negatively charged, and contributes to citrus fibers' ability to form a gel. Arabinose, the second most abundant monosaccharide found in citrus fiber, is found in the branched backbone of galacturonic acid. While arabinose is not charged, its presence in pectin contributes largely to the cross-linking and gelling abilities of citrus fiber. Citrus fiber is heat stable; its cellulose and insoluble portions help to stabilize its apparent viscosity when temperature rises, as compared to purified hydrocolloids (Lundberg et al., 2014). Water absorption occurs not just at the surface of the citrus fiber, but also gets absorbed into the fiber structure and results in swelling. The fibers form a "gel-like" network when they are hydrated with water and it is this functionality that shows promising results to contribute to water retention and texture in processed meat (Lundberg et al., 2014).

Summary

Phosphates are important functional ingredients in processed meats. They are traditionally used because of their ability to increase cook yields, juiciness, and water holding capacity. The complete elimination of phosphates from processed meat is possible, but makes the manufacturing procedures difficult (Toldra et al., 2015). However, given some consumers increasing concern about their food, there has been a push for "clean labels." Some consumers are skeptical of "chemical-sounding" ingredients being added to their foods, even if they are proven safe and serve a functional purpose. For this reason, the meat industry has been lead to consider alternatives to phosphates for application in meat and poultry products. Because of their composition of, fibers function in maintaining water- and fat-binding in meat and poultry products, as well as in providing sensory characteristics in reduced-fat products similar to those of full-fat controls. Most research has been conducted on the partial replacement of fat in meat products with different cereal, fruit, or vegetable fibers, but little or no research has been published on the use of fibers as possible alternatives to phosphate use. Citrus fiber could be a unique approach to the "clean label" conundrum in processed meat and poultry products and function as an alternative to phosphates.

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CHAPTER 3. EVALUATION OF CITRUS FIBER AS A NATURAL ALTERNATIVE TO SODIUM TRIPOLYPHOSPHATE IN UNCURED ALL-PORK BOLOGNA

A paper to be submitted to Meat Science

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Abstract

The effects of sodium tripolyphosphate replacement with citrus fiber on color, texture, lipid oxidation, and sensory characteristics of an uncured all-pork bologna during storage (0–1˚C) was studied. The bologna was assigned one of five treatments: sodium tripolyphosphate control (0.50%), no-sodium-tripolyphosphate control, or various citrus fiber amounts (0.50%, 0.75%, 1.00%), and each replicated three times. Proximate analysis and pH were measured once and all other analytical parameters were measured at regular intervals throughout a 98-d shelf life. Citrus fiber treatments resulted in bologna with acceptable technological parameters, as indicated by similar cook/chill yields and emulsion stability compared to the sodium tripolyphosphate control. The results showed the replacement of sodium tripolyphosphate with citrus fiber did not significantly alter most physical or chemical characteristics of the bologna during refrigerated storage, but some treatment-dependent effects were observed for pH, color, instrumental texture, sensory texture, and sensory moistness.

Key words: bologna, citrus fiber, clean label, phosphate replacement, sodium tripolyphosphate, uncured

Introduction

In the last decade, consumers have become more skeptical of the addition of food additives in further processed products. Some food additives are perceived by consumers as "unhealthy," "unnatural," or "unsafe." While all additives used in manufacture follow USDA regulations, consumers have demanded the removal of conventional food additives for the creation of "clean label" products. "Clean label" is a term given to products that do not contain any chemical sounding ingredients on their label (Baines & Seal, 2012). This has driven the food industry to research natural alternatives to conventional ingredients to meet the needs of this new market and to reformulate their products. The meat industry has the reputation of being perceived as "unhealthy" due to high sodium content and addition of potentially "unsafe" ingredients in processed meat products. To combat this and comply with consumer demands, focus has been on replacing sodium nitrite/nitrate, sodium erythorbate/ascorbate, and sodium phosphates. While it is well established that celery juice powder and cherry powder serve as successful alternatives to sodium nitrite/nitrate and sodium erythorbate/ascorbate (Sebranek & Bacus, 2007), respectively, little published research has been conducted on successful natural alternatives to sodium phosphate.

Phosphates serve as a functional food additive in processed meat products for water retention, texture, and sensory properties. The complete elimination of phosphate is not realistic for successful production of an acceptable processed meat product, particularly with reduced salt and fat content. The use of various binders and starches as functional alternatives to phosphate have been researched (Lee et al., 2015; Ruusunen et al., 2003; Sen et al., 2005). However, there are challenges to using alternative sources to

replace phosphate. Those include maintaining improved water holding capacity, texture, buffering ability, and sensory properties given to meat products by utilizing phosphate, as well as ease of manufacture. Fiber shows potential as a functional alternative to phosphate due to its high surface area contributing to increased water retention and has been added to meat products to increase yield and improve texture. This research was initiated to test the hypothesis that replacing sodium tripolyphosphate with citrus fiber would not introduce negative physical, chemical, or sensory characteristics to uncured all-pork bologna throughout a 98-d shelf life.

Materials and Methods

Experimental Design

The experiment consisted of five different treatments of all-pork bologna, replicated three times. The five treatments included a positive 0.50% sodium tripolyphosphate control (STPP), a negative 0% sodium tripolyphosphate control (No STPP), and three levels of citrus fiber (0.50% CF, 0.75% CF, 1.00% CF). All replications were manufactured at the Iowa State University (ISU) Meat Laboratory, Ames, IA, under USDA inspection.

Manufacture Materials

Spice blends were provided by A.C. Legg, Inc. (Calera, AL, U.S.A), both the cultured celery juice powder (VegStable 506) and cherry powder (VegStable 515) used as natural alternatives to sodium nitrite and sodium erythorbate, respectively, were provided by Florida Food Products, Inc. (Eustis, FL, U.S.A.), dried vinegar powder, Verdad

Powder N6, was provided by Corbion (Lenexa, KS, U.S.A.), sodium tripolyphosphate was obtained from Innophos (Cranbury, NJ, U.S.A.), and the citrus fiber (Citri-Fi 100) was provided by FiberStar (River Falls, WI, U.S.A.).

Product Manufacture

Fresh boneless pork cushions and pork back fat were obtained from a commercial packing plant, transported to the ISU Meats Laboratory, and frozen until three days prior to the day of production. Meat was thawed at 4.4°C for two days and moved into a cooler at 0–1°C for 1–2 days until needed. All treatments were manufactured separately, but following the same protocol, and manufacturing order of treatments was randomized prior to production. Formulations are listed in Table 1. Boneless pork cushion and pork back fat were ground through a 12.7-mm plate (The Biro Manufacturing Co., Marblehead, OH, U.S.A). Ground cushion, salt, spice blend, VegStable 506, VegStable 515, Verdad Powder N6, sodium tripolyphosphate or Citri-Fi 100, and a water/ice mixture were added to a vacuum bowl chopper (KILIA-Fleischerei-und Spezial-Maschinen-Fabrik GmbH, Neumünster, Germany) until a temperature of 4.4°C was reached. The ground back fat was then added and chopping continued until a temperature of 13°C was reached. The resulting batter was immediately loaded into a vacuum stuffer (Handtmann, Albert Hantmann Maschinenfabrik GmbH & Co. KG, Riss, Germany) and manually stuffed into 20.3 x 76.2 cm pre-stuck red bologna casings. Each bologna log was weighed, then placed on a smoke truck, moved into an Alkar oven (DEC International, Inc., Lodi, WI, U.S.A.), and thermally processed according to the schedule shown in Table 2. After thermal processing was complete, the product was cooled at 0–

1°C overnight. Logs were reweighed for cook and chill yields, then casings were removed, and logs were manually sliced (Bizerba, Piscataway, NJ, U.S.A) into 14 g slices, 1 mm in thickness. Four slices of bologna per bag were paced in high barrier bags (oxygen transmission rate of 3–6cm^2/m^2/24-h at 23°C m^2, 0% RH and a water vapor transmission rate of 0.5−0.6 g/645cm2/24-h at 37.78°C, 100% RH, Cryovac, Sealed Air Corporation, Duncan, SC, U.S.A.) and vacuum sealed (Ultravac UV 2100 packaging machine, Koch, Kansas City, MO, U.S.A). All treatments were subsequently stored at 0–1°C for the remainder of the study. Samples were stored either under retail display simulation with fluorescent lights or inside cardboard boxes with no light exposure until day of analysis. The day of packaging was designated as Day 0.

Emulsion stability

Emulsion stability was conducted following the (Rongey, 1965). Approximately 25 g of raw sample was placed into the Wierbicki tubes (Wierbicki, 1957). The filled tubes were placed in a water bath at 72°C for 30 min followed by cooling for 3 min at room temperature. Cooled samples were then centrifuged at 150 rpm for 5 min to force the separation of water and fat from the cooked sample, after which tubes were removed and the amount of fat (top layer) and water (bottom layer) read and calculated as follows:

Eq. 1. $\%\ \text{Water Separation} = \frac{\text{mL water}}{\text{sample weight}}\ \text{x}\ 100$

Eq. 2. $\%\ \text{Fat Separation} = \frac{\text{mL fat}}{\text{sample weight}}\ \text{x}\ 100$

Eq. 3. $\%\ \text{Total Liquid Separation} = \%\ \text{water separation} + \%\ \text{fat separation}$

Proximate Analysis

Fat, moisture, and protein contents were measured in duplicate for each treatment. Fat content was measured by AOAC method 960.39 (AOAC, 2005b) and moisture content was measured by AOAC method 950.46 (AOAC, 2005c). Approximately 5 g of sample was weighed into cotton thimbles. Thimbles were dried for 18-h in an oven at 100−102°C (VWR 1370GM., Sheldon Manufacturing Inc., Cornelius, OR, U.S.A). After drying, thimbles were placed in a desiccator to cool until they reached room temperature. Cooled thimbles were reweighed and percent moisture was determined by using the following equation:

Eq. 4. $$\%\ \text{Moisture} = \frac{\text{dried weight} - \text{extracted weight}}{\text{sample weight}} \text{ x } 100$$

After weights were recorded, thimbles were then extracted with hexane for 7 h using a Soxhlet multi-unit extraction-heating unit (Lab-Line Instruments, Inc., Melrose Park, IL, U.S.A). After 7 h, thimbles were reweighed and percent fat calculated using the following equation:

Eq. 5. $$\%\ \text{Fat} = \frac{\text{dried weight} - \text{extracted weight}}{\text{sample weight}} \text{ x } 100$$

Protein content was measured in accordance with AOAC method 992.15 (AOAC, 2005a) using a TruMac N combustion unit (Leco Corporation, St. Joseph, MI, U.S.A). Percent protein was then calculated by multiplying nitrogen content by 6.25.

pH

For pH measurement, 10 g of sample was ground and mixed with 90 mL distilled water in a 150-mL beaker and stirred vigorously for 60 s. The mixture was filtered through coned 11-µm–filter paper (Whatman Grade 1, GE Healthcare Life Sciences,

Pittsburgh, P.A., U.S.A.) so that liquid formed in the bottom of the cone allowed for insertion of the pH probe. The pH was measured in duplicate using a Mettler Toledo SevenMulti pH meter (Columbus, O.H., U.S.A.).

TBA Analysis

Oxidative rancidity was measured on days 0, 14, 42, 70, and 98 by the 2-thiobarbituric-acid procedure, as modified by (Zipster & Watts, 1962). Approximately 10 g of product sample was weighed into a round-bottom flask, attached to a distillation apparatus, and boiled in combination with 97.5 mL of distilled water, 1 mL sulfanilamide solution, and 2 mL hydrogen chloride solution, until 50 mL of distillate was collected. Five mL of TBA solution was added to 5 mL of distillate and heated in a 70°C water bath for 35 min. After samples cooled for 10 min, a spectrophotometer at 532 nm (Model 4320940, DU 640, Beckman, Fullerton, CA, U.S.A.) was used to measure absorbance and the reading multiplied by a factor of 7.8 to convert to mg malondialdehyde per 1,000 g of sample. Analysis was performed in duplicate and results were averaged.

Instrumental Color Analysis

Color was measured on days 0, 14, 42, 70, and 98 on a HunterLab LabScan instrument (Hunter Associated Laboratories, Inc., Reston, VA, U.S.A.) using illuminant D65 (daylight at 6500K), 10° observer angle, and 2.54-cm aperture. Color values were reported as L (lightness), a (redness), and b (yellowness). Saran wrap was placed over the calibration tiles to account for the packaging material of retail display samples since these samples were kept in packaging during color measurements. Measurements were taken

on the surface of all samples at three different locations for a total of three random surface measurements collected for each of the retail display and no light exposure samples.

Texture Profile Analysis

Texture profile analysis (TPA) was performed in triplicate on days 0, 14, 42, 70, and 98 using a TA-XT2i Texture Analyser (Stable Micro Systems, Surrey, UK). All instrumental texture analyses were conducted on chilled samples (0–1°C). On days 0, 14, 42, 70, and 98, unsliced bologna samples were cored (2.54 cm length, 2.54 cm diameter) and subjected to a simplified TPA test. The samples were compressed to 35% of their original height with a 2-bite sequence at a trigger force of 5.0 g and test speed of 5.00 mm/sec. The texture profile parameters hardness, cohesiveness, springiness, gumminess, and chewiness, were determined as described by (Bourne, 1978).

Sensory Analysis

Sensory analysis was conducted on days 14, 42, 70, and 98 using a ten-member trained sensory panel. The panel was comprised of students, faculty, and staff of Iowa State University. Two separate training sessions were held before evaluation. Every session, a three-digit code was randomly assigned to each treatment sample. Panelists recorded their evaluation on a 15-cm line scale and data were collected using Compusense five (Release 5.6) sensory evaluation software. Panelists evaluated “cured aroma,” “texture,” “moistness,” “cured flavor,” “off-flavor,” and “color.” Sample slices had the rind removed, were cut into eight wedges, the pieces were placed in a large bowl, and mixed to ensure each panelist received a random sampling. Four wedges were placed

in a cup with a lid and held under refrigeration until evaluation, approximately 15 min. In addition to the pieces used for evaluation, an intact slice was evaluated on white butcher paper for visual color evaluation by the panel.

Statistical Analysis

The study was replicated three times. Data were analyzed statistically using the PROC MIXED procedure of the Statistical Analysis System (SASv9.4, SAS Institute, Cary, NC, USA). Differences between treatments and within treatments over time were determined using the Tukey-Kramer pairwise comparison method with significance at $P < 0.05$.

Results & Discussion

Proximate analysis, pH, emulsion stability, and cook/chill yields

Proximate composition of product samples is shown in Table 3. There was a significant difference in fat content between STPP and 1.00% CF. This was not surprising since treatments were formulated to the same protein and moisture targets, and, therefore, slightly different fat targets to account for the varying levels of sodium tripolyphosphate or citrus fiber. Generally, pH decreased with the removal of phosphate, but the only significant difference ($P < 0.05$) in this study was the 0.50% CF treatment which was lower than the STPP control.

Emulsion stability is represented by the weight remaining after the raw bologna batter had been cooked; a higher emulsion stability indicates a more stable emulsion. The purge that separated during cooking consisted of fat and moisture. There were no significant differences ($P > 0.05$) between fat and moisture loss, but the STPP control had a significantly higher ($P < 0.05$) overall emulsion stability than the 0.50% CF and 1.00% CF treatments.

The product was formulated anticipating a cook/chill yield of 96%, which turned out to be close to the actual values for all treatments, and did not differ significantly for each treatment ($P > 0.05$). These results agree with Pietrasik & Janz (2010) who tested various fiber additions and concentrations in low-fat bologna. Yields are important to meat processors because a poor yield can lead to large economic losses.

Instrumental color

Tables 4–5 show instrumental color evaluation for bologna samples stored under retail display lights and in the dark. There was no significant ($P > 0.05$) day x treatment interactions for L, a, or L RD values. There was a significant treatment effect ($P < 0.05$) and a day effect ($P < 0.05$) for L values. There was no significant treatment effect ($P > 0.05$) on a values, but there was a day effect ($P < 0.05$).

Hunter b values had a significant ($P < 0.05$) treatment effect, day effect, and day x treatment effect. Hunter L RD values did not differ significantly ($P > 0.05$) in treatment or day effect. These results agree with Beggs, Bowers, & Brown (1997) where the addition of pea fiber affected only b* values and not L* or a* values in turkey frankfurters. There was no treatment effect ($P > 0.05$) on a RD values, but there was a day effect ($P < 0.05$) and a day x treatment effect ($P < 0.05$). Hunter b RD values had a significant ($P < 0.05$) treatment effect, day effect, and day x treatment effect. While significant, the magnitude of difference is slight and would be considered to be of little practical importance since there were no visual sensory changes, which was confirmed by sensory evaluation in this study.

TBARS

Lipid oxidation is an important determinant of product shelf life. There were no significant differences ($P > 0.05$) for STPP, No STPP, 0.50% CF, 0.75%, and 1.00% CF treatments throughout the 98-day shelf life. TBA values did not exceed 0.2 mg/kg malondialdehyde throughout shelf life, which is well below the level of concern for a

product of this type (Ockerman, 1985). Citrus fiber, therefore, does not promote lipid oxidation in this type of product.

Texture Profile Analysis

Table 6 shows TPA values. There was a significant difference ($P < 0.05$) for treatment, day, and day x treatment. Hardness values were significantly lower ($P < 0.05$) at day 0 than for the rest of shelf life period. Over time, STPP and No STPP were softer than the 1.00% CF ($P < 0.05$). Other studies have also reported that the addition of different fibers resulted in a harder product (Chang & Carpenter, 1997; Claus & Hunt, 1991; Cofrades et al., 2000).

Resilience, cohesion, and springiness were not significantly different ($P > 0.05$) for day effect or day x treatment effect, but there was a significant treatment effect ($P < 0.05$). Resilience, a measure of the force exerted by the sample as it tries to regain its original shape following first compression, was higher in the STPP control than the CF treatments. The STPP control was more cohesive than all the other treatments. Cohesiveness is the ratio of the area of the second compression to the area of the first compression. This differs from other studies where the addition of fiber resulted in greater cohesiveness (Beggs et al., 1997; Pietrasik & Janz, 2010; Shand, 2000). Springiness is how well the sample springs back after the first compression between strokes. There were significant differences ($P < 0.05$) between the STPP control and the 0.50% CF treatment for springiness. There was no treatment or day x treatment effect for gumminess, defined as cohesiveness x hardness, or chewiness, defined as gumminess x

springiness. Gumminess and chewiness were lower ($P < 0.05$) on day 0 than at any other time point in shelf-life.

Sensory

Sensory results are reported in Figure 2. There were no significant differences ($P > 0.05$) across treatment or shelf life for bologna aroma. There was a treatment and day x treatment effect ($P < 0.05$) on texture. STPP was the firmest, while the 0.50% CF treatment was the softest. Moistness differed significantly ($P < 0.05$) across treatment, day, and day x treatment. STPP and No STPP were moister than the citrus fiber treatments. This differs from a study by Choi et al. (2008), who reported higher moistness in 2% rice bran fiber in ground pork treatments. In a study where oat and wheat fibers were added to chicken patties, the fiber treatments were significantly lower in sensory juiciness than the control (Talukder & Sharma, 2010). Bologna flavor did not differ ($P > 0.05$) across treatments, but was stronger on day 14 ($P < 0.05$) than on subsequent time points. There were no significant differences ($P < 0.05$) across treatment or throughout shelf life for off-flavor or lightness.

Conclusions

The sodium tripolyphosphate control, no-sodium-tripolyphosphate control, and citrus fiber treatments (0.50%, 0.75%, and 1.00%) all maintained acceptable quality throughout a 98-day shelf-life. These results suggest that citrus fiber has the potential to replace some of the functional properties of sodium tripolyphosphate in uncured all-pork bologna. While results indicate that citrus fiber addition in replacement of sodium

tripolyphosphate produced an acceptable processed meat product, which, in most attributes, was similar to the control containing sodium tripolyphosphate, the fact that the negative control did not differ from the positive control, as was expected, suggests that the formulations used in this study were too robust, with high quality protein and fat sources, and unable to detect any possible differences. Further research should use a less robust formulation to adequately assess the efficacy of citrus fiber as a full or partial sodium tripolyphosphate replacer.

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Table 1. Uncured all-pork bologna formulations, 100% batch basis

	STPP	No STPP	0.50% CF	0.75% CF	1.00% CF
Ham Cushion	46.08	46.49	45.95	45.68	45.41
Pork Back-fat	30.35	30.62	30.27	30.09	29.91
Salt	1.53	1.54	1.52	1.52	1.51
Spice Blend	1.64	1.67	1.64	1.62	1.60
Citrus Fiber	0.00	0.00	0.50	0.75	1.00
Celery Juice Powder	0.34	0.35	0.34	0.34	0.34
Cherry Powder	0.31	0.31	0.30	0.30	0.30
Vinegar Powder	0.25	0.25	0.25	0.25	0.25
Water/Ice	19.11	18.76	19.22	19.45	19.67
STPP	0.38	0.00	0.00	0.00	0.00

Table 2. Thermal processing for bologna treatments

Step	Step Time (min)	Dry Bulb Temperature (°C)	Wet Bulb Temperature (°C)	Relative Humidity %	Main Blower	Exhaust Damper
Cook	1:00	37.78	31.67	65	8	Auto
Cook	0:45	54.44	40	42	8	Closed
Cook	0:45	65.56	46.11	34	8	Closed
Smoke Cook	1:00	80	65.56	52	6	Auto
Cook	0:01	80	70	64	10	Auto
Cook	0:01	85	80	81	10	Closed
Cold Shower	0:20	10	-17.78	0	0	Auto

Table 3. Means for effect of treatment on proximate composition, pH, emulsion stability, and cook/chill yield

	Fat %	Moisture %	Protein %	pH	Emulsion Stability (%)	Yield (%)
STPP	26.11[a]	56.54[a]	12.62[a]	6.38[a]	99.13[b]	95.60[a]
No STPP	25.79[ab]	56.87[a]	12.55[a]	6.19[ab]	98.47[ab]	94.92[a]
0.50% CF	25.37[ab]	57.38[a]	12.45[a]	5.83[b]	96.70[a]	95.43[a]
0.75% CF	24.86[ab]	57.01[a]	12.49[a]	6.06[ab]	98.12[ab]	95.65[a]
1.00% CF	24.63[b]	57.59[a]	12.57[a]	6.00[ab]	96.53[a]	95.60[a]
SEM	0.28	0.32	0.08	0.10	0.43	<0.01

[a-b] Means in the same column with different letters are significantly different ($P < 0.05$)

Table 4. Means for effect of treatment on Hunter L, a, b values of product stored under retail display lights or in the dark

	Dark			Retail Display		
	L	a	b	L	a	b
STPP	72.14[ab]	7.16[a]	13.45[c]	73.03[a]	7.29[a]	13.30[b]
No STPP	72.63[a]	6.99[a]	13.40[c]	73.72[a]	7.19[a]	13.36[b]
0.50% CF	71.69[b]	7.09[a]	13.69[b]	72.83[a]	7.34[a]	13.81[a]
0.75% CF	72.21[ab]	6.95[a]	13.75[ab]	73.11[a]	7.22[a]	13.84[a]
1.00% CF	71.83[ab]	7.02[a]	13.90[a]	72.93[a]	7.03[a]	14.13[a]
SEM	0.22	0.06	0.04	0.29	0.09	0.09

[a-c] Means in the same column with different letters are significantly different ($P < 0.05$)

Table 5. Means for effect of day on Hunter L, a, b values of product stored under retail display lights or in the dark

	Dark			Retail Display		
	L	a	b	L	a	b
0	71.77[ab]	7.04[ab]	13.56[b]	72.52[a]	7.37[a]	14.37[a]
14	71.82[ab]	7.05[ab]	13.56[b]	73.36[a]	7.46[a]	13.55[b]
42	71.70[b]	7.26[a]	13.83[a]	73.48[a]	7.39[a]	13.54[b]
70	72.63[a]	6.92[b]	13.53[b]	73.09[a]	7.16[a]	13.42[b]
98	72.57[ab]	6.92[b]	13.69[ab]	73.17[a]	6.69[b]	13.55[b]
SEM	0.22	0.06	0.04	0.29	0.09	0.09

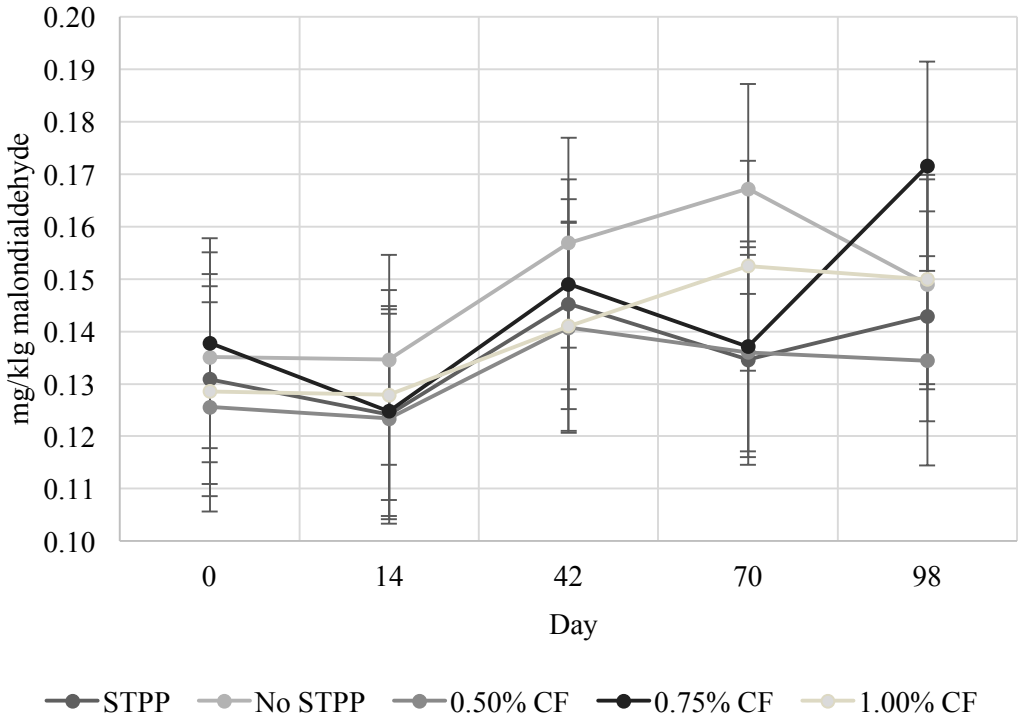
[a-c] Means in the same column with different letters are significantly different ($P < 0.05$)

Table 6. Means for effect of treatment on instrumental texture of uncured all-pork bologna

	Hard-ness (g)	Resilience (%)	Cohesive-ness	Springi-ness (%)	Gummi-ness	Chewi-ness
STPP	4182.31[b]	38.91[a]	0.72[a]	86.66[a]	3026.79[a]	2639.20[a]
No STPP	4233.85[b]	35.20[ab]	0.65[ab]	84.99[ab]	2789.75[a]	2380.16[a]
0.50% CF	4780.14[ab]	33.47[b]	0.62[b]	83.98[b]	2942.00[a]	2471.73[a]
0.75% CF	4520.18[ab]	34.06[b]	0.67[ab]	85.17[ab]	3031.27[a]	2581.25[a]
1.00% CF	5336.26[a]	34.27[b]	0.64[b]	84.67[ab]	3450.17[a]	2927.80[a]
SEM	223.82	1.02	0.02	0.57	168.94	151.08

[a-b] Means in the same column with different letters are significantly different ($P < 0.05$)

Figure 1. Means for effect treatment and day on TBARS of all-pork uncured bologna



Error bars represent S.E.M. averaged across days. S.E.M. = 0.02

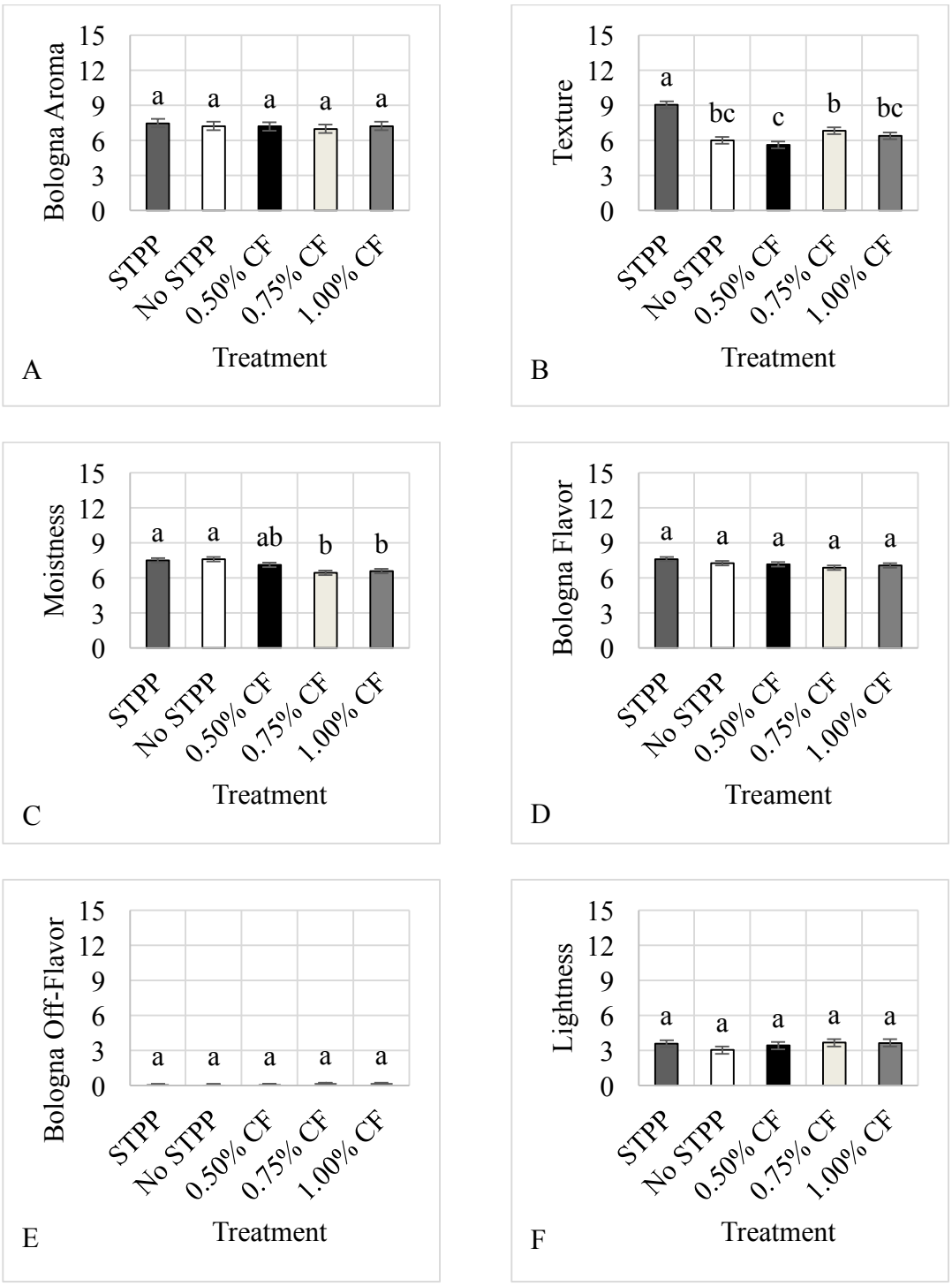


Figure 2. Influence of STPP replacement on the sensory evaluation of bologna aroma (A), texture (B), moistness (C), bologna flavor (D), off-flavor (E), and lightness (F) of uncured all-pork bologna. Means in the same column with different letters are significantly different ($P < 0.05$). Error bars represent S.E.M. averaged across days. Bologna aroma S.E.M. = 0.36. Texture S.E.M. = 0.29. Moistness S.E.M. = 0.19. Bologna flavor S.E.M. = 0.19. Off-flavor S.E.M. = 0.04. Lightness S.E.M. = 0.30.

CHAPTER 4. EVALUATION OF CITRUS FIBER AS A NATURAL ALTERNATIVE TO SODIUM TRIPOLYPHOSPHATE IN OVEN-ROASTED TURKEY BREAST

A paper to be submitted to Poultry Science
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Abstract

The effects of citrus fiber as a sodium tripolyphosphate replacer on color, texture, lipid oxidation, and sensory characteristics of an oven-roasted turkey breast during storage (0–1˚C) was studied. The oven-roasted turkey was assigned one of four treatments: sodium tripolyphosphate control (0.50%), no-sodium-tripolyphosphate control, or citrus fiber treatment (0.25%, 0.50%), and replicated three times. Proximate analysis and pH were measured once and all other analytical parameters were measured at regular intervals throughout 84-d shelf life. Citrus fiber treatments resulted in turkey with acceptable technological parameters, as indicated by similar cook/chill yields compared to the sodium tripolyphosphate control. The results showed the replacement of sodium tripolyphosphate with citrus fiber did not significantly alter most physical, chemical, or sensory characteristics of oven-roasted turkey breast during refrigerated storage.

Keywords: citrus fiber, clean label, phosphate replacement, sodium tripolyphosphate, turkey breast

Introduction

In the last decade, the growing skepticism from consumers regarding food additives has created the demand and market for "clean label" products. "Clean label" is a term given to products that do not contain any chemical sounding ingredients on their label (Baines and Seal, 2012). While all food additives are used in processing to provide specific functionality and following USDA regulations, consumers perceive many of them as "unnatural," "unhealthy," or "unsafe." This has caused the food industry to search for natural alternatives to conventional ingredients that possess the same functional properties desired. The meat industry has the reputation of being "unhealthy" due to sodium content and ingredients utilized in processed meats are perceived as potentially "unsafe." Some of the ingredients that have the most criticism for their presence in processed meat products are sodium nitrite/nitrate, sodium erythorbate/ascorbate, and phosphates. It is well established that celery juice powder and cherry powder serve as natural alternative to sodium nitrite/nitrate and sodium erythorbate/ascorbate, respectively, (Sebranek and Bacus, 2007), but there has been little published research on natural alternatives to phosphate in processed meats.

Phosphates serve as a functional food additive in processed meat and poultry products for their water retention, texture, and sensory properties. Complete removal of phosphate is not probable when trying to successfully produce an acceptable processed meat or poultry product, considering parallel effects to reduce salt and fat content. The use of various binders and starches as functional alternatives to phosphate have been researched (Lee, et al., 2015; Sen, et al., 2005). However, there are challenges to using alternative sources to replace phosphate. Those include maintaining the improved water

holding capacity, texture, buffering ability, and sensory properties given to meat and poultry products by utilizing phosphate. Different dietary fibers show potential as functional alternatives to phosphate due to their high surface area, contributing to increased water retention, and have been added to meat and poultry products to increase yield and improve texture. This research was initiated to test the hypothesis that replacing sodium tripolyphosphate with citrus fiber would not introduce negative physical, chemical, or sensory characteristics to oven-roasted turkey throughout an 84-d shelf life.

Materials and Methods

Experimental Design

The experiment consisted of four different treatments of oven-roasted turkey breast, replicated three times. The four treatments included a positive 0.50% sodium tripolyphosphate control (STPP), a negative sodium tripolyphosphate control (No STPP), and two levels of citrus fiber (0.25% CF and 0.50% CF). All replications were manufactured at the Iowa State University (ISU) Meat Laboratory, Ames, I.A., under USDA inspection.

Manufacture Materials

Sodium nitrite and sodium erythorbate were provided by A.C. Legg, Inc. (Calera, AL, U.S.A), the dried vinegar powder, Verdad Powder N6, was provided by Corbion (Lenexa, KS, U.S.A.), sodium tripolyphosphate was obtained from Innophos (Cranbury, NJ, U.S.A.), and the citrus fiber (Citri-Fi 100M40) was provided by FiberStar (River Falls, WI, U.S.A.).

Product Manufacture

Frozen turkey breasts were obtained from a commercial packing plant and held frozen until production. Meat was thawed at 4.4°C for two days and moved into a cooler at 0–1°C for 1–2 days until needed. Brines were prepared following formulations in Table 1 by adding ingredients in the following order: sodium tripolyphosphate (when applicable), sodium erythorbate, citrus fiber (when applicable), salt, dextrose, Verdad Powder N6, and sodium nitrite. Manufacture order of treatments was randomized prior to production. Turkey breasts were injected to 20% of their green weight (approximately 25 lbs) (Günther Maschinenbau GmbH, Dieburg, Germany) and tumbled for 2 h at approximately 16 RPM (Daniels Food Equip. Inc., Parkers Prairie, MN, U.S.A.). The turkey breasts were then stuffed, using a vacuum stuffer (Handtmann, Albert Hantmann Maschinenfabrik GmbH & Co. KG, Riss, Germany) into clear pre-stuck 20.3 x 101.6 cm fibrous casings. Each turkey log was weighed, placed on a smoke truck, moved into an Alkar oven (DEC International, Inc., Lodi, WI, U.S.A.), and thermally processed according to the schedule shown in Table 2. After thermal processing was complete, the products were cooled at 0–1°C overnight. Logs were reweighed for cook and chill yields, then casings were removed, and logs were manually sliced (Bizerba, Piscataway, NJ, U.S.A) into 14 g slices, 1 mm in thickness. Four slices of turkey per bag were placed in high barrier bags (oxygen transmission rate of 3–6cm^2/m^2/24-h at 23°C m^2, 0% RH and a water vapor transmission rate of 0.5−0.6 g/645cm2/24-h at 37.78°C, 100% RH, Cryovac, Sealed Air Corporation, Duncan, SC, U.S.A.) and vacuum sealed (Ultravac UV 2100 packaging machine, Koch, Kansas City, MO, U.S.A). All treatments were subsequently stored at 0–1°C for the remainder of the study. Samples were stored either under retail

display stimulation with fluorescent lights or inside cardboard boxes with no light exposure until day of analysis. The day of packaging was designated as day 0.

Proximate Analysis

Fat, moisture, and protein contents were measured in duplicate for each treatment. Fat content was measured by AOAC method 960.39 (AOAC, 2005b) and moisture content was measured in accordance with AOAC method 950.46 (AOAC, 2005c). Approximately 5 g of sample was weighed into cotton thimbles. Thimbles were dried for 18-h in an oven at 100−102°C (VWR 1370GM., Sheldon Manufacturing Inc., Cornelius, OR, U.S.A). After drying, thimbles were placed in a desiccator to cool until they reached room temperature. Cooled thimbles were reweighed and percent moisture was determined by using the following equation:

Eq. 6. $$\% \text{ Moisture } = \frac{\text{dried weight} - \text{extracted weight}}{\text{sample weight}} \text{ x } 100$$

After weights were recorded, thimbles were then extracted with hexane for 7 h using a Soxhlet multi-unit extraction-heating unit (Lab-Line Instruments, Inc., Melrose Park, IL, U.S.A). After 7 h, thimbles were reweighed and percent fat calculated using the following equation:

Eq. 7. $$\% \text{ Fat } = \frac{\text{dried weight} - \text{extracted weight}}{\text{sample weight}} \text{ x } 100$$

Protein content was measured in accordance with AOAC method 992.15 (AOAC, 2005a) using a TruMac N combustion unit (Leco Corporation, St. Joseph, MI, U.S.A). Percent protein was then calculated by multiplying nitrogen content by 6.25.

pH

For pH measurement, 10 g of sample was ground and mixed with 90 mL distilled water in a 150-mL beaker and stirred vigorously for 60 s. The mixture was filtered through coned 11-µm–filter paper (Whatman Grade 1, GE Healthcare Life Sciences, Pittsburgh, P.A., U.S.A.) so that liquid formed in the bottom of the cone allowed for insertion of the pH probe. The pH was measured in duplicate using a Mettler Toledo SevenMulti pH meter (Columbus, O.H., U.S.A.).

TBA Analysis

Oxidative rancidity was measured on days 0, 14, 28, 56, and 84 by the 2-thiobarbituric-acid procedure, as modified by (Zipster and Watts, 1962). Approximately 10 g of product sample was weighed into a round-bottom flask, attached to a distillation apparatus, and boiled in combination with 97.5 mL of distilled water, 1 mL sulfanilamide solution, and 2 mL hydrogen chloride solution, until 50 mL of distillate was collected. Five mL of TBA solution was added to 5 mL of distillate and heated in a 70°C water bath for 35 min. After samples cooled for 10 min, a spectrophotometer (Model 4320940, DU 640, Beckman, Fullerton, CA, U.S.A.) at 532 nm was used to measure absorbance and the reading multiplied by a factor of 7.8 to convert to mg malondialdehyde per 1,000 g of sample. Analysis was performed in duplicate and results were averaged.

Instrumental Color Analysis

Color was measured on days 0, 14, 28, 56, and 84 on a HunterLab LabScan instrument (Model LS 1500, Hunter Associated Laboratories, Inc., Reston, VA, U.S.A.)

using illuminant D65 (daylight at 6500K), 10° observer angle, and 2.54-cm aperture. Color values were reported as L (lightness), a (redness), and b (yellowness). Saran wrap was placed over the calibration tiles to account for the packaging material of retail display samples, since these samples remained in packaging for color measurement. Measurements were taken on the surface of all samples at three different locations for a total of three random surface measurements collected for each of the retail display and no-light exposure samples.

Texture Profile Analysis

Texture profile analysis (TPA) was performed in triplicate on days 0, 14, 28, 56, and 84 using a TA-XT2i Texture Analyser (Stable Micro Systems, Surrey, UK). On days 0, 14, 42, 70, and 98, unsliced turkey samples were cored (2.54 cm length, 2.54 cm diameter) and subjected to a simplified TPA test. All instrumental texture analyses were conducted on chilled samples (0–1°C). The samples were compressed to 35% of their original height with a 2-bite sequence at a trigger force of 5.0 g and test speed of 5.00 mm/sec. The texture profile parameters hardness, cohesiveness, springiness, gumminess, and chewiness, were determined as described by (Bourne, 1978).

Sensory Analysis

Sensory analysis was conducted on days 14, 28, 56, and 84 using a ten-member trained sensory panel. The panel was comprised of students, faculty, and staff of Iowa State University. Two separate training sessions were held before evaluation. Every session, a three-digit code was randomly assigned to each treatment sample. Panelists

recorded their evaluation on a 15-cm line scale and data were collected using Compusense five (Release 5.6) sensory evaluation software. Panelists evaluated “aroma,” “texture,” “moistness,” “flavor,” “off-flavor,” and “color.” Sample slices were cut into eight wedges and the pieces were placed in a large bowl and mixed to ensure each panelist received a random sampling. Four wedges were placed in a cup with a lid and held under refrigeration until evaluation, approximately 30 min. In addition to the pieces used for evaluation, an intact slice was evaluated on white butcher paper for visual color evaluation by the panel.

Statistical Analysis

The study was replicated three times. Data were analyzed statistically using the PROC MIXED procedure of the Statistical Analysis System (SASv9.4, SAS Institute, Cary, NC, USA). Differences between treatments and within treatments over time were determined using the Tukey-Kramer pairwise comparison method with significance at $P < 0.05$.

Results & Discussion

Proximate analysis, pH, and cook/chill yields

Proximate composition of oven roasted turkey samples is shown in Table 3. The pH of the 0.50% CF treatment was significantly lower ($P < 0.05$) than from all other treatments, likely due to the acidic nature of the citrus fiber.

Instrumental color

Results for color are reported in Table 4–5. There were no significant treatment, day, or day x treatment differences ($P > 0.05$) for L or a values. There were significant treatment, day, and day x treatment differences ($P < 0.05$) for b values. With the citrus fiber treatments being yellower than the controls. However, the only day showing significant differences ($P < 0.05$) was day 0. For retail display, L values were not significantly different ($P > 0.05$) across day or day x treatment, but a treatment effect ($P < 0.05$) was observed, 0.50% CF being lighter than STPP. Hunter a values for the RD treatment were significantly different ($P < 0.05$) across treatment, day, and day x treatment. No-STPP was significantly redder than 0.50% CF. Hunter b RD was significantly different ($P < 0.05$) across treatment, day, and day x treatment, with CF treatments yellower than the controls. Hunter b values decreased throughout the 84-day shelf life. (Reddy and Rao, 1997) found color values of chicken patties made with various binders were higher overall. Similarly, a study on turkey bologna with poultry protein isolate or soy protein isolate resulted in higher a and b values (Omana, et al., 2012). While there were significant differences ($P < 0.05$) in Hunter color values, they were

slight and would not likely be visually noted by consumers, which is confirmed by sensory evaluation in this study.

TBARS

Lipid oxidation is an important factor in determining length of shelf life and results are reported in Figure 1. There were no significant differences ($P > 0.05$) for STPP, No STPP, 0.25% CF, and 0.50% treatments, throughout the 84-day shelf life. TBA values did not exceed 0.51 mg/kg malondialdehyde throughout shelf life, which is much below the level of concern for a product of this type (Ockerman, 1985). These results indicate that citrus fiber did not have any negative effects on the onset of lipid oxidation.

Texture Profile Analysis

TPA results are shown in Table 6. There were no significant differences ($P > 0.05$) across treatment or day for hardness, adhesiveness, cohesion, springiness, or chewiness, similar to results from (Prabhu and Sebranek, 1997) who saw no significant differences in instrumental texture of hams formulated with kappa-carrageenan and starch. The only significant difference ($P < 0.05$) observed was between the STPP control and 0.50% CF treatment for resilience, with STPP control showing greater resilience than 0.50% CF. Resilience measures the force exerted from the sample to regain its original shape. These results indicate that citrus fiber did not negatively effect textural properties of an oven-roasted turkey breast.

Sensory

Sensory results are reported in Figure 2. There were no significant differences ($P > 0.05$) across treatment or day for sensory evaluation of texture, moistness, turkey flavor, off-flavor, or lightness. Moistness in 0.50% CF was significantly lower ($P < 0.05$) than in control treatments. In a study of restructured steaks, (Chen and Trout, 1991) found that juiciness was higher in steaks with salt and phosphates than in steaks made with various binders. There was no significant day effect ($P > 0.05$) for moistness. Turkey aroma was less intense ($P < 0.05$) on days 14 and 84 than on days 28 and 56. (Garcia, et al., 2002) found that the addition of cereal and fruit fibers caused decreased sensory and textural properties in low-fat and dry fermented sausages. These data indicate that citrus fiber had no negative effects on the sensory properties of oven-roasted turkey breast compared to a sodium tripolyphosphate control.

Conclusions

The sodium tripolyphosphate control, no-sodium-tripolyphosphate control, and citrus fiber treatments (0.25%, 0.50%) all maintained equivalent quality throughout the 84-day shelf life. Citrus fiber treatments as alternatives to sodium tripolyphosphate resulted in turkey with acceptable equivalent parameters, as indicated by similar cook/chill yields. Lipid oxidation across all treatments remained below sensory thresholds for the entirety of the 84-day shelf life period. There were slight differences among sensory evaluation scores for moistness, with the citrus fiber treatments as less moist than the controls. The 0.50% CF were less resilient than the STPP control. Sensory evaluation of color showed no difference in lightness throughout the 84-day shelf life.

While there were instrumental color differences, they were slight and did not result in a product that was visually different or unappealing than the sodium tripolyphosphate control.

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Table 1. Brine formulations for oven-roasted turkey breast

	STPP	No STPP	0.25% CF	0.50% CF
Salt	8.40	8.40	8.40	8.40
Dextrose	3.75	3.75	3.75	3.75
Vinegar Powder	2.10	2.10	2.10	2.10
STPP	0.63	0.00	0.00	0.00
Sodium nitrite	0.05	0.05	0.05	0.05
Sodium erythorbate	0.25	0.25	0.25	0.25
Citrus fiber	0.00	0.00	1.50	3.00
Water	84.83	85.45	83.95	82.45

Table 2. Thermal processing for oven-roasted turkey breast treatments

Step	Step Time	Dry Bulb Temperature (°C)	Wet Bulb Temperature (°C)	% Relative Humidity	Main Blower	Exhaust Damper
Steam Cook	1:00	60	60	100	5	Closed
Steam Cook	0:30	65.56	65.56	100	5	Closed
Steam Cook	0:30	71.11	71.11	100	5	Closed
Steam Cook	0:05	82.22	82.22	100	5	Closed
Cold Shower	0:20	10	-17.78	0	0	Auto

Table 3. Means for effect of treatment on proximate composition, pH, and cook/chill yield

	Fat %	Moisture %	Protein %	pH	Yield %*
STPP	1.52[a]	72.66[a]	24.12[a]	6.18[a]	80.91[a]
No STPP	1.67[a]	72.03[a]	25.03[a]	6.19[a]	79.14[a]
0.25% CF	1.49[a]	72.53[a]	24.37[a]	6.18[a]	81.30[a]
0.50% CF	1.54[a]	71.59[a]	25.07[a]	6.09[b]	77.14[a]
SEM	0.14	0.37	0.46	0.02	0.75

[a-b] Means in the same column with different letters are significantly different ($P < 0.05$)

*Yields conducted on rep 2 and 3 only, product was lost on rep 1

Table 4. Means for effect of treatment on Hunter L, a, b values of product stored under retail display lights or in the dark

	Dark			Retail Display		
	L	a	b	L	a	b
STPP	70.23[a]	7.44[a]	8.59[b]	71.02[b]	6.90[ab]	9.23[b]
No STPP	70.31[a]	7.53[a]	8.80[b]	71.31[ab]	7.10[a]	9.32[b]
0.25% CF	70.94[a]	7.19[a]	9.14[a]	71.77[ab]	6.93[ab]	9.61[a]
0.50% CF	70.21[a]	7.46[a]	9.40[a]	72.65[a]	6.49[b]	9.69[a]
SEM	0.38	0.14	0.07	0.40	0.13	0.06

[a-b] Means in the same column with different letters are significantly different ($P < 0.05$)

Table 5. Means for effect of day on Hunter L, a, b values of product stored under retail display lights or in the dark

	Dark			Retail Display		
	L	a	b	L	a	b
0	70.06[a]	7.48[a]	9.34[a]	72.07[a]	5.80[c]	10.98[a]
14	70.49[a]	7.42[a]	8.89[b]	70.82[a]	7.46[a]	9.31[b]
28	70.61[a]	7.43[a]	8.90[b]	71.06[a]	7.23[ab]	9.12[bc]
56	70.52[a]	7.34[a]	8.92[b]	72.32[a]	6.92[ab]	8.89[c]
84	70.45[a]	7.37[a]	8.86[b]	72.14[a]	6.86[b]	9.01[c]
SEM	0.43	0.15	0.08	0.44	0.14	0.07

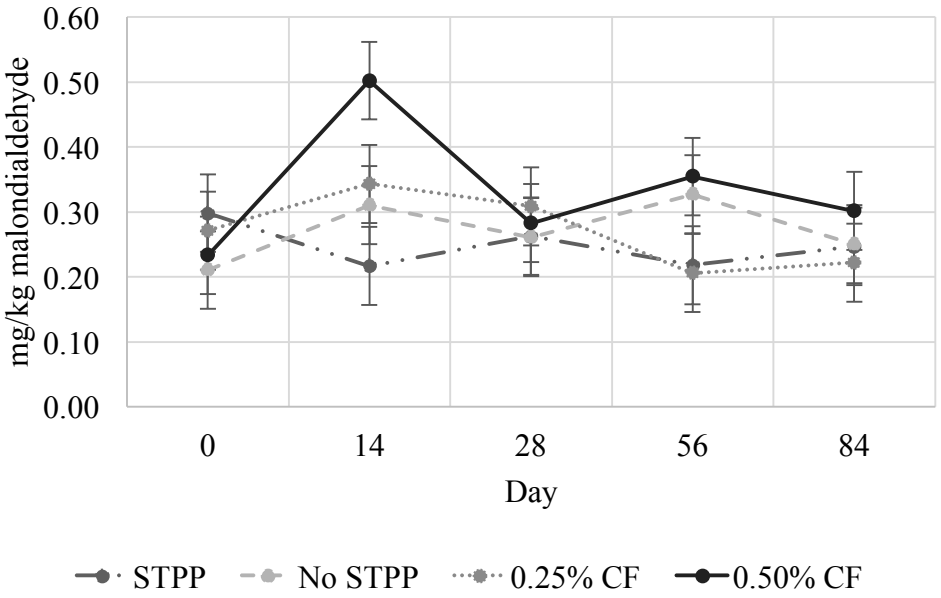
[a-c] Means in the same column with different letters are significantly different ($P < 0.05$)

Table 6. Means for effect of treatment on instrumental texture of oven roasted turkey

	Hardness g	Resilience %	Cohesive-ness	Springiness %	Chewiness
STPP	5870.57[a]	29.69[a]	0.62[a]	77.07[a]	2891.18[a]
No STPP	5565.09[a]	28.76[ab]	0.62[a]	77.78[a]	2721.11[a]
0.25% CF	5170.76[a]	27.13[ab]	0.59[a]	74.86[a]	2363.44[a]
0.50% CF	5712.42[a]	26.29[b]	0.59[a]	75.89[a]	2608.88[a]
SEM	299.64	0.72	0.01	1.36	194.66

[a-c] Means in the same column with different letters are significantly different ($P < 0.05$)

Figure 1. Means for effect of treatment and day on TBARS of oven-roasted turkey breast



Error bars represent S.E.M. averaged across day and treatment. S.E.M = 0.06

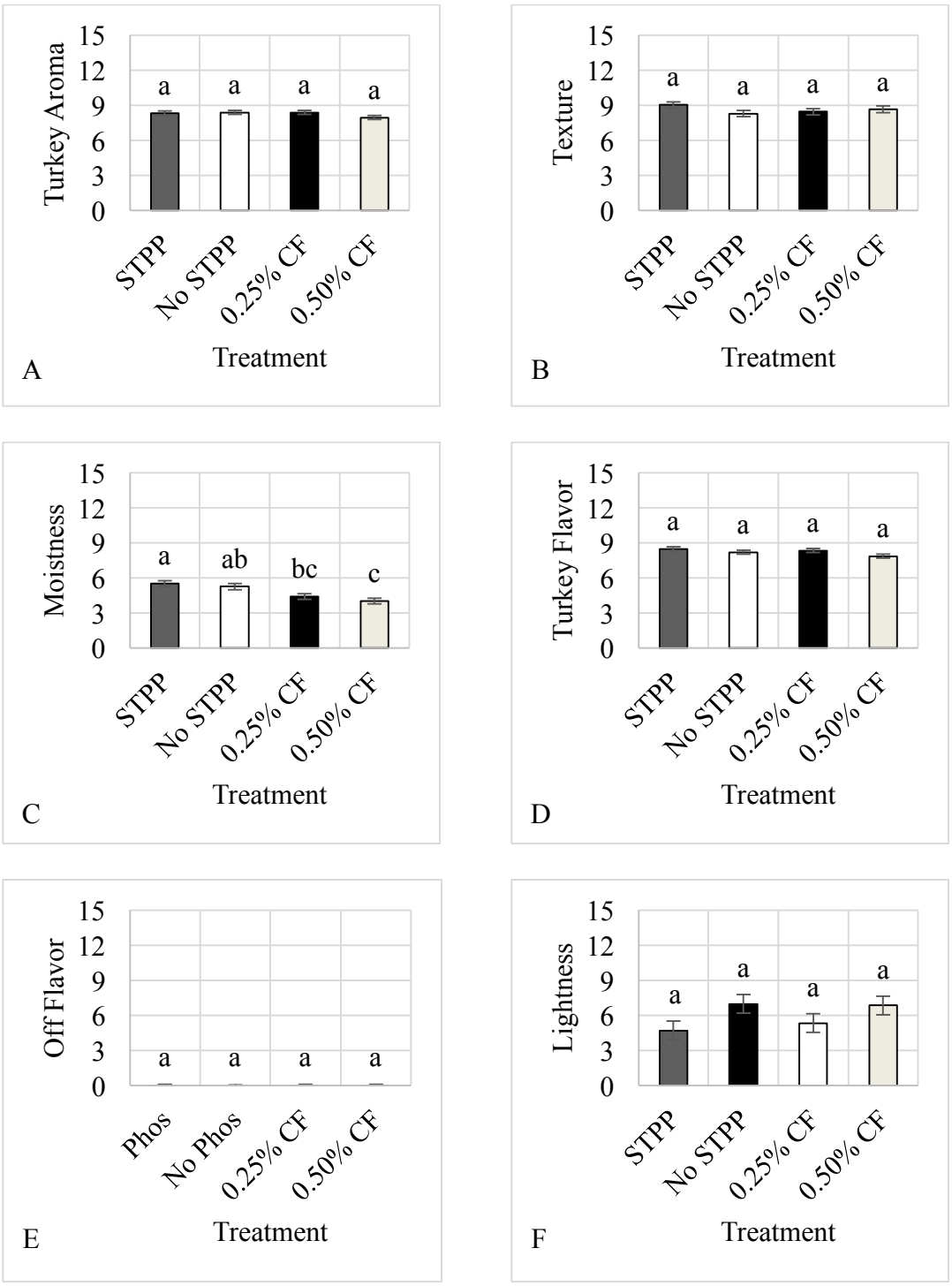


Figure 2. Influence of STPP replacement on the sensory evaluation of turkey aroma (A), texture (B), moistness (C), turkey flavor (D), off-flavor (E), and lightness (F) of oven roasted turkey. Treatments with different letters differ significantly ($P < 0.05$). Error bars represent S.E.M. averaged across day. Turkey aroma S.E.M. = 0.17. Texture S.E.M. = 0.27. Moistness S.E.M. = 0.25. Turkey flavor S.E.M. = 0.17. Off-flavor S.E.M. = 0.04. Lightness S.E.M. = 0.80. Sensory evaluation was conducted on Rep 2 and Rep 3 only.

CHAPTER 5. GENERAL CONCLUSIONS

Phosphates have been used in meat products for decades for their water retention, buffering, and textural properties and contributions. However, in recent years, consumers have become more skeptical of the addition of various food additives. This skepticism has led to the removal of conventional food additives throughout the food industry and replacing them with natural alternatives. The meat industry has the reputation of being unhealthy due to the addition of food additives in further processed meat products. While all food additives are added in compliance with USDA regulations and provide desired functionalities, consumers perceive them as unhealthy. Sodium nitrite, sodium erythorbate, and sodium phosphates are three common ingredients that are perceived to be unhealthy and unsafe by consumers. This has pushed the meat industry to search for natural alternatives to these ingredients that can be used in processed meat products without negatively affecting the acceptability of the product.

Replacing phosphate with alternatives has been a challenge in the processed meat industry, especially when producing a product that has acceptable textural properties. Phosphate improves water holding capacity, texture, and sensory characteristics. The complete elimination of phosphate is not plausible to produce an acceptable product. One specific alternative to phosphate that has become a popular option is citrus fiber. Due to citrus fiber's high surface area and fiber content, it shows promise in its functional properties to retain water, improve texture, and contribute to gelation. This study evaluated the effect of replacing sodium tripolyphosphate with citrus fiber on shelf-life and sensory characteristics in processed meat products.

The results of the current study demonstrated that replacement of sodium tripolyphosphate with citrus fiber in an uncured all-pork bologna and oven-roasted turkey breast has the potential to produce an acceptable product that is stable for up to a 98 and 84-d shelf life, respectively. The products manufactured with citrus fiber had similar physical, chemical, and sensory characteristics as those manufactured with conventional phosphate. As a result, citrus fiber could serve as natural alternative to sodium tripolyphosphate in processed meat products.

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APPENDIX A

TABLES FOR DIFFERENCES WITHIN TREATMENTS OF UNCURED ALL-PORK BOLOGNA OVER TIME

TBARS

Table 1. Mean mg/kg malondialdehyde for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	0.13[a]	0.12[a]	0.15[a]	0.13[a]	0.14[a]
No STPP	0.14[a]	0.13[a]	0.16[a]	0.17[a]	0.15[a]
0.50% CF	0.13[a]	0.12[a]	0.14[a]	0.14[a]	0.13[a]
0.75% CF	0.14[a]	0.12[a]	0.15[a]	0.14[a]	0.17[a]
1.00% CF	0.13[a]	0.13[a]	0.14[a]	0.15[a]	0.15[a]

[a] Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M. = 0.02

TPA

Table 2. Mean hardness (g) for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	3210.52[c]	4932.87[abc]	3727.20[abc]	4479.52[abc]	4561.45[abc]
No STPP	3142.18[c]	4481.25[abc]	4061.77[abc]	4435.83[abc]	5048.23[abc]
0.50% CF	3704.43[abc]	4798.21[abc]	4815.78[abc]	5773.56[abc]	4808.7[abc]
0.75% CF	3645.92[abc]	4340.25[abc]	4504.73[abc]	5398.16[abc]	4711.85[abc]
1.00% CF	3441.42[bc]	5176.31[abc]	5736.31[abc]	6054.82[bc]	6272.45[a]

[a-c] Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 500.47

Table 3. Mean adhesiveness (g/s) for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	-20.52[a]	-51.59[a]	-48.07[a]	-76.93[a]	-71.39[a]
No STPP	-21.57[a]	-81.06[a]	-37.08[a]	-68.50[a]	-82.28[a]
0.50% CF	-26.85[a]	-71.41[a]	-73.61[a]	-78.17[a]	-64.28[a]
0.75% CF	-36.37[a]	-64.39[a]	-73.56[a]	-79.39[a]	-56.05[a]
1.00% CF	-34.77[a]	-68.42[a]	-45.77[a]	-56.05[a]	-71.54[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 13.28

Table 4. Mean resilience (%) for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	43.31[a]	40.66[a]	35.58[a]	36.96[a]	38.04[a]
No STPP	35.35[a]	36.83[a]	33.61[a]	33.87[a]	36.33[a]
0.50% CF	35.32[a]	33.15[a]	35.08[a]	31.35[a]	32.45[a]
0.75% CF	36.88[a]	33.27[a]	34.35[a]	33.85[a]	31.93[a]
1.00% CF	33.47[a]	31.89[a]	37.02[a]	34.48[a]	34.49[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 2.29

Table 5. Mean cohesion for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	0.77[a]	0.73[a]	0.71[a]	0.71[a]	0.71[a]
No STPP	0.64[a]	0.67[a]	0.63[a]	0.66[a]	0.68[a]
0.50% CF	0.66[a]	0.58[a]	0.67[a]	0.60[a]	0.62[a]
0.75% CF	0.72[a]	0.66[a]	0.68[a]	0.65[a]	0.64[a]
1.00% CF	0.66[a]	0.60[a]	0.70[a]	0.66[a]	0.61[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.04

Table 6. Mean springiness (%) for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	85.87[a]	87.14[a]	87.28[a]	86.45[a]	86.57[a]
No STPP	84.90[a]	87.08[a]	84.53[a]	84.63[a]	83.83[a]
0.50% CF	85.32[a]	82.73[a]	85.29[a]	81.49[a]	85.08[a]
0.75% CF	87.45[a]	86.41[a]	83.85[a]	83.33[a]	84.79[a]
1.00% CF	85.46[a]	84.39[a]	85.54[a]	84.72[a]	83.21[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 1.28

Table 7. Mean gumminess for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	2450.14[a]	3604.34[a]	2652.53[a]	3164.88[a]	3262.06[a]
No STPP	2018.76[a]	3018.36[a]	2574.76[a]	2908.28[a]	3428.57[a]
0.50% CF	2400.72[a]	2768.64[a]	3202.35[a]	3352.37[a]	2985.90[a]
0.75% CF	2618.37[a]	2888.72[a]	3060.50[a]	3544.39[a]	3044.36[a]
1.00% CF	2303.21[a]	3105.16[a]	3993.54[a]	4005.71[a]	3843.23[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 377.76

Table 8. Mean chewiness for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	2145.09[a]	3166.18[a]	2318.72[a]	2733.54[a]	2832.47[a]
No STPP	1734.25[a]	2631.28[a]	2188.44[a]	2461.67[a]	2885.16[a]
0.50% CF	2052.60[a]	2303.23[a]	2733.96[a]	2729.24[a]	2539.60[a]
0.75% CF	2292.88[a]	2502.90[a]	2574.23[a]	2948.40[a]	2587.82[a]
1.00% CF	1973.14[a]	2641.88[a]	3407.89[a]	3398.50[a]	3217.58[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 337.82

Instrumental Color

Table 9. Mean Hunter L for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	72.09[a]	72.04[a]	71.73[a]	72.13[a]	72.73[a]
No STPP	72.59[a]	72.40[a]	71.69[a]	73.16[a]	73.31[a]
0.50% CF	71.48[a]	71.46[a]	71.39[a]	72.10[a]	72.01[a]
0.75% CF	71.79[a]	71.66[a]	72.05[a]	73.01[a]	72.52[a]
1.00% CF	70.89[a]	71.54[a]	71.66[a]	72.76[a]	72.30[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.49

Table 10. Mean Hunter a for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	7.03[a]	7.10[a]	7.34[a]	7.25[a]	7.05[a]
No STPP	6.94[a]	7.00[a]	7.31[a]	6.92[a]	6.80[a]
0.50% CF	7.09[a]	7.10[a]	7.31[a]	6.89[a]	7.06[a]
0.75% CF	7.00[a]	7.05[a]	7.12[a]	6.74[a]	6.82[a]
1.00% CF	7.15[a]	7.01[a]	7.24[a]	6.81[a]	6.87[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.14

Table 11. Meat Hunter b for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	13.15[e]	13.35[cde]	13.65[abcde]	13.55[bcde]	13.53[bcde]
No STPP	13.31[de]	13.34[cde]	13.63[abcde]	13.34[cde]	13.40[cde]
0.50% CF	13.66[abcde]	13.65[abcde]	13.95[ab]	13.42[cde]	13.80[abcd]
0.75% CF	13.70[abcd]	13.76[abcd]	13.85[abc]	13.69[abcd]	13.75[abcd]
1.00% CF	13.97[ab]	13.84[abc]	14.07[a]	13.65[abcde]	13.97[a]

[a-e] Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.09

Table 12. Mean Hunter L retail display for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	71.96[a]	73.36[a]	74.05[a]	73.06[a]	72.74[a]
No STPP	73.31[a]	74.30[a]	73.94[a]	73.45[a]	73.59[a]
0.50% CF	72.27[a]	72.84[a]	73.05[a]	72.95[a]	73.03
0.75% CF	72.59[a]	73.33[a]	73.16[a]	73.32[a]	73.12[a]
1.00% CF	72.46[a]	72.96[a]	73.19[a]	72.65[a]	73.40[a]

[a] Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.65

Table 13. Mean Hunter a retail display for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	7.57^{ab}	7.50^{abc}	7.34^{abc}	7.41^{abc}	6.65^{abc}
No STPP	7.24^{abc}	7.29^{abc}	7.08^{abc}	7.26^{abc}	7.08^{abc}
0.50% CF	7.32^{abc}	7.78^{a}	7.68^{a}	7.10^{abc}	6.82^{abc}
0.75% CF	7.49^{abc}	7.37^{abc}	7.58^{ab}	7.17^{abc}	6.51^{bc}
1.00% CF	7.22^{abc}	7.38^{abc}	7.27^{abc}	6.89^{abc}	6.40^{c}

$^{a-c}$ Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.21

Table 14. Mean Hunter b retail display for each treatment at each time point

	Day 0	Day 14	Day 42	Day 70	Day 98
STPP	13.77^{abcde}	13.36^{cde}	13.19^{de}	13.04^{e}	13.12^{de}
No STPP	14.19^{abcd}	13.16^{de}	13.34^{cde}	12.96^{e}	13.14^{de}
0.50% CF	14.72^{ab}	13.55^{cde}	13.56^{cde}	13.54^{cde}	13.67^{bcde}
0.75% CF	14.41^{abc}	13.75^{abcde}	13.69^{abcde}	13.55^{cde}	13.79^{abcde}
1.00% CF	14.77^{a}	13.91^{abcde}	13.92^{abcde}	14.01^{abcde}	14.04^{abcde}

$^{a-e}$Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.20

Sensory Analysis

Table 15. Mean bologna aroma for each treatment at each time point

	Day 14	Day 42	Day 70	Day 98
STPP	8.38^{a}	6.75^{a}	7.82^{a}	6.92^{a}
No STPP	6.99^{a}	6.93^{a}	7.76^{a}	7.14^{a}
0.50% CF	7.46^{a}	7.20^{a}	6.85^{a}	7.24^{a}
0.75% CF	7.72^{a}	6.48^{a}	7.15^{a}	6.59^{a}
1.00% CF	7.54^{a}	7.46^{a}	6.47^{a}	7.35^{a}

^{a}Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.72

Table 16. Mean bologna flavor for each treatment at each time point

	Day 14	Day 42	Day 70	Day 98
STPP	8.33[a]	7.20[ab]	7.56[ab]	7.39[ab]
No STPP	7.35[ab]	7.42[ab]	7.28[ab]	6.98[ab]
0.50% CF	7.44[ab]	7.06[ab]	6.85[ab]	7.24[ab]
0.75% CF	7.92[ab]	6.19[b]	6.49[ab]	6.88[ab]
1.00% CF	7.64[ab]	7.34[ab]	6.35[ab]	6.87[ab]

[a-b] Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.37

Table 17. Mean texture for each treatment at each time point

	Day 14	Day 42	Day 70	Day 98
STPP	9.52[a]	8.50[abcd]	8.91[abc]	9.23[ab]
No STPP	5.91[cde]	5.80[de]	6.13[cde]	6.10[cde]
0.50% CF	5.25[e]	6.28[bcde]	5.06[e]	5.90[cde]
0.75% CF	7.76[abcde]	6.48[abcde]	6.48[abcde]	6.57[abcde]
1.00% CF	6.44[bcde]	6.11[cde]	6.90[abcde]	6.13[cde]

[a-e] Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.37

Table 18. Mean moistness for each treatment at each time point

	Day 14	Day 42	Day 70	Day 98
STPP	7.79[ab]	7.53[abcd]	7.50[abcd]	7.14[abcd]
No STPP	8.44[a]	7.33[abcd]	7.17[abcd]	7.44[abcd]
0.50% CF	7.64[abc]	7.34[abcd]	6.68[abcd]	6.88[abcd]
0.75% CF	7.13[abcd]	6.52[abcd]	5.75[cd]	6.34[bcd]
1.00% CF	8.13[ab]	6.38[bcd]	5.59[d]	6.19[bcd]

[a-d] Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.37

Table 19. Mean off-flavor for each treatment at each time point

	Day 14	Day 42	Day 70	Day 98
STPP	0.11^{ab}	0.15^{ab}	0.04^{b}	0.21^{ab}
No STPP	0.05^{ab}	0.11^{ab}	0.10^{ab}	0.17^{ab}
0.50% CF	0.05^{ab}	0.07^{ab}	0.31^{ab}	0.11^{ab}
0.75% CF	0.19^{ab}	0.19^{ab}	0.19^{ab}	0.40^{ab}
1.00% CF	0.45^{a}	0.05^{ab}	0.11^{ab}	0.25^{ab}

[a-b] Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.08

Table 20. Mean lightness for each treatment at each time point

	Day 14	Day 42	Day 70	Day 98
STPP	3.53^{a}	3.75^{a}	3.75^{a}	3.38^{a}
No STPP	3.26^{a}	3.01^{a}	3.16^{a}	2.73^{a}
0.50% CF	3.69^{a}	3.13^{a}	3.78^{a}	3.13^{a}
0.75% CF	2.87^{a}	3.41^{a}	4.92^{a}	3.49^{a}
1.00% CF	3.84^{a}	3.37^{a}	4.03^{a}	3.40^{a}

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.59

APPENDIX B

TABLES FOR DIFFERENCES WITHIN TREATMENTS OF OVEN-ROASTED TURKEY BREAST OVER TIME

TBARS

Table 1. Mean mg/kg malondialdehyde for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	0.30[a]	0.22[a]	0.26[a]	0.22[a]	0.25[a]
No STPP	0.21[a]	0.31[a]	0.26[a]	0.33[a]	0.25[a]
0.25% CF	0.27[a]	0.34[a]	0.31[a]	0.21[a]	0.22[a]
0.50% CF	0.23[a]	0.50[a]	0.28[a]	0.35[a]	0.30[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.30

TPA

Table 2. Mean hardness (g) for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	4921.59[a]	5843.57[a]	5757.11[a]	6517.30[a]	6313.28[a]
No STPP	4490.08[a]	6685.11[a]	5354.88[a]	5781.21[a]	5514.16[a]
0.25% CF	4188.48[a]	5573.67[a]	6239.93[a]	5055.43[a]	4796.32[a]
0.50% CF	5705.10[a]	5052.05[a]	5160.74[a]	5567.46[a]	7076.71[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 670.02

Table 3. Mean adhesiveness (g/s) for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	-11.28[a]	-20.60[a]	-17.07[a]	-11.99[a]	-10.74[a]
No STPP	-1.28[a]	-15.18[a]	-5.12[a]	-2.84[a]	-5.91[a]
0.25% CF	-13.02[a]	-13.58[a]	-19.48[a]	-2.84[a]	-13.30[a]
0.50% CF	-10.05[a]	-16.31[a]	-16.03[a]	-1.43[a]	-17.58[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 9.00

Table 4. Mean resilience (%) for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	30.53[ab]	28.85[ab]	28.93[ab]	27.74[ab]	32.41[a]
No STPP	27.67[ab]	29.44[ab]	28.35[ab]	29.02[ab]	29.29[ab]
0.25% CF	24.00[ab]	26.92[ab]	28.13[ab]	27.76[ab]	28.83[ab]
0.50% CF	25.55[b]	23.60[ab]	25.95[ab]	27.45[ab]	28.92[ab]

[a-b] Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 1.62

Table 5. Mean cohesion for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	0.62[a]	0.61[a]	0.63[a]	0.58[a]	0.66[a]
No STPP	0.60[a]	0.62[a]	0.61[a]	0.62[a]	0.64[a]
0.25% CF	0.56[a]	0.57[a]	0.61[a]	0.59[a]	0.62[a]
0.50% CF	0.57[a]	0.54[a]	0.60[a]	0.61[a]	0.63[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.03

Table 6. Mean springiness (%) for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	72.43[a]	76.21[a]	79.15[a]	76.92[a]	80.64[a]
No STPP	78.10[a]	77.84[a]	79.87[a]	74.84[a]	78.25[a]
0.25% CF	69.99[a]	75.34[a]	79.84[a]	75.57[a]	73.55[a]
0.50% CF	76.46[a]	75.29[a]	76.79[a]	74.06[a]	76.86[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 3.04

Table 7. Mean gumminess for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	3089.69[a]	3618.63[a]	3638.98[a]	3888.36[a]	4184.24[a]
No STPP	2764.75[a]	4191.96[a]	3257.86[a]	3577.91[a]	3542.02[a]
0.25% CF	2352.18[a]	3194.45[a]	3924.27[a]	3051.94[a]	2962.32[a]
0.50% CF	3280.21[a]	2793.66[a]	3069.97[a]	3412.71[a]	4462.91[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 478.53

Table 8. Mean chewiness for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	2348.75[a]	2758.08[a]	2873.34[a]	3061.94[a]	3413.79[a]
No STPP	2219.52[a]	3269.38[a]	2616.83[a]	2719.90[a]	2779.93[a]
0.25% CF	1644.97[a]	2417.17[a]	3178.55[a]	2313.07[a]	2263.45[a]
0.50% CF	2537.75[a]	2120.55[a]	2355.85[a]	2546.32[a]	3483.91[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 435.26

Instrumental Color

Table 9. Mean Hunter L for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	70.07[a]	70.88[a]	70.46[a]	69.85[a]	69.91[a]
No STPP	69.48[a]	70.71[a]	71.28[a]	70.03[a]	70.08[a]
0.25% CF	70.54[a]	70.66[a]	71.04[a]	71.83[a]	70.64[a]
0.50% CF	70.14[a]	69.72[a]	69.66[a]	70.39[a]	71.16[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.85

Table 10. Mean Hunter a for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	7.40[a]	7.49[a]	7.47[a]	7.51[a]	7.32[a]
No STPP	7.81[a]	7.43[a]	7.25[a]	7.65[a]	7.51[a]
0.25% CF	7.31[a]	7.20[a]	7.24[a]	6.85[a]	7.37[a]
0.50% CF	7.40[a]	7.56[a]	7.74[a]	7.34[a]	7.28[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.31

Table 11. Meat Hunter b for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	8.81[cd]	8.59[cd]	8.49[d]	8.46[d]	8.61[cd]
No STPP	9.10[abcd]	8.73[cd]	8.58[cd]	8.70[cd]	8.87[bcd]
0.25% CF	9.76[a]	8.86[bcd]	9.18[abcd]	9.21[abcd]	8.69[cd]
0.50% CF	9.67[ab]	9.38[abc]	9.36[abc]	9.32[abc]	9.26[abcd]

[a-d]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.15

Table 12. Mean Hunter L retail display for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	70.85[a]	70.85[a]	70.33[a]	71.50[a]	71.54[a]
No STPP	73.25[a]	70.19[a]	69.88[a]	72.29[a]	70.93[a]
0.25% CF	71.69[a]	70.11[a]	71.59[a]	73.17[a]	72.29[a]
0.50% CF	72.48[a]	72.13[a]	72.46[a]	72.33[a]	73.82[a]

[a-d]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.88

Table 13. Mean Hunter a retail display for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	6.13[bcdef]	7.28[abcd]	7.14[abcde]	6.98[abcdef]	6.95[abcdef]
No STPP	5.60[f]	7.76[a]	7.52[ab]	7.11[abcdef]	7.52[ab]
0.25% CF	5.64[ef]	7.93[a]	7.35[abc]	6.65[abcdef]	7.07[abcdef]
0.50% CF	5.84[def]	6.85[abcdef]	6.92[abcdef]	6.94[abcdef]	5.90[cdef]

[a-f]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.28

Table 14. Mean Hunter b retail display for each treatment at each time point

	Day 0	Day 14	Day 28	Day 56	Day 84
STPP	10.65[a]	8.93[bcd]	9.11[bcd]	8.61[d]	8.84[cd]
No STPP	10.73[a]	9.19[bcd]	9.03[bcd]	8.68[d]	8.94[bcd]
0.25% CF	11.24[a]	9.49[bc]	9.07[bcd]	9.31[bcd]	8.93[bcd]
0.50% CF	11.29[a]	9.61[b]	9.26[bcd]	8.96[bcd]	9.32[bcd]

[a-d]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.14

Sensory Analysis

Table 15. Mean turkey aroma for each treatment at each time point

	Day 14	Day 28	Day 56	Day 84
STPP	8.16[ab]	9.27[a]	8.32[ab]	7.51[ab]
No STPP	8.01[ab]	8.87[ab]	9.01[ab]	7.61[ab]
0.25% CF	8.47[ab]	8.50[ab]	8.10[ab]	8.42a[b]
0.50% CF	7.20[a]	8.23[ab]	8.27[ab]	8.04a[b]

[a-b]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.34

Table 16. Mean turkey flavor for each treatment at each time point

	Day 14	Day 28	Day 56	Day 84
STPP	8.40[a]	8.87[a]	8.37[a]	8.29[a]
No STPP	8.29[a]	8.70[a]	8.26[a]	7.49[a]
0.25% CF	8.38[a]	8.22[a]	8.04[a]	8.68[a]
0.50% CF	7.41[a]	8.08[a]	7.72[a]	8.22[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.33

Table 17. Mean texture for each treatment at each time point

	Day 14	Day 28	Day 56	Day 84
STPP	8.67[a]	9.03[a]	8.99[a]	9.45[a]
No STPP	7.59[a]	9.40[a]	7.47[a]	8.67[a]
0.25% CF	8.32[a]	7.59[a]	9.23[a]	8.65[a]
0.50% CF	9.04[a]	8.85[a]	8.65[a]	8.07[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.54

Table 18. Mean moistness for each treatment at each time point

	Day 14	Day 28	Day 56	Day 84
STPP	5.19[ab]	5.24[ab]	6.09[a]	5.56[ab]
No STPP	5.62[ab]	4.54[ab]	6.35[a]	4.52[ab]
0.25% CF	4.10[ab]	5.39[ab]	3.85[ab]	4.32[b]
0.50% CF	3.25[b]	4.49[ab]	4.33[ab]	4.08[ab]

[a-b]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.54

Table 19. Mean off-flavor for each treatment for each time point

	Day 14	Day 28	Day 56	Day 84
STPP	0.06[a]	0.00[a]	0.13[a]	0.21[a]
No STPP	0.00[a]	0.05[a]	0.04[a]	0.10[a]
0.25% CF	0.04[a]	0.01[a]	0.23[a]	0.09[a]
0.50% CF	0.04[a]	0.05[a]	0.09[a]	0.21[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 0.07

Table 20. Mean lightness for each treatment for each time point

	Day 14	Day 28	Day 56	Day 84
STPP	4.11[a]	5.75[a]	4.51[a]	4.56[a]
No STPP	7.91[a]	6.65[a]	7.70[a]	5.72[a]
0.25% CF	5.71[a]	5.69[a]	5.13[a]	4.91[a]
0.50% CF	6.54[a]	6.86[a]	6.06[a]	8.05[a]

[a]Means in the same column with different letters are significantly different ($P < 0.05$)
S.E.M = 1.60

APPENDIX C

SENSORY EVALUATION OF BOLOGNA

Date_____ **Panelist**_____ **Sample #**_____

Cured Bologna Aroma

_____
None Intense

Texture

_____
Soft Firm

Moistness

_____
Not Moist Moist

Cured Bologna Flavor

_____
None Intense

Off-flavor

_____
None Intense

If you detected an Off-Flavor, please describe_____

SENSORY EVALUATION OF BOLOGNA COLOR

Date_____ Participant ID number: _____

Code number of the <u>first</u> sample:

Evaluate the intensity of the COLOR

_____

Light Dark

Code number of the <u>second</u> sample:

Evaluate the intensity of the COLOR

_____

Light Dark

Code number of the <u>third</u> sample:

Evaluate the intensity of the COLOR

_____

Light Dark

Code number of the <u>fourth</u> sample:

Evaluate the intensity of the COLOR

_____

Light Dark

Code number of the <u>fifth</u> sample:

Evaluate the intensity of the COLOR

_____

Light Dark

APPENDIX D

SENSORY EVALUATION OF OVEN ROASTED DELI TURKEY

Date_____ **Panelist**_____ **Sample #**_____

Deli Turkey Aroma

_____

None Intense

Texture

_____

Soft Firm

Moistness

_____

Not Moist Moist

Deil Turkey Flavor

_____

None Intense

Off-flavor

_____

None Intense

If you detected an Off-Flavor, please describe_____

SENSORY EVALUATION OF OVEN ROASTED DELI TURKEY COLOR

Date_____ **Participant ID number: _____**

Code number of the <u>first</u> sample: _____

Evaluate the intensity of the COLOR

_____

Light Dark

Code number of the <u>second</u> sample: _____

Evaluate the intensity of the COLOR

_____

Light Dark

Code number of the <u>third</u> sample: _____

Evaluate the intensity of the COLOR

_____

Light Dark

Code number of the <u>fourth</u> sample: _____

Evaluate the intensity of the COLOR

_____

Light Dark

APPENDIX E

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 11/16/2016

To: Dr. Rodrigo Tarte
215D Meat Lab

From: Office for Responsible Research

Title: Evaluation of Citrus Fiber as a Natural Phosphate Alternative in Processed Meat

IRB ID: 16-527

Study Review Date: 11/16/2016

The project referenced above has been declared exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b) because it meets the following federal requirements for exemption:

- (6) Taste and food quality evaluation consumer acceptance studies if
  - Wholesome foods without additives are consumed; or
  - A food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe by the Food and Drug Administration (FDA) or approved by the Environmental Protection Agency (EPA) or the Food Safety and Inspection Service (FSIS) of the U.S. Department of Agriculture (USDA).

The determination of exemption means that:

- **You do not need to submit an application for annual continuing review.**
- **You must carry out the research as described in the IRB application.** Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any modifications to the research procedures (e.g., method of data collection, nature or scope of information to be collected, changes in confidentiality measures, etc.), modifications that result in the inclusion of participants from vulnerable populations, and/or any change that may increase the risk or discomfort to participants. Changes to key personnel must also be approved. The purpose of review is to determine if the project still meets the federal criteria for exemption.

  Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

  Detailed information about requirements for submission of modifications can be found on the Exempt Study Modification Form. A Personnel Change Form may be submitted when the only modification involves changes in study staff. If it is determined that exemption is no longer warranted, then an Application for Approval of Research Involving Humans Form will need to be submitted and approved before proceeding with data collection.

Please note that you must submit all research involving human participants for review. **Only the IRB or designees may make the determination of exemption**, even if you conduct a study in the future that is exactly like this study.

Please be aware that **approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **An IRB determination of exemption in no way implies or guarantees that permission from these other entities will be granted.**

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.