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Utilization of Phosphate Alternatives in Chunked and Formed Deli Ham and Marinated Chicken Breast

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Utilization of phosphate alternatives in chunked and formed deli ham and marinated chicken breast

By

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Porcine *Semimembranosus* muscles were vacuum tumbled with phosphate, without phosphate, fiber dry vinegar, or whey protein concentrate (WPC). Consumers preferred (P<0.05) deli ham with phosphate, without phosphate and WPC over the oat fiber with vinegar treatment. In addition, the phosphate treatment had less cooking loss, (P<0.05) greater bind strength (P<0.05) and more intact slices (P<0.05) than other treatments. In addition, WPC produced ham with a higher (P<0.05) CIE *l** and a lower (P<0.05) *b** value than other treatments. Consumers preferred (P<0.05) chicken breasts marinated with phosphate with respect to flavor and aroma over the negative phosphate treatment and oat fiber treatments. Chicken breast with phosphate increased pH and had less cooking loss (P<0.05) as compared to chicken with WPC and without phosphate. Results indicated that oat fiber has potential as a phosphate replacer in marinated chicken, and WPC has potential as a phosphate replacer in deli ham.

DEDICATION

The African proverb “it takes a village to raise a child” fit my life. There are so many people who played a part in getting me where I am today. My next-door neighbor Deloris Jason has known me since I was two and she is as much a part of my family as I am to hers. As a nontraditional college graduate who obtained her M.S. degree she bestowed her wisdom of both the real world and college along with home cooked meals that I will be forever grateful for. Lee R. Paige has been the only consistent male figure in my life. A memory that I will never forget is you seeing me off the start of my freshman year of college. You have always been a dependable person I could call on. Thank you Uncle Lee. Dionne Atley- McCurry is the big sister you hate one day and love the next. You are a great mother, wife, sister, and friend and I appreciate all the good times we’ve had and I’m looking forward to many more to come. Gone, but not forgotten Johnny and Madeline Robinson will forever be in my heart for the upbringing, lessons, good times and bad times. I love you both and may you continue to rest in peace. Deidre Robinson thank you for everything. I do not think that there is a more genuine, kind hearted person than you. Lastly, my mother, Alma Harris. How can I thank you enough for the numerous sacrifices you’ve made to make my life better. I thank God for such a loving, wise, and understanding mother as you. You have been inspiration in my life and it is by you and God that I have it made it thus far. Thank you Lukane.

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CHAPTER I

INTRODUCTION

Consumer demand for clean labeling has led research to evaluate ingredients that are perceived as natural or clean label as replacements to traditional ingredients in meat products. Consumer demand is also for short and concise ingredient lists that include ingredients that they can pronounce and are familiar with. Sodium tripolyphosphate (STP) is commonly used to improve the juiciness and tenderness of meat products. However, STP is not considered natural by consumers or the United States Department of Agriculture (USDA). According to Casco et al. (2013a) phosphates are not a natural ingredient and are extracted from mineral rocks by acid extraction. However, scientists state that phosphate is naturally present in the body as adenosine triphosphate (ATP). The USDA Food Safety and Inspection Service (FISI 1998) defines all natural as an ingredient or product that has been minimally processed, does not contain artificial flavors or flavorings, color agents, chemical preservatives, or any other synthetic ingredient. STP is one of the main ingredients used in meat, poultry, and seafood marinating. STP increases the water holding capacity (WHC) of meat by opening the meat protein structure to allow more water to reside in meat products (Huynh 2011a). Increasing WHC is one of the most important functions of an STP alternative since it enhances juiciness, tenderness, and yields, which in turn increases profitability. Although STP is a functional ingredient that provides desirable product qualities, it can have negative impacts on the human body if consumed in large quantities such as an increased risk of bone disease (Dimitrakopoulou et al. 1998). A serum phosphate level above a concentration of 1.45 mmol/L indicates hyperphosphatameia (Ritz 2012). Countries such as Italy and France have decreased the usage of phosphates in poultry products due to negative consumer perception (Petracci 2013). To meet consumer demand several ingredients, have been investigated as potential alternatives for STP. Prabhu and Husak (2014) evaluated sodium carbonate in combination with native potato starch as a replacement for phosphate. These researchers found that native starches were able to replace the water binding and texture provided by phosphate, but were not effective at disassociating the actin-myosin complex. Decreasing the amount of added water is also a potential solution that would help decrease the amount of STP that is needed to bind water. The objective of the present study was to evaluate whey protein concentrate, oat fiber, and oat fiber with vinegar as potential STP alternatives in chunked and formed deli ham and marinated whole chicken breasts. The rationale behind why these ingredients were chosen as potential alternatives is because of their emulsification properties. All blends of oat fiber and whey protein concentrate contained either pork collagen or chicken collagen to strengthen their binding abilities. Fibers also contain botanical extracts that help prevent oxidation in the absence of phosphate. Previous research done by Hayes et al. (1998) demonstrated that pork loin formulated with salt and whey protein concentrate 80 were considered very tender on a 6/8-point hedonic scale. This indicates the ability of whey protein concentrate to bind water thus increasing tenderness. Sharma (2010) evaluated oat bran in chicken patties and found that it contains ß- glucan, a hydrophilic component that binds water. This indicates the ability of oat bran to increase moisture in meat products, increasing palatability. The ability to effectively increase protein extraction in chunked and formed deli ham and increase yields of whole chicken breast using the potential phosphate alternatives, oat fiber and whey protein concentrate in this study were evaluated through cooking yields, tenderness, and sensory acceptability of the chicken breast and deli ham.

CHAPTER II

LITERATURE REVIEW

2.1 Basic brine ingredients

2.1.1 Phosphates

A key ingredient used in a basic brine and in meat processing is food grade phosphate. According to Petracci et al., (2013), phosphates are the salts of phosphoric acid which are used to improve the quality of meat and seafood through enhancing juiciness and tenderness. Phosphates are regulated by the USDA-FSIS (United States Department of Agriculture Food Safety Inspection Service) and can be included at up to 0.5% of the final product weight (USDA-FSIS 1998). The ingredient is classified as G.R.A.S (Generally Recognized As Safe) by the Food and Drug Administration. The phosphate molecule (PO_4^{3-}) is bound to either sodium or potassium as monophosphate, diphosphate, polyphosphates, and metaphosphates. Phosphates are polyvalent ions which can form hundreds to thousands of phosphate tetrahedra (Huynh 2011; Lampila et al., 2002). Monophosphates consist of one phosphate molecule; diphosphates consist of two phosphate molecules. Polyphosphates consist of three or more phosphate molecules in a straight chain, and metaphosphates consist of 6, 7, or 13 phosphates in a ring. Diphosphates are the most functional form of phosphate due to their ability to dissociate actin and myosin thus, increasing the physical interstitial space for water binding. Alkaline phosphates are the most commonly used phosphates in meat and poultry, due to their ability to increase pH and WHC. Acid phosphates can be used for color development in cured meats, and the tuna industry. Acid phosphates are monosodium phosphate, monoammonium phosphate, and sodium acid pyrophosphates; the alkali phosphates include di and trisodium, sodium tripolyphosphate (stp) and tetrasodium phosphates (Alvarado et al., 2007). Phosphates have different functions based on their structure and chain length. The two basic forms of phosphates include chain (linear phosphates) and ring. Only chain phosphates are permitted for food use; ring phosphates are used for water treatment, metal cleaning, and detergent production (Huynh 2011).

Phosphates usually have low water solubility, which is why it is always the first ingredient added to the water prior to the addition of the other ingredients being added. The phosphate should be dissolved first before other ingredients are added. Meat processors will often use a blend of phosphates to achieve functionality objectives. Important factors influence the choice of phosphate mixtures such as solubility, pH, and its effect on meat proteins (Huynh 2011d). STP is the most commonly used phosphate in the meat industry and is the predominate phosphate in phosphate blends that are used in meat systems (Miller 1998; Feiner 2006). Vote et al (2000) reported that using sodium chloride and sodium lactate with STP inhibited soapy flavors. Phosphorus is an essential mineral and an important constituent of adenosine triphosphate (ATP) and is essential to teeth and bone formation (Soetan 2010). Recommended daily intake of phosphorus for an adult 19 years or older is 700 mg. Negative health implications associated with an excess amount of phosphorus includes diarrhea and hardening of organs and soft tissues. Phosphorus toxicity is rare and is mainly a concern with dialysis patients that require a low phosphate diet (Vann et al. 2007). Sodium bicarbonates or carbonates could be used as a phosphate replacer. Petracci et al., (2012) reported that poultry meat formulated with salt and bicarbonate or a combination of salt, bicarbonate, and phosphate had the highest marinade retention at 10.2% and 11.6%, respectively, when used with poultry breast meat.

2.1.2 Sodium chloride

The Egyptians called salt 'natron' which means divine salt and in Rome the Latin term 'salarium' is derived from salt which would be given as a payment or salary to a Roman legionary (Albarracin et al. 2011). Salt is not regulated by any governmental agency since it is a self-limiting ingredient. A salt concentration of 1-1.6% is the most widely used in marinated poultry meat formulations (Petracci 2013).

In meat processing, the chloride ion is the most functional component of salt. The Cl^- ion imparts a negative charge on the myofibrillar proteins, which opens up the structure of muscle fibers so that more water can be incorporated into the meat (Desmond 2006). Na+ ions also provide functionality by forming a cloud around filaments and its ionic affinity (Offer and Trinick 1983). The sodium ion is responsible for the taste and flavor contribution of salt. The oldest way of preserving food is covering it with salt. Fluxes in the salting process occur in two steps: First, water is removed from the food due to osmotic pressure. Second, water flows from lower salt concentrations to higher salt concentrations which dissolves the salt into the food product more rapidly (Albarracin et al. 2011). A more rapid method for incorporating salt into a meat product is brine salting. Brine salting consists of placing raw material in a saturated brine solution, which reduces salting time due to the presolubilization of salt (Albarracin et al. 2011). Injection of brines can be done to equally distribute the brine solution in the meat product. Injection salting consists of needle insertion in the product to uniformly spread the curing solution (Albarracin et al. 2011). Salt is also beneficial to health. Salt fortification with iodine provides a necessary nutrient. In severely iodine deficient populations <25µg/L of blood, hypothyroidism and brain damage are the dominate diseases (Laurberg et al. 2010). Although salt is a multifunctional ingredient in the meat industry, its consumption can contribute to health concerns. The RDI for sodium for ages 19-70 is 1500 mg/d whereas 2500 mg is the maximum level likely to pose no risk or adverse effects (Karppanen et al. 2006). Hypertension is a direct precursor for heart disease, which is correlated with elevated consumption of sodium. Due to the direct relationship between sodium intake and high blood pressure and other diseases, consumer demand for low dietary sodium has led to the production of low sodium restructured meat products (Sun 2009). Sun (2009), Jimenez et al (1998), and Kuraishi (1997) report that transglutaminase, KCl, dietary fiber, and caseinate can all be used as substitutes of a portion of sodium chloride in meat processing. One of the most commonly used alternatives for sodium chloride is potassium chloride. However, only 25% to 50% of potassium chloride can be substituted for sodium chloride since greater than 50% imparts bitterness and loss of saltiness in meat products (Desmond 2006). Potential health concerns have been raised pertaining to KCL usage since certain population sub-groups are susceptible (Type I diabetes, chronic renal insufficiency, end stage renal disease, severe heart failure and adrenal insufficiency) due to high potassium load from these salt substitutes (Desmond 2006). For example, Morton Salt and Cargill Salt have manufactured various forms of salt that can be used at reduced levels to decrease sodium content in meat products (Desmond 2006).

2.1.2.1 Sodium chloride functionality

Sodium chloride improves solubilization/extraction of salt soluble proteins, enhances taste, and improves microbial stability (Petracci et al. 2013). Salt shifts the ionic strength so that the myofibrillar proteins have a more negative charge. The greater the difference between ultimate meat pH and its isoelectric point, leads to greater water binding. The isoelectric point is the point at which a particular molecule carries no electrical charge (Petracci et al., 2012). An increase in WHC is most likely due to the Cl^- ion being more strongly bound than the Na+ ion. The chloride ion has been shown to bind meat protein filaments and increase the electrostatic repulsive force between them (Miller 1998). Salt also has a synergistic relationship with phosphate. According to Huynh (2011), the addition of salt and phosphate at the same time allows proteins to become solubilized or activated to a higher degree. This allows the solubilized protein to entrap or encapsulate fat and immobilize greater amounts of water. Use of salt decreases also water activity in meat, thus increasing shelf life and acting as a means of preservation. Historically, salt was added to meat at very high concentrations prior to the invention and availability of refrigeration (Miller 1998).

2.2 Ingredient Technology in Poultry Marinating

2.2.1 Phosphate Functionality

Phosphates have several functions in meat products including increasing pH, buffer capacity, sequestering of cations, and providing ionic charge strength (Huynh 2011). The increase in pH and ionic strength leads to increased water holding capacity in poultry products. From an economic and quality standpoint, increasing water holding capacity is the most important aspect of phosphate addition to meat (Marcy 1987).WHC in poultry is increased by shifting the pH further away from its isoelectric point. Huynh (2011) stated that phosphate enhances the water binding capacity of myofibrillar proteins by increasing electrostatic forces to create large gaps between actin and myosin. Alkaline phosphates such as sodium tripolyphosphate have an approximate pH of 9.5, which increases the pH so that it is further away from the isoelectric point of the myofibrillar proteins. Mckee & Alvarado (2007) report that phosphates increase and stabilize pH due to the buffering capacity of the short chain phosphates such as orthophosphates. Buffering capacity is defined as moles of an acid or base necessary to change the pH of a solution by 1. This increases the water holding capacity of poultry breast meat, which enhances tenderness and juiciness.

2.3 Ingredient Technology in Restructured Ham

2.3.1 Sweetener Functionality

Goldfein & Slavin (2015), reported that a sweetener is any naturally or synthetically made substance that provides a sweet taste to beverages or food. The most commonly used sweetener is sucrose or table sugar. Sugar is often used to counteract the harshness of salt in processed meat products. Sugar is also used to impart color to ham and other meat products and improve water holding capacity. The Maillard browning reaction and caramelization are used to impart color in a variety of foods. Caramelization occurs when sugars are heated above their melting point causing them to degrade. Maillard browning is the result of the interaction between an amino acid and a reducing sugar during heating a (Goldfein & Slavin, 2015), which imparts flavor and color to meats. Sugar can also cause spoilage of a meat product. The leuconostoc is a gram-positive microorganism that can ferment sucrose in meat products causing them to spoil.

2.3.2 Phosphate Functionality

In a restructured ham product, protein extraction is the main function of marinating, phosphate, and tumbling. However, in a whole muscle product such as a marinated chicken breast, excessive protein extraction is undesirable since the desired function is increased yields, and improved tenderness and juiciness. In cured meats such as ham, phosphates have the ability to sequester cations that are naturally present in meat. The ability of phosphates to sequester ions such as Ca, Mg, and Fe prevents the development of off-flavors and off odors in cured meats (Wierbicki et al., 1976). Use of phosphates in conjunction with salt and the mechanical action of a tumbler increase the solubility of myosin and actomyosin. Phosphates and NaCl allow the unbound myosin to solubilize during mixing and form a gel upon heating (Lampila, 2013). The reduction of particle size and the increase in surface area increases emulsion stability. This can increase the value of less valuable cuts of meat by creating a product that is similar to that of a whole muscle product that is sliceable and does not have holes or cracks in the texture.

2.3.3 Nitrite Functionality

The uses of nitrate and its precursor nitrite in meat products dates back to 200 BC (Honikel, 2008). Nitrite was first approved by the USDA in 1925 at a maximum level of 200mg/kg in cured meat products (Bedale et al., 2016). Nitrite is also approved at a maxium limit of 200 ppm in whole muscle, 156 ppm in comminuted or ground meat products, and 120 ppm in bacon. Nitrate has to be reduced to nitrite to impart its functional properties on cured meat such as in dry cured ham, fermented meats frankfurters and other products that are aged. The reducing activity of the meat and microorganisms reduce nitrate to nitrite during meat handling (Honikel, 2008). Nitrite and its precursor nitrate positively affect the appearance, flavor, safety, and quality of cured meat (Bedale, et. al 2016). As far as appearance, nitrite is reduced to nitrous acid and nitric oxide, and upon heating nitrosylhemochrome reacts with myoglobin to form the cured color in meat. Nitrite inhibits the growth of *Clostridium botulinum* a deadly organism. Cured color formation also protects flavor in meat products. The NO molecule can oxidize to NO_2 which also contributes to the inhibition of rancidity or warmed over flavor (Honikel 2008).

2.3.4 Erythorbate Functionality

The use of nitrate and nitrite in cured meat was nearly banned in the 1970s in the United States due to health concerns (Bedale et al., 2016). When residual nitrites that remain in meat products are heated to high temperatures in products such as bacon, nitrosamines may be formed. Nitrosamines are known carcinogens in animals. Thus, erythorbate is added to the meat formulation to prevent nitrosamine formation, since it inhibits the presence of residual nitrite in the meat product (Honikel, 2008). Erythorbate and ascorbate also act as cure accelerators, which speeds the reduction of nitrite to nitric oxide.

2.4 Water Holding Capacity

Water holding capacity is defined as the ability of a meat system to retain its natural water content, but closely related to water holding capacity is the ability of meat to take up added water at elevated salt concentrations (Hamm, 1960). Water is often the most abundant non-meat ingredient and subsequently the least expensive ingredient in a brine solution. Water is a V-shaped molecule with an electronegative oxygen atom that pulls the electrons from the covalent bond between the oxygen atom and the hydrogen atoms, which leaves each hydrogen atom with a partial positive charge and the oxygen atom with a partial negative charge. This allows water to bind strongly to myofibrillar proteins, specifically actin and myosin. Water is found within myofibrils, between the myofibrils, and the cell membranes (Huff-Lonergan 1998; Offer 1992). Water also exists in three different forms in meat. The three different forms are bound water, entrapped water, and free water. Bound water exists in the vicinity of non-aqueous constituents and has reduced mobility. Entrapped water is water held by steric effects within the structure of the muscle, and free water flows unimpeded within the muscle (Huff-Lonergan & Lonergan, 1998). The ability of a meat product to take up and absorb water has substantial benefits for the consumer and the processor. Increasing water holding capacity leads to higher yields, stable meat emulsions, and improved sensory properties (Huynh 2011). There are two complimentary hypotheses of how water is trapped in the meat structure. Hamm (1972) proposed the electrostatic mechanism of swelling by the selective binding of chloride ions to increase meat pH so that it is further away from its isoelectric point. Offer and Knight (1988) stated that selective binding does not cause repulsion between filaments, but suggested that osmotic force pulls water into the system. As rigor mortis is resolved, muscle protein pH decreases so it is approaching their isoelectric point which is approximately 5.1. This leads to less space for water to be bound or trapped. (Alvarado & McKee, 2007). The isoelectric point is when the net charge of a protein is zero, meaning the number of positive and negative charges on the proteins are essentially equal (Huff-Lonergan & Lonergan, 1998). After resolution of rigor, actin and myosin have rejoined through cross-bridges to form actomyosin.

2.5 Processing Technology

2.5.1 Tumbling

Tumbling is a marinating technique that is used by meat processors to increase product tenderness, juiciness, and produce restructured meat products. Meat can also be tumble marinated to improve flavor, improve tenderness and increase product shelf life (Alvarado & McKee, 2007). Tumblers are baffled rotating drums that provide mechanical action on a meat product. This creates a product that is tender and allows salt soluble proteins to come to the surface of the meat. Physical forces during tumbling disrupt muscle fibers to extract salt soluble proteins which are essential for binding meat pieces together. Furthermore, protein extraction serves two functions. First, proteins coagulate during heating to improve binding properties. Second, extracted protein acts as a sealer when heated which facilitates moisture retention (Alvarado & McKee, 2007). Protein coagulation on the surface helps in the adherence of batter and breading on to the meat. An ionic strength of 0.6, a pH of 6.0 and a temperature of less than 7°C contribute to maximizing protein extraction and gel formation during heating (Schmidt, 1984). Processing time, rotational speed and piece size impact the properties of restructured meat products (Daudin et al., 2016). For example, the length of time a meat product is tumbled directly affects the texture and the amount of brine that the product picks up or absorbs. Over tumbling can cause a product to have a rubbery like texture while under tumbling would create a product with decreased yields and poor texture. Meat product tumbled at 25 rpm and 3,000 revolutions were significantly harder, gummier, and chewier (Boles & Shand 2002), 2002). Intermittent tumbling is often used and includes alternate periods of rotation with rest periods. Tumbler speed directly influences the rate at which the mechanical action of the baffles impart on the meat. Slower speeds cause less disruption of meat fibers, while faster speeds cause greater damage to the fibers. Rotational speeds vary, with lower speeds geared towards marinade retention and greater speeds geared toward protein extraction (Daudin et al., 2016). The size of the tumbler will also greatly affect the quality of the meat product. Tumblers with a bigger radius will extract more proteins in a shorter amount of time than smaller tumblers when tumbled the same amount of time. Speed and time will need to be adjusted accordingly to the amount of product, the size of the tumbler, and the desired mechanical action. Tumbling is most often performed under vacuum due to its ability to remove air from a meat product. Pulling a vacuum during tumbling increases speed, uniformity, and depth of brine penetration (Mckee & Alvarado, 2007).

2.5.2 Massaging

Massaging is a less physical process in comparison to tumbling and involves frictional energy that results from the rubbing of one meat surface on another or on a smooth surface of a container (Krause et al 1978). Since massagers do less damage structurally to a meat product, they are commonly used for marinating delicate foods such as fish or shrimp. Instead of meat hitting the baffles of a tumbler, massagers force meat products to rub up against each other and the walls of the massager itself. Massagers exist in two designs. One design includes vertical paddles and one design contains horizontal paddles. Vertical paddles cause less damage to meat and have a faster massage treatment (Knipe 2004). Massagers function in a similar manner to tumblers, but massaging is a less severe treatment (Mckee & Alvarado 2007). The friction between meat to meat interactions and between the walls of the machine creates heat and can lead to protein denaturation if excessive. The ideal temperature to massage a meat product is 4 to 8°C because the use of cold brines. To prevent temperature increase due to massaging, some massagers have circulation of coolant around the coils of the machine. Massaging time must also be monitored. Longer massaging times will increase protein solubilization, but if the massaging time is too long, it can impart negative effects.

2.5.3 Injection Marinating

Injection marinating involves piercing meat with needles that pump brine or marinade into a meat product (Mckee & Alvarado 2007). Injection is auseful form of marination due to its ability to inject a consistent amount of brine in the product, improve product consistency and save time. Different needle sizes and the type of injection method influences the way the brine is dispersed throughout the meat product. Salmon marination research by Birkeland et al.(2003) used needles 3 mm in diameter 320 mm in length and 2x0.6 mm in bore diameter. Conventional injection and spray injection have different methods of dispersing brine throughout a meat product. Previous research by Ray et al., (2010) found that beef that is mechanically tenderized with hollow or solid needles is known as non-intact beef. Potential issues that can occur during the injection of marinades and or brines include the following: needles can get clogged and improperly distribute brine, meat muscles that contain bones can cause the needles to break or bend and the use of recirculated solutions can increase microbial risk (Ray et al., 2010). These issues made it required for processors by the the order of the Food Safety and Inspection Service (FSIS) to label beef that has been tenderized along with validated cooking instructions. Brine pressure can also negatively or positively affect a meat product. Brine pressure that is too high can disrupt muscle fibers, while brine pressure that is too low can cause unequal brine uniformity.

2.6 Potential Alternatives

2.6.1 Whey Protein Concentrate (WPC)

Whey proteins are one of the two main protein constituents that make up milk. Whey is the liquid substance that is left over from cheese production that is collected and used as an ingredient in many food products. Whey protein contains approximately 16% protein, whey protein concentrate is approximately 34% protein, and isolated whey protein is approximately 8% protein. The two primary proteins of whey are β-lactoglobulin and α-lactalbumin which are globular in structure. Jovanovi et al. (1998) stated that β-lactoglobulin and α-lactalbumin represent 70% of the total whey protein fraction and the globular structure of whey proteins can contribute to the functionality in many foods. These functions include, but are not limited to gelation, emulsification, water binding, and foam formation. The most important function of whey proteins is to to form a gel and bind water. Whey proteins are very heat liable, which allows the protein to unfold and increase water binding (Kneifel & Seiler, 1993). The ability of whey proteins to form gels capable of holding water is very important in processed meat, dairy, and bakery products (Jovanovi et al. 1998). Water control is very important to meat processors. The ability to hold on to lean meat's original water on top of supplementary water is a challenge, especially during cooking (Barbut 2010). Previous research by Kneifel & Seiler, (1993) demonstrated that one of the main constituents of whey protein, β-lactoglobulin has an average water holding capacity of 6.7g of water/100g product.

This would drastically have an effect on the meat quality and could be a possible alternative to phosphate. The ability of WPC to form a gel and bind water is based on various chemical reactions and intrinsic factors, including disulfide interactions and hydrogen bridges. Furthermore, WPC is able to produce a gel at 60-90℃. The gel strength and temperature is dependent on heating time, pH, salt concentration, and ionic strength (Jovanovi et al., 1998). Barbut (2010) stated that any non-meat ingredient must be compatible with salt soluble proteins or it will disrupt the structure and lower yields. Whey proteins also have the ability to form stable emulsions in food systems. Dietary changes have increased the use of non-meat ingredients, such as whey protein that bind supplementary water and replace some of the fat (Barbut 2010).

2.6.2 Oat Fiber

Dietary fiber is defined as the remnant edible part of plants that resists digestion (Zhang et al 2010). Soluble fiber is digestible by the body, while insoluble fiber is non-digestible. The positive health claims about oats and oat fiber have contributed to meat processors including them in formulations. Fibers have numerous health benefits such as maintaining bowel integrity, lowering cholesterol, and controlling blood sugar (Decker & Park, 2010). Fiber recommendations are 30-38g for men and 25g for women between 18 and 50 per day (Brown et al.,1999). The main polysaccharide in oat fiber is β-glucan which is a gelling, emulsifying, and thickening agent (Ahmad et al. 2012). These functionalities make oat fiber a candidate for research as a phosphate alternative. Many characteristics of oat fiber such as water absorption make it functional in low fat bologna and frankfurters (Steenblock & Sebranek, 2001). This ability to hold added water increases the yield of a meat product and allows processors to dilute or decrease the amount of fat in a product. Fat is important for human nutrition as a source of essential fatty acids and provides most of the energy in the diet (Zhang et al 2010). Reducing fat in processed meat is accomplished either by using leaner cuts of meat, dilution of fat by adding water, and adding other non-meat ingredients (Steenblock & Sebranek 2001). Thus, there is a need for ingredients that can impart similar qualities and functionality of phosphate. Oat fiber can be used as a fat replacer in ground beef and pork sausage due to its ability to retain water (Keeton, 1994). While oat fiber does allow for fat replacement and could potentially be a phosphate alternative, over use of the ingredient negatively affects meat quality. Overuse or misuse of oat bran or oat fiber causes problems with patty formation, crumbly texture, raw color appearance, off flavors not associated with beef and a decreased shelf life.(Keeton, 1994). Oat fiber in this study was used with and without dry vinegar to impart ionic strength that dissociates in the meat system

2.6.3 Plum

Plum ingredients contain up to 17% sorbitol, which is used as a humectant to bind water molecules (Jarvis et al. 2015). This attraction of water molecules can be used to create a juicier product, thus imparting one of the critical qualities that phosphate has on meat and poultry. Pectin, which is much like sorbitol in its ability to aid in moisture retention is also found in plums. Jarvis et al. (2015) reported that pectin had an equivalent marinade retention and water holding capacity when compared to sodium tripolyphosphate. These two functional ingredients alone found in plum make it more than suitable as a potential phosphate alternative. Nuñez de Gonzalez et al., (2009) reported that hamburgers containing 3-5% dried plum puree retained more moisture after cooking than control hamburgers with no ingredients added and were approved by the

USDA for school lunches. Plum also contains malic acid which is able to add flavor to a meat product.

CHAPTER III

EVALUATION OF PHOSPHATE ALTERNATIVES IN MARINATED CHICKEN BREAST

3.1 Materials and Methods

3.1.1 Sample Preparation

Broiler breast meat (0.19-0.25 kg per fillet) was obtained from a local poultry processor 24 h after deboning, and transported in coolers on ice approximately 100 km to Mississippi State University. Samples were stored at 2-3°C and marinated within 24 h. Marinade formulations included 1.0 % NaCl (salt, Culinox 999, Morton Salt, NY) and either 0.4% sodium tripolyphosphate (STPnew, ICL Performance Products, St. Louis, MO) or a phosphate substitute treatment and water. The treatment variables consisted of 1) Positive phosphate (0.4 % STP_{new}, 1 % salt and 13.6 % water); 2) Negative phosphate (1 % salt and 14 % water); 3) (Whey protein concentrate (WPC), 1 % salt, 0.94 % WPC blend and 13.06 % water); 4) Oat Fiber (OF, 0.94 % oat fiber blend, 1 % salt and 13.04 % water); 5) Oat Fiber with dry vinegar (OFV, 0.94 % oat fiber, 0.25 % dry vinegar (DV), 1 % salt, and 12.81 % water). The oat fiber and WPC (Bravo 550, Grande, WI) proprietary blends also contained rosemary, oregano, and chicken broth. Dry ingredients were placed into a blender with water and ice (0-2°C) and blended using a 2-speed hand blender (Oster Hand Blender w Blending Cup Rancine, WI). Temperature readings were recorded using a Taylor TruTemp thermometer (3519N Oak Brook, IL) before the addition of ingredients with water and ice before and after shear and with the ingredients before and after shear. Final temperatures of the treatments were -6 to -7℃.

3.1.2 Processing

A Biro Vaccum Tumbler (VTS-44 Marblehead, OH) 825mm in length and 393.7 in width with twin 9.1kg drums was rolled into a cooler (3℃) 24hr prior to tumbling. The brine weighing approximately 0.91 kg was poured into the drum, labeled with the specific treatment, along with 7.8 kg of chicken. Silicon lid gaskets were coated with cooking oil to create a tighter seal prior to pulling a vacuum in the drum. The drums were placed under 25 mm hg and tumbled for 30 min at 8 rpm. Upon completion of tumbling, the temperature (4℃) was recorded with aTaylor TruTemp thermometer (3519N Oak Brook, IL) and the chicken was placed on racks for 10 min to allow the samples to drip prior to cooking to ensure an accurate determination of marinade pick up.

3.1.3 Percent Pick up

After vacuum tumbling and allowing the samples to drip for 10 minutes, the chicken breast were reweighed to determine the percent pickup. The desired pick up percentage for the chicken breast was 15%. Percent pick up was recorded as the difference in weight of the chicken breast meat before and after tumbling using the following formula:

$$\%Pickup= [(Marinated\ weight-Raw\ weight)/ (Raw\ weight)] \times 100 \qquad (3.1)$$

3.1.4 Cooking Loss

Chicken breast were then evenly spaced on cooking racks and placed in a Hobart Steam Oven (Troy, OH) at (177℃) until an internal temperature of (74℃) was reached.

Internal temperature was determined by inserting an Acu-Rite meat thermometer (model 00732, Lake Geneva, WI) in the thickest part of the meat. Three chicken breasts were weighed before and after cooking for each treatment to determine the cooking loss. Cooking loss was recorded as the difference in weight of chicken breast meat before and after cooking using the following formula:

$$\% \text{ cooking loss} = [(\text{raw weight} - \text{cooked weight})/ (\text{raw weight})] \times 100 \qquad (3.2)$$

3.1.5 pH Evaluation

Instrumental pH measurements were taken 24 h after marinating of breast fillets (n=8) for each treatment within each replication. The pH was measured by using an Acumet Portable pH meter (Model AP61 Fisher Scientific Pittsburgh, PA) by inserting a penetrating probe model (05998-20, Cole Palmer, Vernon Hills, IL) 2.5 cm below the pectoralis major muscle at approximately 2.5 cm from the top of the breast, and 2.5cm from the breast bone allowing the pH to stabilize before recording it.

3.1.6 Color Evaluation

Instrumental color measurements were taken for the breast fillets (n=8) for each treatment within each replication that were used for pH measurements. Color values for each chicken breast for each treatment were averaged and expressed using the Commission International de l'Elairage (CIE) scale for L* (muscle lightness) a* (muscle redness) and b* (muscle yellowness). Values were measured by the Hunter Lab MiniScan 45/0° color spectrophotometer EZ (model 4500L; Hunter Laboratories, Reston, VA) that uses a xenon flash lamp to illuminate the raw and cooked chicken breast. The observer angle was set to D65/10°. The instrument was calibrated before taking color measurements using an instrument standard white calibration plate (serial no MSEZ1584). Two measurements were taken per breast.

3.1.7 Instrumental Tenderness

Tenderness was measured following a procedure similar to that of Meek et al. (2000). Breast fillets that were used for cooking loss determinations were used for shear force determinations (n=8 for each treatment within a replication). Cooked chicken breasts from each treatment were cut into six adjacent1 cm (width) X 1 cm (thickness) X 2 cm (length) strips to assess the instrumental tenderness. Each strip was then sheared once perpendicular to the muscle fibers. The Warner-Bratzer shear force apparatus was attached to an Instron Universal Testing machine (Model 3345 Canton, MA 02021) with a 50-kg transducer and a cross speed of 200mm/min. Shear force (N) was reported as the maximum peak force required to shear through each sample.

3.1.8 Consumer Acceptability

Three consumer based sensory panels (n=180 total panelist) were conducted to evaluate the appearance, aroma, texture, flavor and overall acceptability of chicken breast treatments. Cooked chicken breast fillets were cut into 2.5 X 2.5 X 2.5 cm cubes and kept warm (60 to 70℃) using 7.6L covered chafer dishes (53042, Polarware Co., Kiel, WI) approximately 10-15 min until panelist were able to evaluate the samples. Three digit numbers were randomly assigned to treatments to identify samples, and sample order was randomized to account for the sampling order bias. The samples were presented in a monadic serving order. Panelist were provided with water, apple juice, and unsalted crackers to cleanse their pallets. Each panelist was asked to evaluate 5 coded chicken breast samples using a 9 point hedonic scale where 1=dislike extremely, 5=neither like nor dislike, and 9=like extremely (Meilgaard et al. 2007).

3.1.9 Statistical Analysis

A Randomized Complete Block design with three replications was used to test the effect of adding Whey Protein Concentrate, Oat Fiber, and Oat Fiber DV on quality parameters and sensory acceptability of chicken breast (SAS version 9.2, SAS Institute, Cary, NC). Duncan's multiple range test was utilized to separate the treatment means when significant differences occurred among treatments. For overall acceptability data agglomerative hiearchical clustering (ACH) using Wards method (XLSTAT version 2016, Addinsoft USA, New York, NY) was performed to group consumers together based on their preference of broiler breast meat from different marinade treatments. After separation into clusters, the entire data set was evaluated to confirm that the data for each panelist was relatively close to the means of the treatments within the cluster where they were grouped. Randomized complete block designs were used to differentiate ($P < 0.05$) among treatments within each cluster. When significant differences occurred ($P < 0.05$) among treatments, the Duncan's multiple range test was used to separate treatment means within each consumer cluster.

3.2 Results and Discussion

3.2.1 Cooking Loss

The phosphate treatment had less ($P<0.05$) cooking loss and a greater pH than the other treatments (Table 3.1). This indicates that phosphate is able to shift meat pH further away from its isoelectric point, thus increasing the amount of water that can be trapped within proteins. Lampila, (2013) reported that phosphates restore the water holding capacity of meat, which decreases with the onset of rigor mortis. Thus, less water is lost during the cooking process with the addition of STP to chicken formulations. Positive phosphate treatments in this study did include NaCl up to 1.0% which also aids in moisture retention due to the ability of NaCl to increase the ionic strength of myofibrillar proteins in meat. Previous research done by Lopez et. al. (2012) indicated that broiler breast meat marinated with 1.0% NaCl increased moisture retention and that phosphate alone did not improve cooking yield. All other treatments were not significantly different (P>0.05) in their ability to retain water after cooking. Although they were not different, the oat fiber treatment had the lowest mean value of 25.9% cooking loss as compared to whey protein concentrate and the negative phosphate treatment. Sharma (2009) reported that chicken patties formulated with at least 10% oat bran increased cooking yield due to an increased concentration of soluble dietary fiber.

3.2.2 Shear Force

No differences (P>0.05) existed between samples with respect to shear force (Table 3.1). Lack of difference may be attributed to large standard error due to the high variability in shear force which ranged in values from 10 to 40N. Research by Schilling et al. (2003) indicated that all samples would be highly acceptable to consumers with respect to tenderness based on these shear values. The disruption of meat fibers during tumbling may have also aided in all treatments being sufficiently tender. Research done by Szerman et al., (2007) demonstrated that injection of whey protein concentrate and sodium chloride into *sous vide* beef had lower shear force values than the non-injected beef. Previous studies (Barbut 2006) have also indicated that chicken breast meat with batter formulated using dairy proteins (casein and modified whey) have improved texture when compared to chicken breast meat battered with non-meat ingredients included in the formulation.

3.2.3 Marinade Retention

No differences existed ($P>0.05$) between samples with respect to marinade pick up percentage (Table 3.1). Though there was lack of difference, the positive phosphate treatment had the highest numerical average (8.8). Marinade pick up percentage did not reach the target of 15%, which is most likely due to the use of a small tumbler. The tumbler barrels have a minimum capacity of (7 kg) whereas the amount of chicken used in this study was (7.8 kg). The meat to tumbler ratio may have caused unequal brine distribution, thus causing pick up percentage to fail to meet the target. Lack of difference in pH among the negative phosphate, whey, and fiber treatments may have also contributed to the lack of difference in marinade pick up.

3.2.4 Consumer Acceptability

No differences existed ($P>0.05$) in consumer acceptability with respect to appearance, texture and overall acceptability (Table 3.2). The lack of difference between samples may have been due to all samples being tender as indicated by shear force. Likewise, failure to reach 15% marinade pick up causing unequal distribution of brine may have caused consumers to rate chicken breast similarly regardless of treatment. The positive phosphate and whey treatment had greater mean scores ($P<0.05$) with respect to aroma in comparison to all other treatments. Moreover, the positive phosphate treatment flavor was preferred ($P<0.05$) over the oat fiber, oat fiber with vinegar and negative phosphate treatments. Previous research by Saha et al., (2009) reported greater consumer acceptability when chicken fillets were enhanced with salt and phosphate in comparison to a non-enhanced control treatment. Water and juiciness are directly correlated with how tender a meat product is which is correlated with flavor.

3.2.5 Cluster Analysis

Panelists in cluster 1(17.5%) did not like baked chicken breast, but preferred ($P<0.05$) the oat fiber treatment over other treatments (Table 3.3). Cluster 2 (18.7% of panelists) rated chicken breast between like moderately and like very much. , In addition, the positive phosphate, whey protein concentrate, and oat fiber treatments were all preferred ($P<0.05$) over the negative phosphate treatment in this cluster. Cluster 3 consisted of the greatest percentage of panelist (40.9%) and liked the chicken breast treatments slightly. Panelists in cluster 3 preferred ($P<0.05$) the negative phosphate treatment over the positive phosphate, oat fiber, and oat fiber with dry vinegar treatments. Cluster 4 consisted of (8.8% of panelists). These panelists preferred ($P<0.05$) the positive and negative treatments over all other treatments. Cluster 5 consisted of 14.1% of panelists. These panelists preferred ($P<0.05$) the positive phosphate and the whey protein concentrate treatments. The oat fiber treatment was also preferred ($P<0.05$) over the negative phosphate treatment. The positive phosphate treatment was rated at least liked slightly by 82% of the panelists. The oat fiber treatment was liked slightly or greater by 77% of the panelists, while 74% of panelists rated the whey protein concentrate treatment at least like slightly or greater. Both the oat fiber with dry vinegar and negative phosphate treatments were like slightly or greater by 68% of the panelists. This indicates that incorporating oat fiber into chicken marinades can effectively increase the percentage of panelists that like chicken breast as compared to the negative phosphate treatment. Thus, oat fiber has the most potential as a phosphate replacer in cooked, marinated chicken out of the treatments evaluated in this study.

Table 3.1 Marinade retention, cooking loss, shear force, and pH of broiler breasts that were vacuum-tumble marinated with sodium tripolyphospate, and phosphate substitutes

Treatments	Marinade pick-up (%)	Cooking Loss (%)	Shear force (N)	Raw pH after marination
Negative Phosphate	8.4^{a}	26.5^{b}	20.5^{a}	5.85^{b}
Positive Phosphate	8.8^{a}	22.0^{a}	15.5^{a}	5.98^{a}
Oat fiber blend	8.2^{a}	25.9^{b}	19.5^{a}	5.80^{b}
Oat fiber blend with vinegar	8.3^{a}	26.5^{b}	18.1^{a}	5.83^{b}
Whey protein concentrate blend	8.5^{a}	26.9^{b}	14.8^{a}	5.85^{b}
Pooled SEM	0.18	0.80	1.42	0.01
P-value	0.27	<0.05	0.37	<0.05

$^{a\text{-}b}$Means within a column with different superscripts are significantly different (P < 0.05). n = 6 subsamples per treatment (t=5) for each replication (r=3).

Table 3.2 Effects of vacuum-tumbling chicken breast meat with salt and phosphate or salt and phosphate substitutes on the consumer evaluation of appearance, aroma, texture, flavor, and overall acceptability

Treatments	Appearance acceptability	Aroma acceptability	Texture acceptability	Flavor acceptability	Overall Acceptability
Negative Phosphate	6.4^{a}	6.1^{b}	6.3^{a}	6.2^{b}	6.1^{a}
Positive Phosphate	6.5^{a}	6.4^{a}	6.4^{a}	6.6^{a}	6.4^{a}
Oat fiber blend	6.2^{a}	6.1^{b}	6.5^{a}	6.2^{b}	6.3^{a}
Oat fiber blend with vinegar	6.3^{a}	6.1^{b}	6.2^{a}	6.3^{b}	6.2^{a}
Whey protein concentrate blend	6.2^{a}	6.4^{a}	6.3^{a}	6.4^{ab}	6.3^{a}
Pooled SEM	0.11	0.09	0.17	0.14	0.14
P-value	0.49	<0.05	0.41	<0.05	0.22

(n =170)

$^{a\text{-}c}$Consumer acceptability was based on a 9-point scale (1=dislike extremely, 5=neither like nor dislike, and 9=like extremely). Means with the same letter within each column are not significantly different (*P* > 0.05).

Table 3.3 Mean scores for overall consumer acceptability of broiler breasts that were marinated with salt and phosphate or salt and phosphate substitutes according to different clusters of consumer segments using a hedonic scale[1].

Cluster	Panelist (%)	Negative Phosphate	Positive Phosphate	Oat fiber blend	Oat fiber blend with vinegar	Whey protein concentrate blend
1	17.5	4.1^{c}	4.6^{bc}	6.1^{a}	5.2^{b}	4.9^{b}
2	18.7	7.3^{b}	7.7^{a}	7.8^{a}	7.6^{ab}	7.7^{a}
3	40.9	6.9^{a}	6.4^{b}	6.3^{b}	6.2^{b}	6.6^{ab}
4	8.8	7.7^{a}	6.7^{a}	4.0^{c}	6.0^{b}	4.8^{c}
5	14.1	3.8^{c}	6.9^{a}	5.6^{b}	3.5^{c}	6.6^{a}
Percentage of panelists that rated the treatment like slightly (6) or greater		68 %	82 %	77 %	68 %	74 %

(n=170)

[1]Consumer acceptability was based on a 9-point scale (1=dislike extremely, 5=neither like nor dislike, and 9=like extremely). Means with the same letter within each column are not significantly different ($P > 0.05$). Cluster 4 was not separated statistically due to insufficient sample size.

CHAPTER IV

EVALUATION OF PHOSPHATE ALTERNATIVES IN CHUNKED AND FORMED DELI HAM

4.1 Materials and Methods

4.1.1 Sample Preparation

Porcine *semimembranosus* muscles (0.91- 1.4 kg) were shipped from a local pork processor (24h postmortem) to Tupelo, MS and then transported on ice, in coolers for approximately 100 km to Mississippi State University. Samples were stored at 2-3°C and then made into deli ham within 24h. Brine formulations consisted of 1.0 % NaCl (salt, Culinox 999, Morton Salt, NY,) 0.096% sodium nitrite (Double Cure Bloomfield Farms Bardstown, KY), 0.045% sodium erythorbate (Magnolia Seasoning Company West Point, MS) 0.9% evaporated cane sugar (Florida Crystals, West Palm Beach, FL) and either 0.4% sodium tripolyphosphate (STPnew, B.K. Giulini Corp, Simi Valley, CA) or a phosphate alternative treatment and water. The treatment variables consisted of 1) Positive phosphate (0.4 % STP_{new} 1 % salt and 13.6 % water); 2) Negative phosphate (1 % salt and 14 % water); 3) (Whey protein concentrate (WPC), 1 % salt, 0.94 % WPC blend and 13.06 % water); 4) Oat Fiber with dry vinegar (OFV, 0.94 % oat fiber,0.25 % dry vinegar (DV), 1 % salt, and 12.81 % water). The oat fiber and WPC (Bravo 550, Grande, WI) proprietary blends also contained rosemary, oregano, and pork broth. Dry ingredients were incorporated into a mixture of water and ice (0-2°C) using a 2-speed hand blender (Oster Hand Blender w Blending Cup, Racine, WI). Temperature readings were recorded using a Taylor TruTemp thermometer (3519N Oak Brook, IL) before the addition of ingredients with water and ice before and after shear and with the ingredients before and after shear. Final temperatures of the treatments were -6 to -7℃.

4.1.2 Chunking and Forming

Porcine *semimembranosus* muscles were knife cut into 2.54 cm^3 cubes. Each treatment batch weighed 6.8 kg and contained 5.2 kg of meat and 1.6 kg of brine. A 0.78 kg portion of the meat block was finely ground in a Rival food chopper (Model fprvmc 3002 1.5 cup- cup food chopper Kansas City, MO) to increase protein bind. A total of 0.24 kg of brine was included with the 0.78 kg of finely ground meat with a small portion of ham emulsion. The rest of the meat and brine were added to the tumbler. The finely ground meat and additional brine were added at a later time in the tumbling process.

4.1.3 Tumbling Cycle

A Biro Vacuum Tumbler (VTS-44 Marblehead, OH) that was 825 mm in length and 393.7 mm in width with twin 9.1kg drums was rolled into a cooler (3℃) 24 h prior to tumbling. Silicon lid gaskets were coated with cooking oil to create a tighter seal upon vacuuming. The cubed ham portions were placed under 25 mm Hg and tumbled at a speed of 8 rpm. The ham muscles were tumbled using a four-cycle intermittent pattern that consisted of 20 min periods of tumbling followed by 10 min rest periods. After the last 10 min rest period, the vacuum was released and the 0.78 kg ground meat was added with 0.24 kg of the brine solution to improve protein bind and vacuum tumbled for an additional 20 min. Upon completion of tumbling the temperature (4°C) was recorded with a Taylor TruTemp thermometer (3519N Oak Brook, IL).

4.1.4 Percent Pickup

Percent pick up was recorded as the difference in weight of the raw ham muscles before and after tumbling using the following formula:

$$\%Pickup = [(Tumbled\ weight - Raw\ weight)/ (Raw\ weight)] \times 100 \qquad (4.1)$$

Meat lugs (Butcher and Packer Supply Company, Model Jumbolugg Madison Heights, MI) with ham chunks were then covered in Saran wrap (Cling Plus Racine, WI) and placed in a walk in cooler (3°C) for 16 hrs.

4.1.5 Stuffing

Cellulose casings were soaked in warm water for 2-3 min prior to stuffing the chunked and formed cubes. A Tipper Tie (model PTNV Apex, North Carolina) was used to tie one end of the casing. A modified stuffing horn was used to keep the casing open as the meat was fed inside until the casing contained 1.5-1.75 kg of meat. The open end of the casing was then pulled tight and clipped with the Tipper Tie and tagged with the appropriate label.

4.1.6 Cooking Schedule

The stuffed ham samples for each treatment were randomly placed in between two ham mold racks with four springs to place pressure on the hams. The racks were cooked in a Kemtec Smokehouse (Model 100XLT Charlotte, NC) with the following smokehouse program: 1) Drying cycle for 45 min with a 60°C dry bulb and 42°C wet bulb.; 2) cook cycle for 60 min with 66°C dry bulb and 46°C wet bulb; 3) Cook cycle for 60 min with 77℃ dry bulb and 62℃ wet bulb; 4) Cook cycle until an internal temperature of 71℃ at 82℃ dry bulb and 26°C wet bulb; 5) Cold shower for 15 mins. After completion of the smokehouse program, hams were placed in a walk-in cooler (2-3°C) for 16h.

4.1.7 Cooking Loss

Cooking loss was recorded as the difference in weight of the restructured ham before and after cooking in the smokehouse using the following formula:

$$\% \text{ cooking loss} = [(\text{raw weight} - \text{cooked weight})/ (\text{raw weight})] \times 100 \qquad (4.2)$$

4.1.8 Protein Bind

A Protein-Bind method devised for slices of product was used to measure the peak force (N) necessary to break through a 12.7 mm slice of ham. Two ham slices (n=8) from each treatment were analyzed for each replication. Ham slices were pushed down on to nails that were drilled into the top of plexiglass to secure ham slices during testing. Nail holes were positioned 0.5mm apart in 1 mm holes with a diameter of 4.5 mm in the with an inside circular diameter of 4.0 mm. A steel ball (chrome alloy grade 25) 25mm in diameter was attached to a rod and then to an Instron (model 3345 Canton, MA 02021) using a chuck. The instron was set at a speed of 100 mm/min. The ham slice was positioned so that the steel ball would penetrate through the middle of the slice.

4.1.9 pH Evaluation

The pH was measured by using an Acumet Portable (Model AP61 by Fisher Scientific Pittsburgh, PA) by inserting a penetrating probe (Model 05998-20, Cole Palmer, Vernon Hills, IL) into both ends of the 1.5-1.75 kg restructured ham (n=8) prior to slicing.

4.1.10 Slicing and Packaging

The hams were sliced into 12.7mm slices to determinecooked color and 1.578mm thickness for slice integrity using a Hobart (model 3100 manual meat slicer Troy, OH). Slice integrity was defined as the number of slices out of 100 that contained no holes, or cracks in the meat texture. The ham slices were then vacuum packaged (Model 75840157 Vacuum Pouches Koch Supplies Inc, Kansas City, MO) stored at 2-3°C until evaluations were completed.

4.1.11 Color Evaluation

Commission International de l'Elairage (CIE) L* (muscle lightness) a* (muscle redness) and b* (muscle yellowness) values were measured using the Hunter Lab MiniScan 45/0° color spectrophotometer EZ (model 4500L; Hunter Laboratories, Reston, VA). The instrument was calibrated before taking color measurements using an instrument standard white calibration plate (serial no MSEZ1584). Measurements on the front and back of three 12.7 mm ham slices were taken from each ham treatment using a xenon flash lamp to illuminate the sample at an observer angle D65/10°. A total of thirty-six measurements were taken for each treatment within each replication.

4.1.12 Consumer Acceptability

Three consumer based sensory panels (n=172 total panelists) were conducted to evaluate the appearance, aroma, texture, flavor and overall acceptability of chunked and formed restructured ham. Smoked restructured 12.7 mm thick ham slices were cut into 2.5 X 2.5 X 2.5 cm cubes and kept cold (2 to 3℃) in Dart 2oz plastic portion containers (Model 200pc Mason, MI) inside a Viking Professional side by side refrigerator/ freezer

(Model Pf930609 Greenwood, MS) until panelists evaluated the samples. Three digit numbers were randomly assigned to treatments to identify samples, and sample order was randomized to account for the sampling order bias. The samples were presented in a monadic serving order. Panelists were provided with water, apple juice, and unsalted crackers to cleanse their pallets. Each panelist was asked to evaluate 4 coded ham samples using a 9 point hedonic scale where 1=dislike extremely, 5=neither like nor dislike, and 9=like extremely (Meilgaard et al. 2007).

4.1.13 Statistical Analysis

A Randomized Complete Block design with three replications was used to test the treatment effects of adding Whey Protein Concentrate, Fiber, and Fiber DV on quality parameters and sensory acceptability of ham (SAS version 9.4, SAS Institute, Cary, NC). When significant differences occurred for a response ($P<0.05$), Duncan's multiple range test was utilized to separate the treatment means. For overall acceptability data agglomerative hiearchical clustering (ACH) using Wards method (XLSTAT version 2016, Addinsoft USA, New York, NY) was performed to group consumers together based on their preference of deli ham from different marinade treatments. After separation into clusters, the entire data set was evaluated to confirm that the data for each panelist was relatively close to the means of the treatments within the cluster where they were grouped. Randomized complete block designs were used to differentiate ($P < 0.05$) among treatments within each cluster. When significant differences occurred ($P < 0.05$) among treatments, the Duncan's multiple range test was used to separate treatment means within each consumer cluster.

4.2 Results and Discussion

4.2.1 Cook Loss

The positive phosphate treatment had less cooking loss ($P<0.05$) when compared to all other treatments (Table 5.1). This is due to the ability of phosphates to shift meat away from its isoelectric point, which allows more space for water to reside and its ability to seal in water upon heating. No differences existed ($P>0.05$) among the negative phosphate control, and the whey protein concentrate and oat fiber treatments. Although, these treatments can bind water, increased ionic strength and pH is needed to improve functionality. Therefore, there is a need for an ingredient that can not only bind water, but increase the pH of the marinade. Although previous research done by Fernández-Ginés, et. al (1998) indicated that fiber has been used to increase the cooking yield in meat products due to its ability to bind fat and water. Steenblock & Sebranek, (2001) reported a 3% reduction of purge when oat fiber was used in bologna and frankfurter formulations. Whey protein concentrate was similar to oat fiber in its effect to lower cook loss. Ingredients need to be added to increase the negative charges of the oat fiber and whey protein concentrate to lower the cooking loss percentage. Cooking cycles may also need to be modified to maximize whey protein concentrate and oat fiber functionality.

4.2.2 Protein Bind

Sodium tripolyphosphate produced ham with the greatest bind strength ($P<0.05$) as compared to other treatments (Table 5.1). This is due to the synergistic effect that phosphate and sodium chloride have on meat proteins particularly myosin. Siegel & Schmidt (1979) reported that salt is able to a solubilize myosin, while phosphates act to dissociate actomyosin which frees up myosin to participate in interactions upon heating.

Phosphates and sodium chloride along with the mechanical action of tumbling increases protein extraction. This creates a tacky like substance on the surface of the meat, and upon heating this substance forms a gel which binds the individual chunks into one deli meat product that resembles a whole muscle product. The fiber dry vinegar, whey, and no phosphate treatments were not different (P>0.05) from each other with respect to protein bind. Although not different, the oat fiber treatment showed the most promise as a phosphate replacer with respect to protein bind. Aleson-Carbonell etal., (1998) and Imeson (1977) suggested that low bind strength of oat fiber was caused by certain polysaccharides that hinder the formation of a strong protein-protein network. The low binding strength of whey protein was observed by Wit (1988). This researcher stated that as whey proteins are heated to 95℃ and cooled, they do not aggregate until subsequent cooling.

4.2.3 Slice Integrity

All treatments were different (P<0.05) in terms of the amount of slices displayed without holes, or cracks (Table 5.1). Ham slices formulated with sodium tripolyphosphate had the greatest number of intact slices (P<0.05) as compared to all other treatments. This is due to the aforementioned explanation on the synergistic ability of phosphate and salt to free up myosin to form a gel. In comparison of the alternatives, ham formulated with whey protein concentrate had more intact slices (P<0.05) when compared to the fiber dry vinegar treatment. This may be because glucan is a polysaccharide in oat fiber, which may have inhibited its ability to aggregate meat proteins. WPC had better bind than fiber. Hams formulated with the negative phosphate had fewer intact slices (P<0.05) than any other treatment. This treatment consisted of salt and water, and without additional functional ingredients incorportated into the formula, was not able to extract enough proteins to create a strong protein-protein network.

4.2.4 Color Evaluation

There were no differences (P>0.05) with respect to lightness *l** with ham slices from the whey protein concentrate, phosphate, and oat fiber treatments (Table 5.2). The negative phosphate ham slices were darker (P<0.05) (lower *l*)* than ham slices from the whey protein concentrate treatment. No differences (P>0.05) existed with respect to redness *a** among all treatments. All treatments contained nitrite at an equal concentration which imparted the reddish/pinkish cured color to the hams. The fiber dry vinegar treatment was less yellow (P<0.05) than the whey protein concentrate and the positive phosphate treatments. The negative phosphate treatments were also less yellow (P<0.05) than the positive phosphate treatment.

4.2.5 Consumer Acceptability

On average, all hams were liked slightly to like moderately with respect to all acceptability attributes (Table 5.3). Ham appearance of the positive phosphate treatment were liked more (P<0.05) than all other treatments. Lampila, (2013) reported that phosphates protect color by binding metals that oxidize color pigments. No other differences existed (P>0.05) among hams formulated with whey, fiber dry vinegar and negative phosphate with respect to appearance. The aroma of ham slices from the phosphate treatments were liked more (P<0.05) than the fiber dry vinegar and negative phosphate treatments. No differences (P>0.05) existed between the whey protein concentrate treatment and all other treatments in aroma acceptability. The oat fiber dry vinegar treatment was liked less ($P<0.05$) than all other treatments with respect to flavor, texture, and overall acceptability. It is not known if this decrease of acceptability is due to the vinegar, oat fiber, or the combination of the two.

4.2.6 Cluster Analysis

Evaluating consumer preference of food products allows the utilization of cluster analysis (Table 5.4) to group panelists together based on their ratings of deli ham. Panelists in cluster 1 (28.9%) rated all deli ham treatments like slightly and preferred ($P <0.05$) the whey protein concentrate and positive phosphate treatments over the oat fiber with vinegar treatment. Cluster 2 panelists (13.9%) ($P <0.05$) preferred negative phosphate, oat fiber with vinegar and the whey protein concentrate over the positive phosphate treatment. Cluster 3 panelists (39.4%) had no preference ($P >0.05$) for any of the treatments and all deli hams were liked moderately. Panelists in cluster 4 (10%) preferred ($P <0.05$) the positive phosphate treatment over all treatments and the whey protein concentrate and negative phosphate treatments were preferred ($P <0.05$) over the oat fiber with vinegar treatment. Cluster 5 panelists (7.8%) preferred ($P <0.05$) the negative phosphate treatment over the positive phosphate and the fiber with vinegar treatment. The positive phosphate and whey protein concentrate treatment were also preferred ($P <0.05$) over the oat fiber with vinegar treatment in cluster 5. Between 82 and 90% of panelists liked the negative phosphate, positive phosphate, and whey protein concentrate treatments. This indicates that whey protein concentrate could potentially be used as a phosphate replacer, if additional ingredients or process changes could be included to improve cooking yields and sliceability.

CHAPTER V

CONCLUSION

5.1 Conclusions

Whey protein concentrate and oat fiber have the potential to be phosphate alternatives in marinated chicken breast and chunked and formed deli ham. Shear force values for both the marinated chicken breast and the deli ham formulated with oat fiber or whey protein concentrate were considered tender. Consumer acceptability of the marinated chicken breast formulated with oat fiber or whey protein concentrate were rated at least liked slightly on a 9–point hedonic scale. Cluster analysis of the marinated chicken breast showed that 77% of consumers rated the oat fiber treatment and 74% of consumers rated the whey protein concentrate treatment liked slightly or greater. Consumer acceptability of deli hams formulated with oat fiber with vinegar or whey protein concentrate were rated at least like slightly on a 9-point hedonic scale. Cluster analysis of the deli ham showed that 53% of consumers rated the oat fiber with vinegar and 90% of consumers rated whey protein concentrate liked slightly or greater. Deli ham formulated with whey protein concentrate had more intact slices of ham among the treatments. Both the oat fiber and whey protein concentrate were ineffective at increasing meat pH and lowering cooking loss. Future research should be explored to determine ingredients that can increase negative charges on myofibrillar proteins to maximize yield and functionality for use in conjunction with oat fiber and whey protein concentrate as a potential phosphate replacer in meat systems.

Table 5.1 Cooking loss, protein bind, and sliceability of 12.7 and 1.5875 mm thick ham slices with positive and negative controls of phosphate, whey protein concentrate, and fiber dry vinegar

Treatments	Pos Phos	Neg Phos	WPC	Fiber Dv
Cooking loss	9.6[b]	17.6[a]	15.3[a]	10.6[a]
Protein bind	18.9[a]	7.9[b]	9[b]	10[b]
Intact slices	59.5[d]	2[a]	6[c]	5[b]

[a-d] Means with the same letter within each column are not significantly different (p >0.05)
Pos Phos: Positive Phosphate WPC: Whey Protein Concentrate Neg Phos: Negative Phosphate Fiber Dv: Fiber Dry Vinegar

Table 5.2 Cooked color of 12.7 mm sliced deli ham with positive and negative control of phosphates, whey protein concentrate, and fiber dry vinegar

Treatment	**CIE L***	**CIE a***	**CIE b***
Pos Phos	65.6[ab]	10.8[a]	10.1[a]
WPC	67.3[a]	10.5[a]	9.8[ab]
Neg Phos	64.8[b]	10.4[a]	9.2[bc]
Fiber DV	65.5[ab]	10.0[a]	8.4[c]

[a-c] Means with the same letter within each column are not significantly different (p >0.05)
Pos Phos: Positive Phosphate WPC: Whey Protein Concentrate Neg Phos: Negative Phosphate Fiber Dv: Fiber Dry Vinegar

Table 5.3 Consumer acceptability on a 9-point hedonic scale[1] of deli ham with positive and negative controls of phosphates and whey protein concentrate, and fiber dry vinegar

Treatment	**Appearance**	**Aroma**	**Flavor**	**Texture**	**Overall Acceptability**
Pos phos	7.1[a]	7.0[a]	6.5[a]	6.5[a]	6.7[a]
WPC	6.6[b]	6.6[ab]	6.7[a]	6.6[a]	6.6[a]
Neg phos	6.5[b]	6.6[b]	6.7[a]	6.5[a]	6.8[a]
Fiber DV	6.4[b]	6.6[b]	6.2[b]	5.9[b]	6.2[b]
SEM	0.01	0.09	0.01	0.12	0.01
P Value	0.01	0.01	0.01	0.01	0.01

(n=120 panelist 2 replications)
[a-c]Means with the same letter within each column are not significantly different (p >0.05)
[1]The hedonic scale was based on a 9-point scale (9= like extremely; 5= neither like nor dislike; 1= dislike extremely) Pos Phos: Positive Phosphate WPC: Whey Protein Concentrate Neg Phos: Negative Phosphate Fiber Dv: Fiber Dry Vinegar

Table 5.4 Mean scores for overall consumer acceptability of Deli Ham that were marinated with salt and phosphate or salt and phosphate substitutes according to different clusters of consumer segments using a hedonic scale[1].

Cluster	Panelist (%)	Negative Phosphate	Positive Phosphate	Oat fiber blend with vinegar	Whey protein concentrate blend
1	28.9	6.3[ab]	6.7[a]	5.9[b]	6.4[a]
2	13.9	6.2[a]	3.9[b]	6.4[a]	6.3[a]
3	39.4	7.6[a]	7.6[a]	7.6[a]	7.3[a]
4	10.0	4.7[b]	6.9[a]	3.1[c]	4.3[b]
5	7.8	7.8[a]	6.7[b]	3.1[c]	7.4[ab]
Percentage of panelists that rated the treatment like slightly (6) or greater		90%	86%	53%	90%

(n=170)
[a-c]Means with the same letter within each column are not significantly different (p >0.05)
[1]The hedonic scale was based on a 9-point scale (9= like extremely; 5= neither like nor dislike; 1= dislike extremely) Pos Phos: Positive Phosphate WPC: Whey Protein Concentrate Neg Phos: Negative Phosphate Fiber Dv: Fiber Dry Vinegar

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