

QUALITY, YIELD, SHELF-LIFE, AND TENDERNESS OF PORK LOINS
ENHANCED WITH EITHER A SALT AND PHOSPHATE BRINE, A SALT AND
PORK PROTEIN SOLUTION, OR A SALT, VINEGAR, AND PORK PROTEIN
SOLUTION

by

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(Under the Direction of T. Dean Pringle)

ABSTRACT

This study compared the ability of a pork protein solution (PPS) to substitute for a salt/phosphate (CTL) marinade in enhanced pork loins by measuring quality, yield, shelf-life, tenderness, and sensory traits. Loins ($n = 78$) were sorted into three groups of similar initial quality and injected with either CTL brine, salt and PPS, or salt, vinegar, and PPS. Loins enhanced with PPS had reduced sodium content as compared to the CTL brine. Thaw loss and total loss were greater in chops from PPS loins compared to chops from CTL loins. There were advantages in microbial shelf-life of loins enhanced with salt, vinegar and PPS compared to loins injected with CTL or salt and PPS. With consumer trends towards reduced-sodium products, PPS injection appears to have advantages over traditional enhancement technologies. However, additional research should be conducted to improve the yield characteristics of PPS-injected pork products.

INDEX WORDS: Pork, Enhancement, Protein solution

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DEDICATION

This thesis is dedicated to my truly loving and supportive parents, Allen Dale Miller and Dorothy Marie Miller. You have poured out your love for me and have instilled in me character and morals that have and will continue to make me successful in all of my endeavors. You are the most giving and selfless people that I know and I cannot thank you enough for your kindness and encouragement.

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PREFACE

This manuscript is written in accordance with the style guidelines of *Meat Science*, a scientific journal which focuses on research pertinent to the meat industry. Chapter 1 is an introduction to the purpose of enhancement brines and how pork protein solution may serve as an improvement over traditional enhancement technologies. Chapter 2 is a review of the literature pertaining to pork protein solution and pork quality. Chapter 3 describes the materials and methods used to determine the ability of pork protein solution to be used as a replacement for salt and phosphate enhancement brines. Chapter 4 is a discussion of the results that were obtained from this study. Chapter 5 is a brief conclusion of this thesis.

CHAPTER 1

INTRODUCTION

The Purpose of Enhancement Brines

The success of any meat product is influenced by consumer demand and satisfaction. The meat industry strives to meet consumer demands for consistent, high quality meat products at an affordable cost to the producer, packer, processor, retailer, and consumer (Robins et al., 2002). The pork industry has utilized enhancement technology to meet these requirements and provide consumers with tender, juicy products (Sheard et al., 1999). Enhancements or marinades are solutions of water and other ingredients such as salt, phosphates, antioxidants, flavorings, or proteins which are added to fresh, whole muscle meat. These solutions add moisture to products and may improve sensory characteristics.

The addition of marinade solutions to enhance the eating quality of pork and other meat products is now a well-established practice in the UK, the USA and other countries (Bjerklie, 1998; Rust, 1998; Sheard & Tali, 2004). Enhancement brines which include salt and phosphates have been studied extensively for their ability to enhance pork products (Prestat et al., 2002; Jensen et al., 2003). The meat industry is constantly evaluating new and improved enhancement technologies in the continual pursuit of consumer satisfaction at an affordable price.

The pork industry has struggled with the challenge of providing consumers with fresh pork that can be cooked at home and remain juicy and tender. Consumers tend to overcook pork as they have concerns over Trichinosis. Trichinosis is no longer a problem in the United States and there is no need to cook pork to well-done. The U.S. Department of Agriculture's Food Safety Inspection Service has even updated their pork cooking guidelines

to indicate the pork can be consumed safely after cooking to an internal temperature of 145°F followed by a 3 min rest time which is 15°F below the previous guidelines. However, consumers continue to cook pork at elevated temperatures, causing the meat to lose its moisture to the surrounding atmosphere and causing the meat to undesirably lose its natural or added flavors, causing it to become less palatable (Kelleher & Williamson, 2005). One method used to provide consumers with the tender, juicy eating experience that they desire is to enhance whole muscle pork products. Enhancement provides insurance that the product will remain juicy and tender even at a higher than necessary final internal temperature. Injection with enhancement brines have the ability to provide consumers with a more palatable eating experience.

Consumer Trends Toward Clean Labels and Reduced-Sodium Meat Products

Consumer trends are leaning toward cleaner labels and reduced-sodium meat products, which creates a challenge for traditional enhancement technologies. Consumers are more interested than ever in what their meat products contain and how they have been prepared. This trend is evident in the 2010 National Meat Case Study which noted that nutritional labeling on the package expanded from 34% in 2002 to 61% in 2010 in all meat products and from 32% in 2002 to 53% in 2010 in pork products. Products with a natural claim on the label grew 10% from 2004 to 2010. And even more importantly, enhanced pork product counts declined 6% from 45% in 2004 to 39% in 2010. These labeling trends may also be related to potential changes in labeling laws and companies preparing for those changes. These labeling changes are also associated with consumers demands to know more about their products and a trend toward transparency in labeling and the meat industry.

However, this trend does not have to continue as enhanced products can provide nutritional benefits with clean labels at a reduced cost. Using enhancement, the meat industry has an opportunity to fulfill consumer demands for healthy and nutritious meat products with low sodium and low fat (Vandendriessche, 2008).

The majority of the U.S. population consumes in excess of the daily dietary guidelines for sodium, and excessive sodium consumption raises blood pressure, which contributes to the first and fourth leading causes of death, heart disease and stroke, respectively (Moshfegh, et al., 2012). In order to reduce U.S. sodium intake as a whole, food manufacturers, processors, restaurants, and school-lunch programs should strive to produce and serve reduced-sodium products (Moshfegh, et al., 2012). The Institute of Medicine recommended that food manufacturers voluntarily reduce sodium content in the products that they produce (Institute of Medicine, 2010). The meat industry should work to produce enhanced pork products with reduced sodium content in order to aide in the effort to reduce heart disease and stroke while providing consumers with tender, juicy whole muscle pork products.

Pork Protein Solution as a Potential Improved Enhancement Technology

Pork protein solution is minimally-processed and made with natural ingredients through a patented method that may result in reduced-sodium, enhanced products (Kelleher & Williamson, 2005). Pork protein solution is a solution of lean pork trim and water which can be mixed with salt, vinegar, or other processing aides. Ground lean pork trim is chopped with water and the pH of the resulting solution is reduced with citric acid to allow the proteins to bind more water as the pH moves farther away from their isoelectric point. The proteins are in solution at a pH of 3.8, which allows for the excess fat that is still solid to be

skimmed away. The pH is then readjusted to the basic side of the isoelectric point (pH 7.3) with sodium bicarbonate creating water, carbon dioxide, and sodium. The carbon dioxide simply bubbles off as an effervescent solution. Proteins at a pH of 7.3 show enhanced water-holding capacity and can be injected into whole-muscle meat products to improve water uptake. The resulting pH of the enhanced meat product is near the normal pH of meat (≈ 5.8) allowing the product to have a clean label as it still has similar characteristics to meat that has not gone through the process.

Scientific Objective

Currently, salt and phosphate marinade solutions are used throughout the industry to allow for the incorporation of added water to whole muscle products and to provide for sensory benefits. The objective of this study is to evaluate the ability of a pork protein solution to substitute for a salt/phosphate marinade in enhanced pork loins by measuring quality, yield, shelf-life, tenderness, and sensory traits. This is an original study as pork protein solution is a patented product that has not been evaluated as an enhancement brine for fresh, boneless pork loins (NAMP #413). This study shows significant scientific value as the incorporation of improved enhancement technologies in the meat industry may allow processors to produce high quality meat products at an affordable price with reduced-sodium content and cleaner labels.

Hypothesis

It is expected that enhancement with pork protein solution will result in chops with reduced-sodium content as compared to those of loins injected with salt and phosphate, as less sodium is initially added to the enhancement brine.

Additionally, it is expected that chops produced from loins enhanced with pork protein solution will have elevated moisture levels and enhanced juiciness sensory scores due to enhanced moisture retention as the proteins within the pork protein solution will bind additional water as compared to the salt and phosphate brine. This hypothesis is also a result of previous experimentation with ground beef patties and addition of dry pork protein isolates, beef protein enhanced patties seemed to be juicier than control patties.

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CHAPTER 2

REVIEW OF LITERATURE

History and Purpose of Pork Loin Enhancement

The meat industry is a progressive field which continuously strives to improve demand by producing high quality products that are palatable and appealing to the consumer, while minimizing input costs through efficiency and utilizing economical ingredients and materials. A premier example of this continual advancement is the enhancement of pork loins through addition of non-meat ingredients to improve sensory attributes and yields. The effects of various brine formulations, injection/absorption methods, times postmortem of enhancements, and numerous other factors on the quality and efficiency of pork loin enhancements have been studied. However, the meat industry continuously progresses and therefore, continuous study of alternative enhancement solutions that are more economical, healthier, and safer are necessary.

Meisinger (2003) defined enhancement of fresh pork as the process of adding non-meat ingredients to fresh pork to improve the eating quality (juiciness, tenderness, and flavor) of the final product. The meat industry continuously evaluates methods to extend the shelf-life and enhance moisture retention in pork loins in order to more effectively market “case ready” whole pork loins (Sutton et al., 1997). The meat industry enhances whole muscle pork and other meat products through the use of brines and alternative marinade solutions to improve palatability (Sheard & Tali, 2004). Marination technologies are used to maintain consumer-eating satisfaction and to maintain market share (Baublits et al., 2006). Needle injection of whole, boneless pork loins with marinades can aid the pork industry in meeting consumer satisfaction (Detienne & Wicker, 1999). Approximately 60% of fresh

pork was enhanced in 2003 (Gooding et al., 2009) and pumping has clearly shown quality benefits in both beef and pork (Vote et al., 2000). Ultimately, the goal of the pork industry is to improve global consumer demand and it is evident that enhancement aides in meeting that goal.

Additionally, there are numerous options for enhancement and fresh pork products are routinely injected with a variety of brines including flavorings, sodium chloride, sodium/potassium lactate, sodium tripolyphosphate, and water to improve and maintain the palatability of pork cuts (Vote et al., 2000). Enhancement with these ingredients considerably improves tenderness and juiciness of pork loins (Hayes et al., 2006; Sutton, Brewer, & McKeith, 1997).

With a multitude of options for brine formulations, it is difficult to identify a single brine that meets the requirements of all product formulations and there is continual research evaluating emerging ingredients and alternative mixtures for brines. However, polyphosphates are commonly utilized in the production of enhanced meat and poultry products (Detienne & Wicker, 1999). Phosphates are the most common ingredient used for enhancements. Phosphates increase muscle pH, resulting in increased water-holding capacity, less purge loss, more stable color, and better flavor (Sutton, Brewer, & McKeith, 1997). Lawrence et al. (2004) found that phosphate and salt solution enhancements resulted in greater yields, additional water-binding capacity, and higher sensory tenderness evaluations of beef longissimus than calcium lactate enhancements. It is clear that salt and phosphate have been identified as positive contributors to meat quality and yields through enhancements and thus the salt/phosphate brine has become the industry standard for

comparison of new brine ingredients. In general, fresh pork loins benefit from enhancement creating a more palatable product at a lower cost.

Brine Description

Salt and phosphate brines can improve yields, tenderness, and juiciness through their ability to bind water and cause protein swelling (Baublitis, 2006; Hellendorn, 1962; Sherman, 1962; Shults, Russell, & Wierbicki, 1972). Sutton et al. (1997) found that pork loins injected with sodium lactate produced an alkaline flavor. However, beef strip loins injected with up to 15% phosphate/lactate/chloride treatments showed lower ratings for “soapy” or alkaline flavors than untreated control steaks and water injected steaks (Vote et al., 2000). Jensen et al. (2003) found that pork loin chops injected with acetate, lactate, and/or lactate/diacetate showed advantages over those pumped with a salt/phosphate brine in terms of tenderness, juiciness, and pork flavor. Murphy and Zerbe (2004) found that sodium dextrose, sodium phosphate, and sodium dextrose phosphate solutions all increased ultimate pH with no adverse color or microbiological effects when infused pre-rigor into lamb carcasses.

Phosphates have been used extensively in brines and work in specific ways based on their structure. After hydrolysis to pyrophosphate, polyphosphate, has two major effects including weakening the binding of myosin heads to actin, promoting the dissociation of actomyosin, and promoting the depolymerization of myosin filaments which allows limited expansion of the filament lattice (Offer & Trinick, 1983). This expansion allows polyphosphate-enhanced meat to absorb and retain more added water than untreated meat (Sheard et al., 1999). The increased tenderness of polyphosphate-enhanced meat can be attributed to the higher water content of cooked samples and the weakened sarcomere

structure (Sheard et al., 1999). While it is understood that addition of polyphosphates improves tenderness and juiciness (Sutton, Brewer, & McKeith, 1997), the consumer acceptability of polyphosphate-enhanced meat may be limited due to negative flavor effects and consumer preference of 'additive-free' meat products (Sheard et al., 1999).

It is obvious that there has been intense discussion and analysis of the advantages of certain brines over others and there are different findings based on species, cut, quality of initial product, lipid content of initial product, enhancement method, and other factors. Each of the previous discussed studies formulated controls for these factors within their individual studies. However, as results vary among studies, it is difficult to compare the results of the studies to each other.

Therefore, it is important to identify a single product of interest such as boneless pork loins and control all factors of influence and only compare the results within this study. For example, the results of the present study should only be utilized to compare salt/phosphate brines with pork protein solution brine within the boneless pork loins injected 7 d postmortem.

Muscle Protein Extraction Methods

Postmortem muscle proteins have been classified as contractile or myofibrillar, water soluble or sarcoplasmic, and water insoluble or connective tissue (Hultin, 1985). Myofibrillar proteins, especially myosin and actomyosin, are believed to be responsible for gelation (Niwa, 1992). Differences in concentrations of these various proteins occur due to differences in species and muscle location within species.

It is of high interest to identify methods to separate these protein types in order to effectively market each type of protein and to enhance products with only certain protein

types. Proteus Industries, Inc. has patented a low pH method to separate these proteins into individual products that can be effectively marketed with solubilized myofibrillar and sarcoplasmic proteins entering the whole muscle injection brine supply chain (Kelleher & Williamson, 2005). These solubilized myofibrillar and sarcoplasmic proteins can be labeled as protein solution and have an elevated water-holding capacity at pH's lower and higher than their isoelectric point. This product must be analyzed to determine its potential for use as an enhancement solution.

Ionic strength, pH, and salt type are the main indicators of protein extractability of salts (Franks, 1993). Protein extractability also depends on the extracting procedure including volume of extraction solution, duration of homogenization, centrifugal force and time, temperature, fat:lean ratio of meat product, specie of meat product, and a multitude of other factors which make defining extractant method among a variety of meat products an extremely difficult process (Munasinghe & Sakai, 2004). As Selmane, Christophe, and Gholamreza (2008) worked to define the optimum extraction procedure conditions for slaughterhouse by-products, they studied variations of pH, temperature, and operation time and found that functional properties of proteins are strongly dependent on the treatments applied. Therefore, the extraction process must be optimized in order to obtain the most functional proteins which will create proteins with the highest water holding capacity and possibly the products with the highest yields.

High ionic strength salt solutions have been utilized to extract proteins for meat batter production in the processed meat industry (Lopez-Bote, Warriss, & Brown, 1989). In pork meat, sodium chloride has the highest protein extractability as compared to lithium chloride and potassium chloride, which seems to be a result of increased myosin extraction

(Munasinghe & Sakai, 2004). However, Kelleher and Hultin (1991) found that lithium chloride had the highest protein extractability in fish meat compared to sodium chloride and potassium chloride.

Myofibrillar proteins are primarily responsible for the binding of water in muscle (Hamm, 1960). By raising the net charge of a protein solution with the addition of either acid or base, the microstructure of the muscle fiber is loosened and there is an increase in immobilized water within the muscle fiber (Hamm, 1960).

Sodium chloride increases the water-holding capacity of meat proteins when pH exceeds the isoelectric point and decreases the water-holding capacity when the isoelectric point exceeds the pH (Hamm, 1960). This effect is primarily due to chlorine anion which causes a strengthening of the interaction between oppositely charge groups when the pH is less than the isoelectric point, while sodium chloride causes a weakening of the same interaction when pH exceeds the isoelectric point (Hamm, 1960).

Therefore, a brine of pork protein solution and salt would be of particular interest to study in comparison to current industry salt/phosphate brines.

Pump Rate

A salt/phosphate solution enhancement at an 18% pump rate as compared to 12% can improve sensory tenderness ratings without decreasing product yields (Baublitis, Pohlman, Brown, & Johnson, 2005). However, phosphates at high levels can produce off flavors (Smith et al., 1984). Hayes et al. (2006) utilized a 110% of the green weight pump rate to study the effect of enhancement with either a salt and sodium tripolyphosphate, salt and β -lactoglobuli, or salt and whey protein concentrate on the physical and sensory properties of pork loins and found differences in sensory tenderness and juiciness, Warner-Bratzler shear

force, objective color, drip loss, purge loss, and protein content between treatments. The results of Hayes et al. (2006) indicate that a pump rate of 110% of the green weight is high enough to exhibit results from differences in enhancement solutions. Baublits et al. (2006) found that loins treated with 12% pump rates exhibited higher ultimate pH values, lower shear force values, and lower incidence of off-flavor reports from sensory panels than untreated chops.

Currently, the industry is utilizing a variety of pump rates based on production methods and goals. In the present study, a 12% injection rate was utilized as this is a common pump rate that typically shows advantages with salt/phosphate brines. A 12% pump rate is common in industry and is high enough to show to effects of various brines on pork quality and yields. It is also important to note that injection rate effects are associated with the concentration of the ingredients within the brine.

Pork Quality

Due to the increasing global demand of pork products, the study of quality in enhanced pork is imperative to the progression of the pork industry (McKeith, 2010b). Pork quality has been studied for over fifty years and it is evident that consumers and segments of the industry have varying definitions of pork quality which has resulted in confusion throughout the industry (Bray, 1966; McKeith, 2010a).

Meat scientists have traditionally defined fresh meat quality, including that of fresh pork loins as the factors associated with the palatability of fresh and cured products coupled with economic losses during processing and distribution of those products (Bray, 1966). Meat quality also includes those factors that affect price or preference for certain meat items. Meisinger (2003) explained that the pork industry needed to develop clear economic signals

to easily and objectively measure “quality” in order to meet varying consumer demands for a variety of pork products.

Color, texture, firmness, water-holding capacity (WHC), tenderness, marbling, flavor, juiciness, glycolytic potential, muscle fiber type, nutritional value, safety and pH have been studied as indicators of pork quality (Bray, 1966; Huff-Lonergan, 2002; Koohmaraie & Geesink, 2006; McKeith, 2010a). While all of the previously listed traits are measures of pork quality, tenderness has consistently ranked as the most important quality aspect of meat and consumers are even willing to pay a premium for guaranteed tender meat (Koohmaraie & Geesink, 2006; Miller et al., 2001). Additionally, pH is another one of the major gauges of meat quality and the pork industry consistently uses pH to differentiate product of varying quality (Holmer et al., 2009).

There are significant correlations among biochemical traits, subjective sensory evaluations, and objective instrumental measurements of quality and identifying those correlations is important in order to significantly improve pork quality (Huff-Lonergan et al., 2002). For example, the pork industry has made tremendous advances towards the goal of improving the lean to fat ratio of market hogs through genetic selection. Within the Berkshire breed, subjective color, marbling, and firmness scores were all significantly correlated with sensory scores except for juiciness; and subjective color was significantly correlated with firmness, drip loss, and instrumental tenderness (Star Probe) (Huff-Lonergan et al., 2002). These results indicate that darker meat was correlated with firmer, more tender meat that showed less drip loss (Huff-Lonergan et al., 2002). Products with higher marbling scores and intramuscular lipid content received higher firmness scores (Huff-Lonergan et al., 2002). However, it is not feasible to measure the sensory and visual traits described above

directly. It is beneficial to understand the relationship between biochemical characteristics and the quality traits described above in order to make more rapid genetic progress. Huff-Lonergan et al. (2002) found that postmortem pH at 24 and 48 h was most highly correlated with color, drip loss, tenderness, flavor and off-flavor scores, and cook loss. Glycolytic potential which is a measure of the amount of glycogen present at slaughter and lactate content have been shown to have a significantly positive relationship with objective lightness and drip loss values while being negatively correlated with pH. Additionally, sensory panel tenderness, juiciness, flavor, and off-flavor scores and instrumental tenderness (Star Probe) were most highly correlated to ultimate pH and factors that impact pH decline including residual glycogen, lactate, and glycolytic potential (Huff-Lonergan et al., 2002). The addition of enhancement brines can impact ultimate pH and therefore should impact sensory panel scores for tenderness, juiciness, flavor, and off-flavor and instrumental tenderness. Understanding these relationships can save the meat industry time and money through directly studying biochemical traits to predict pork quality rather than sensory and instrumental indicators of quality.

Pork quality attributes can be separated into two categories including those that influence purchasing decisions in the retail market such as color, marbling, subcutaneous fat content, purge loss, water holding capacity, and marketing schemes and those that influence after-purchase satisfaction such as sensory characteristics including juiciness, tenderness, and flavor (Gooding et al., 2009).

Tenderness

Tenderness is defined as the ease with which a meat product is penetrated, fractured, and broken down during the mastication process (Jeremiah, 1988). Tenderness of meat is

influenced during two phases including the toughening phase and the tenderization phase. Tenderness is also influenced through the background effect which is related to the organization of the perimysium.

The toughening phase is related to rigor development and the formation of actomyosin bonds and the shortening of sarcomeres (Wheeler and Koohmaraie, 1994). Rigor development occurs in all species and shows similar decreases in tenderness and shortening of sarcomeres (Koohmaraie, 2007). Herring et al. (1967) suggested that there is a strong negative correlation between meat toughness and sarcomere length in bovine muscles. Therefore, as stronger actomyosin bonds form, the sarcomere shortens and meat becomes tougher.

However, there is a highly variable tenderization phase which helps to counteract the toughening phase through postmortem proteolysis. Koohmaraie, Doumit, and Wheeler (1996) believed that proteolysis of certain cytoskeletal proteins that aid in upholding the sarcomere structure result in increased tenderization. The calpain system contributes to the effect of the tenderization phase by degrading cytoskeletal proteins thereby resulting in weakening of the Z-disks and fragmentation of the myofibrils (Koohmaraie & Geesink, 2006).

This tenderization process takes varying amounts of time due to differences in species, postmortem pH decline, calcium levels, genetic influences, glycogen levels in the muscle tissue, and other additional factors. Pork typically requires a relatively short postmortem aging period to achieve tenderization due to the young age of the animal at processing and common industry practices to enhance tenderization such as brine injections (Lawrie, 1998). Sheard et al. (1999) showed that processing has larger effects on tenderness

than those produced during production. Gault (1985) found that increased water holding capacity markedly influenced cooked meat tenderness, irrespective of the lipid content of the muscles. Hayes et al. (2006) showed that Warner-Bratzler shear force, a measure of the maximal force needed to shear a cylindrical core of meat heated in water, was lower in enhanced than non-enhanced pork loin chops.

Research has shown varying results regarding the causes of tenderization and the ability to influence those causes and therefore the industry has followed a postmortem route of controlling tenderness through enhancement technology. Enhancement is consistent, relatively inexpensive, and increases yields.

pH

It has been clearly shown that pH has a significant impact on water-holding capacity (WHC) and that WHC increases on either side of the isoelectric point of meat (Gault, 1985). Therefore, it is desired to produce pork products at pH levels that differ significantly from the isoelectric point to improve their WHC and yields without imparting any negative visual, microbiological, or sensory defects on the product. Initial and ultimate pH can influence protein denaturation and quality attributes including color and water-holding capacity which influence processing yields, export acceptability, consumer preferences, and sensory characteristics (Bidner et al., 2004).

One of the most prominent effects of pH includes its influence on color. As muscle pH moves away from the isoelectric point of meat, muscle appears darker due to increased light absorbance by the muscle (Price & Schweigert, 1987). Additionally, Offer (1991) concluded that drip loss increases as muscle pH decreases. Holmer (2009) concluded that

increased length of aging time of high pH pork loins will result in microbial proliferation that can decrease shelf-life.

An intermediate pH (5.4-6.0) may be the best option in a program with extensive aging as high pH is associated with enhanced quality but may result in increased unacceptable flavor intensity and low pH is associated with extended shelf-life (Bidner et al., 2004; Holmer et al., 2009). Holmer et al. (2009) found that at 7 d of aging aerobic plate count (APC) is relatively unaffected by pH, but, that at d 28 pork with pH ranging from 6.25 to 6.30 had a 3 log greater APC density than pork with a pH ranging between 5.40 to 5.45. However, Bidner et al. (2004) stated that high pH pork loins may have increased juiciness and tenderness and Holmer et al. (2009) stated that higher pH pork will have superior quality as compared to lower pH pork. Bidner et al. (2004) reported that high pH pork loins may have lower pork flavor intensity and a higher rate of off-flavor incidence. With the clear advantages in shelf-life of low pH pork and quality advantages of high pH pork, an intermediate pH of 5.4-6.0 may be the best option for the majority of pork loins.

Color

Visual attributes of pork are becoming more pertinent as consumers are viewing more case-ready products under bright fluorescent light and allowing their visual observations to substantially impact their purchasing decisions (Gooding et al., 2009). Consumers use a variety of factors to make purchasing decisions at the meat case and color is one of the most important factors (Gooding et al., 2009). Consumers are continuously becoming more educated and are studying their meat products of choice in more detail. Brewer and McKeith (1999) even reported that consumers discriminate against pork described as “very light pink”.

The National Pork Board suggests that the optimum pork color is pinkish grey, which is a color score of three to four on the National Pork Producer's Council color scoring system (NPPC Pork Quality Solutions Team, 1998). This color scoring system ranges from one to six, with one being very pale and 6 being very dark (NPPC Pork Quality Solutions Team, 1998). The previous method described is a subjective method of visual analysis for pork lean color. Bidner et al. (2004) found that ultimate pH explained 79% of the variation in subjective color and that as pH increased, subjective color score also increased or became darker.

Objective color measurements utilize instruments such as colorimeters which measure L^* , a^* , and b^* values which are correlated to lightness, redness, and yellowness, respectively. Instrumental color measurements can be used to correlate or confirm perceptions of the human eye or subjective color measurements. Instrumental color measurements typically measure surface reflection. However, extraction and quantification of pigment content can also be used to objectively measure color even though this process is labor intensive, variable, and destructive of the product (Mancini & Hunt, 2005). Bidner et al. (2004) found that as ultimate thoracic pH, a measure of pH on 5 g of longissimus tissue removed at the 10th rib homogenized in water, increased, L^* values decreased indicating darker meat (Brewer et al., 2001).

Therefore, it is important to study pork color and to choose processing methods that either positively impact color or have no detrimental effects on color. However, pork color can be difficult to predict throughout a carcass. Waylan, Unruh, and Johnson (1999) reported that pH and color are inconsistent along the length of the longissimus muscle and this creates a problem for sorting loins into quality groups. However, after Norman, Berg, Ellersieck,

and Lorenzen's (2004) attempt to formulate regression equations to predict color and pH throughout pork loins resulted in low R^2 values, it was concluded that the current method of sorting pork loins based on blade or sirloin objective color were acceptable.

Sensory Attributes

Bryhni et al. (2003) concluded that consumer preference and consumption of pork are influenced by detection of quality differences and that the meat industry can benefit substantially by accounting for sensory characteristics during production. In order to produce high culinary quality meat products that satisfy consumer demand, knowledge of the consumers' choices and preferences is necessary (Aaslyng et al., 2007; Bryhni et al., 2003).

If consumer acceptance is important in product development, research focus should be placed on consumer response to variations in sensory attributes including color, flavor, juiciness, and tenderness (Aaslyng et al., 2007). Young consumers' preference for meat has been related to sensory quality attributes of the meat, which shows a trend towards this consumer preference in the future (King et al., 2004). This indicates that potential enhancement brines should be evaluated for sensory quality including juiciness, tenderness, and flavor as the future consumer is placing significant emphasis on these traits.

Injection of fresh pork loins with a water and sodium tripolyphosphate brine improved tenderness and juiciness but reduced pork flavor intensity and increased abnormal flavor intensity (Sheard et al., 1999). Sutton et al. (1997) showed that pork flavor, salt intensity, and alkalinity were enhanced by sodium lactate addition and that color was not affected by sodium lactate or sodium tripolyphosphate addition. Sutton et al. (1997) concluded that pork loins showed increased moisture retention and few negative effects on sensory characteristics with the addition of either sodium lactate or sodium tripolyphosphate.

Enhancement of pork loins to 110% of the green weight with 0.4% salt, 0.4% phosphate and added water solution resulted in improved sensory attributes of chops even when cooked to excessive endpoint temperatures of 80 °C (Prestat, Jensen, McKeith, & Brewer, 2002).

It is obvious that sensory attributes are important to consumers and have a major impact on repeat purchases of products. Therefore, sensory attributes should be studied on products to indicate their consumer acceptance and potential market share in the meat industry.

Enhancement and Yields

There are clear economic benefits in the addition of low-cost ingredients to high value whole muscle meat products, especially those that can bind water and promote the sale of “added water” meat products. Higher yields mean increased margins. This trend towards enhanced products due to the positive impact on yields has been demonstrated in the pork industry, especially within the United States.

Sutton et al. (1997) showed that pump yields increased and purge loss was reduced with the addition of sodium tripolyphosphate. Injections with calcium lactate and phosphate and salt solutions have been shown to significantly increase pump yield and decrease expressible moisture when compared to calcium lactate solutions, indicating the importance of phosphate and salt in improved yields of enhancement solutions (Lawrence et al., 2004). Addition of phosphates often increases the ultimate pH which improves the water-holding capacity of meat which can increase tenderness (Murphy & Zerbe, 2004).

It is important to study the effect of alternative enhancement methods on yields and water-holding capacity in order to improve and maintain the economic benefit of enhancement within the pork industry.

Microbiology of Pork Loins

Food spoilage and safety are of utmost importance today and therefore products that show improvements in shelf-life and microbiological standards are truly the future of this industry. Longer shelf-life allows for products to be placed on display for longer periods of time prior to spoilage which creates less waste in the retail market.

Treatment with a sodium lactate or a sodium lactate and vinegar mixture of hot-boned pork sausage patties resulted in reduced Aerobic Plate Count (APC) by a minimum of 2 logs at 14 d postmortem and a minimum of 1 log at 16 and 18 d postmortem as compared to BHA/BHT treated control patties (Bradley et al., 2011). Salts of acetic and lactic acids in enhancement solutions have inhibited microbial growth and extended shelf-life to a higher degree than salt and phosphate brines (Jensen et al., 2003). It is important to note that reduced APCs do not result directly into extended shelf-life.

Enhancements can have positive or negative effects on shelf-life and microbiological quality. Therefore, study of pathogens and spoilage organisms are vital to the success of any enhancement brine.

Summary and Additional Research

As the pork industry strives to grow globally, enhancement of products, particularly boneless pork loins, will continue to expand. Research should be completed on potential additions of brines based on pH, color, marbling, water-holding capacity, tenderness, sensory attributes, yields, safety, and microbiological quality. Enhanced products have the opportunity to improve efficiency, a key to feeding an exponentially growing population that will double by 2050. Efficiency, safety, and technology are vital to meeting this demand for protein products and pork loin enhancement can clearly help to meet that goal. High quality

protein products can significantly improve the health of a population through nutrition and therefore the more meat that can be produced, the more people that can be fed meat protein. Pork protein solution is a product that uses less expensive proteins to enhance more valuable meat products allowing for there to be a greater amount of more desirable meat products as compared to the less expensive products that are not in high demand by consumers.

The present project will study the effect of pork loin enhancement with a sodium/phosphate brine or a pork protein solution on purge, yield, tenderness, color, pH, marbling, shelf-life through microbiological sampling, proximate analysis, and sensory attributes. This study will help to determine whether enhancement with pork protein solution is a viable method that is competitive with salt/phosphate brines. Potential limitations include methods of injection, including site, and equipment usage as these attributes should clearly represent industry methods in order to make this study usable for the meat industry. An additional limitation includes transportation of loins to the University of Georgia Meat Science and Technology Center from a production site, as this step in the process may have significant effects on purge and shelf-life. Temperature and transportation should be consistent with industry standards in order to not influence purge or shelf-life.

Additional research should be done to evaluate the use of advanced meat recovery/mechanically separated meat and offal in the protein extraction process that was described above. These products are extremely inexpensive and should be utilized to improve their value to the industry. If valuable proteins can be extracted from these products at a low cost and incorporated into higher value meat products, then yields of those products will increase.

The effects of enhancement in other whole muscle products in a variety of species should also be studied in order to use enhancement to its full ability. Education efforts should also be made to make consumers aware of the positive attributes of enhancement and the research that has been conducted thus far to prove the safety of these products. This education will possibly diminish the current negative stigma of processed and enhanced meats.

Considering all these issues, the effect of enhancement with a pork protein solution or a salt/phosphate brine will provide necessary data to continue to improve global demand and supply of pork loins.

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CHAPTER 3

MATERIALS AND METHODS

Boneless Pork Loin Collection

Fresh, boneless pork loins (NAMP, 413; n=90) were collected from a large, commercial processing plant and shipped to a further processing plant in the Southeastern United States 72 h postmortem. Loins were transported to the University of Georgia Meat Science and Technology Center 96 h postmortem and surface temperature remained under 4.44°C during transportation. Loins were stored at 4±2°C until 120 h postmortem and then evaluated for initial quality.

Lean Pork Trim Collection

The injection brines containing pork protein solution include 90/10 lean pork trim as an ingredient. Fresh lean pork trim (81.65 kg) was collected from a large, commercial further processing plant in the Southeastern United States and transported to the University of Georgia Meat Science and Technology Center and surface temperature remained under 4.44°C during transportation.

Preparation of Pork Protein Solution (PPS)

Lean pork trim was chopped in water (20% w/w) and then the pH was reduced to 3.8 with food grade citric acid (Jungbunzlauer Suisse AG, Port Colborne, Ontario, Canada). The fat was skimmed from the solution and the pH was raised to 7.3 with food grade sodium bicarbonate (Arm & Hammer, Church & Dwight, Co, Inc., Princeton, New Jersey, United States of America).

Boneless Pork Loin Selection and Initial Loin Quality Measures

Fresh, boneless pork loins (NAMP #413; n=90) were evaluated for initial quality, green weight, and initial purge in order to form three groups (n=26 per group for a total n=78) for further treatment and analysis. Loins (n=12) not used to form the three groups were discarded. Statistical analysis was used to determine that the 3 treatment groups (n=26) were of similar initial quality in order to accurately determine the effects of enhancement. Twelve loins were used for microbial analysis and fourteen loins were used for quality analysis per treatment.

Initial purge was calculated by weighing loins in their initial bag. Loins were removed from the bag, gently blotted, and reweighed. Bags (n=10) were collected, cleaned, dried, and weighed to determine mean bag weight. Initial purge was calculated using the following equation:

$$[((\text{Initial wt. in bag} - \text{bag wt.}) - (\text{Initial wt. out of bag})) / (\text{Initial wt. in bag} - \text{bag wt.})] \times 100\%.$$

A portion of the sirloin-end of the loin was removed in order to evaluate a freshly-bloomed meat surface and loins were allowed to bloom for 20 min. prior to quality evaluation. Objective CIE color measurements [Lightness (L*), redness (a*), and yellowness (b*)] were taken using a Minolta Chroma Meter (Model CR-310, wide-area illumination, 50 mm-diameter measuring area, 0° viewing angle, C Illuminant; Minolta Co., Ltd.; Ramset, NJ, USA) on the sirloin end of the loin. Standardized white and black tiles were used to calibrate the colorimeter. Three readings of L*, a*, and b* were taken per loin and averaged.

Initial marbling was determined with National Pork Producers Council marbling scores (NPPC, 1999) on the sirloin end of the loin on a scale of 1 to 10 (higher numbers indicate more intramuscular fat).

Initial pH was determined on the sirloin end of the loin with a portable pH 11 meter (Eutech Instruments Pte Ltd / Oakton Instruments, Vernon Hills, IL, USA) equipped with a spear-tipped probe.

Preparation of Enhancement Brines

Three enhancement brines were prepared with the following final concentrations in the uncooked loins:

- I. Control brine (3.4% salt, 3.4% Brifisol 85 Instant Phosphate (BK Giulini Corporation, Simi Valley, California, United States of America) 93.2% water)
- II. Salt and PPS (3.4% salt in 96.6% PPS)
- III. Salt, vinegar, and PPS (3.4% salt and 1.3% dried vinegar (World Technology Ingredients, Inc., Jefferson, Georgia, United States of America) in 95.3% PPS)

Injection with Enhancement Brines

Loins were injected to approximately 113.0% of initial weight using an Inject Star B-172 model with 18 needles (Inject Star of the Americas, Inc., Mountain View, Arkansas, United States of America). Hypodermic needles were utilized with large ports in order to allow PPS to easily pass through ports. Percent pump was determined using the following equation:

$$(\text{Pumped wt.} - \text{Initial wt.}) / \text{Initial wt.} \times 100 \%$$

Loins were vacuum packaged in Cryovac® Grip & Tear™ heat shrink loin bags which have an exceptional oxygen barrier (Sealed Air Corporation, Duncan, South Carolina, United States of America) and shrunk in a steam kettle ($60 \pm 2^\circ\text{C}$). Loins used for quality analysis were aged at $4 \pm 2^\circ\text{C}$ for 7 additional days (total of 12 d post-fabrication) before being sampled. Loins used for microbial analysis were aged for 28, 30, or 32 d at $4 \pm 2^\circ\text{C}$.

Preparation of Loins for Microbial Analysis

Twelve loins from each treatment were randomly assigned to microbial testing for 3 aging periods (d 28, d 30, d 32 post-fabrication; n=4 per treatment and aging period combination) and stored at $4\pm 2^{\circ}\text{C}$ until delivery to Food Safety Net Services in Atlanta, GA. These aging periods are common for shelf-life evaluations for vacuum-packaged, refrigerated products. Loins were transported to the Food Safety Net lab on ice so that surface temperature remained under 5°C . At Food Safety Net Services, loins were analyzed for aerobic plate count (APC), lactic acid bacteria (LAB), *E. coli*, coliforms, Enterobacteriaceae, and *Pseudomonas*. APC was tested using the AOAC approved procedure with the APC Petrifilm (3M Microbiology, St. Paul, MN, USA). LAB was tested using MRS media in an anaerobic environment according to the Bacteriological Analytical Manual of the Food and Drug Administration. *E. coli* and coliform testing was completed using the AOAC approved procedure with the Total Coliform Petrifilm (3M Microbiology, St. Paul, MN, USA). Enterobacteriaceae counts were tested for using the AOAC approved procedure with Enterobacteriaceae Petrifilm (3M Microbiology, St. Paul, MN, USA). *Pseudomonas* was tested for using the Food and Drug Administration's Bacteriological Analytical Manual approved method with SMA, MLB, and CET media. Results were reported as Colony Forming Units (CFU) per mL. CFU per mL values were converted to log CFU/mL.

Pumped Loin Quality Measures

Twelve days post-fabrication, loins (n=14 per treatment) were weighed in Cryovac® Grip & Tear™ heat shrink bags. Loins were removed from bags, blotted dry, and weighed. Pumped purge loss was calculated using the following equation:

$$\frac{[(\text{Pumped wt. in bag} - \text{bag wt.}) - (\text{Pumped wt. out of bag})]}{(\text{Pumped wt. in bag} - \text{bag wt.})} \times 100\%$$

Meat quality attributes were also analyzed including pH, objective color, and marbling. A portion of the sirloin-end of the loin was removed to evaluate quality on a freshly-bloomed meat surface. Loins were allowed to bloom for 20 min. prior to quality evaluation. Objective CIE color measurements [Lightness (L*), redness (a*), and yellowness (b*)] were taken by a Minolta Chroma Meter (Model CR-310, wide-area illumination, 50 mm-diameter measuring area, 0° viewing angle, C Illuminant; Minolta Co., Ltd.; Ramset, NJ, USA) on the sirloin end of the loin. Standardized white and black tiles were used to calibrate the colorimeter. Three readings of L*, a*, and b* were taken per loin and averaged.

Initial marbling as determined with National Pork Producers Council marbling scores (NPPC, 1999) on the sirloin end of the loin on a scale of 1 to 10 (higher numbers indicate more intramuscular fat).

Initial pH was measured on the blade and sirloin ends of the loin with a portable pH 11 meter (Eutech Instruments Pte Ltd / Oakton Instruments, Vernon Hills, IL, USA) equipped with a spear-tipped probe. The blade and sirloin pH measurements were averaged.

Preparation of Loins for Retail Purge, Proximate Analysis, and Additional Quality

Measures

Loins were sliced for further analysis by the following procedure moving from the anterior end to the sirloin end of the loin. The blade end was removed by cutting 7.6 cm of loin from the blade end and discarding. A 2.5-cm chop was then cut and placed in a tray to measure retail purge. A 2.5-cm chop was cut for determination of proximate analysis. All excess subcutaneous fat and connective tissue was trimmed and the chop was vacuum

packaged (15.2 x 29.2 cm sample bag, Sealed Air Corporation, Duncan, South Carolina, United States of America), heat shrunk in a steam kettle ($60 \pm 2^{\circ}\text{C}$), and frozen at $-20 \pm 2^{\circ}\text{C}$. A 17.8-cm loin section was removed, vacuum packaged (B2630 loin vacuum package bags, Sealed Air Corporation, Duncan, South Carolina, United States of America), and frozen at $-20 \pm 2^{\circ}\text{C}$ for further analysis of sensory characteristics and instrumental tenderness. A 2.5-cm chop was then cut and placed in the retail purge tray. A 5.1-cm section was removed and discarded. Finally, a 2.5-cm chop was cut and placed in the retail display tray along with the other two previously cut chops. Any remaining portion of the loin was discarded.

Retail Display Characteristics

Three 2.5-cm thick chops that were cut for retail display evaluation as described above were placed on an absorbent pad in a white supermarket foam tray and wrapped in high oxygen PVC overwrap with the cut face of the chop facing away from the foam tray. Trays containing chops were held at $4 \pm 2^{\circ}\text{C}$ for 120 h and throughout that time period retail subjective retail pork color and discoloration scores and objective retail color measurements were completed every 24 h. Retail purge was calculated using weights recorded on d 0 and 5.

The 3 chops were weighed at 0 h, held for 120 h at $4 \pm 2^{\circ}\text{C}$, blotted dry, and weighed. Retail purge was calculated by the following equation:

$$[(\text{Retail wt. day 0} - \text{retail wt. day 5}) / \text{retail wt. day 0}] \times 100\%$$

Objective CIE color measurements [Lightness (L^*), redness (a^*), and yellowness (b^*)] were taken by a Minolta Chroma Meter (Model CR-310, wide-area illumination, 50 mm-diameter measuring area, 0° viewing angle, C Illuminant; Minolta Co., Ltd.; Ramset, NJ, USA). Standardized white and black tiles were used to calibrate the colorimeter. During the

retail display period, three objective color measurements were taken per day (one measurement per chop) with three readings of L^* , a^* , and b^* where L^* correlates to lightness to darkness, a^* correlates to redness to greenness, and b^* correlates to yellowness to blueness, were taken per output for d 0, 1, 2, 3, 4, and 5.

Additionally, a panel analyzed the chops daily for subjective color and reported pork color on a scale of 1 to 6 and discoloration on a scale of 1 to 7. Pork color was evaluated using the following scale: 6=Dark purplish red, 5=Purplish red, 4=Reddish pink, 3=Pink, 2=Grayish pink, 1=Pale purplish gray according to the American Meat Science Association's Guidelines for Meat Color Evaluation. Panelists utilized the National Pork Producer's Council color score cards for fresh pork during their evaluations of color. Surface discoloration was determined with the following scale: 7=Total discoloration (100%), 6=Extensive discoloration (88-99%), 5=Moderate discoloration (60-79%), 4=Modest discoloration (40-59%), 3=Small discoloration (20-39%), 2=Slight discoloration (1-19%), 1=No discoloration (0%). A copy of the Retail Subjective Color Sheet is available in Appendix B. Color measurements for each loin were averaged and analyzed by treatment, display day, and treatment by display day interaction.

Preparation of Loin Section for Cooking Analysis

The frozen ($-20\pm 2^\circ\text{C}$) 17.8-cm loin section was removed from the freezer and sliced using a band saw into five 2.5-cm chops. Four chops were used to evaluate cooking characteristics and the final chop was saved for potential re-analysis. All chops were individually vacuum packaged and stored at $-20\pm 2^\circ\text{C}$ until analysis.

Cooking Characteristics

Four frozen chops ($-20\pm 2^{\circ}\text{C}$) were weighed per loin, with 3 chops being used to evaluate instrumental tenderness and 1 chop to evaluate sensory characteristics. Chops were thawed overnight at $4\pm 2^{\circ}\text{C}$ on trays with plastic overwrap to prevent evaporative loss. Chops were blotted dry and thawed weights were measured. Thermocouples were inserted into the geometric center of the chops and initial temperature was measured. Chops were placed on open hearth grills and cooked to an internal temperature of 71°C . Cook time was measured in minutes. Chops were removed from the grills, blotted dry, and cooked weight was measured.

Thaw loss was calculated by: $[(\text{Frozen wt.} - \text{Thaw wt.})/\text{Frozen wt.}] \times 100\%$

Cook loss was calculated by: $[(\text{Thaw wt.} - \text{Cooked wt.})/\text{Thaw wt.}] \times 100\%$

Total loss was calculated by: $[(\text{Frozen wt.} - \text{Cooked wt.})/\text{Frozen wt.}] \times 100\%$

Sensory and Shear Force Analysis

All sensory analysis was conducted according to the University of Georgia Institutional Review Board policies (IRB #2012-10783-0). Evaluations were completed according to the guidelines presented by the American Meat Science Association. Panelists, that had been previously trained, were subjected to a 3-d refresher on sensory evaluation of pork loin chops. For sensory analysis, 2.5-cm thick chops were thawed overnight at $4\pm 2^{\circ}\text{C}$ in plastic containers with lids. Panelists were trained to analyze raw odor of the chops. Panelists rated the raw odor on a 6-point hedonic scale, with 1 equating to no off-odor detected and 6 equating to an extremely strong off-odor detected. The Raw Odor Evaluation Score Sheet is provided in Appendix C.

Chops were then placed on plastic trays and wrapped with plastic overwrap to prevent evaporative loss and placed in a cooler at $4\pm 2^{\circ}\text{C}$ overnight. Copper/Constantan thermocouples were inserted into the approximate geometric center of the chops. Chops were cooked to 71°C on an open-hearth grill (Farberware, Model 455ND, Bronx, New York, United States of America) and cut into 1.3 cm wide x 1.3 cm long x 2.5 cm high cubes. Samples were kept warm under a heating lamp until 2 cubes per loin chop were placed in preheated yogurt makers (Euro-Cusine, Inc., Model YM80, Commerce, California, United States of America) to keep samples warm until sampling. Panelists were provided with unsalted crackers and water to cleanse their pallets between samples. Sensory panelists recorded scores for tenderness, juiciness, pork flavor intensity, non-pork flavor, saltiness, and overall acceptability on cooked samples. The panelist ballot consisted of 4 questions anchored on an 8-point hedonic scale and 2 questions anchored on a 6-point hedonic scale with tenderness scores of 1 equating to extremely tough and 8 to extremely tender; juiciness scores of 1 equating to extremely dry and 8 to extremely juicy; pork-flavor intensity scores of 1 correlating to extremely bland and 8 to extremely intense; overall acceptability scores of 1 equating to disliked extremely and 8 to liked extremely; saltiness scores of 1 correlating to no salty flavor detected and 6 correlating to extreme salty flavor; and non-pork flavor scores of 1 equating to no non-pork flavor detected and 6 equating to extreme non-pork flavor. The cooked sensory evaluation sheet is included in Appendix D.

For slice shear force determination, USDA guidelines for slice shear force were followed and chops were thawed overnight at $4\pm 2^{\circ}\text{C}$ and cooked in the same manner as for sensory analysis. Cooked chops were prepared for slice shear force by cutting parallel to the muscle fibers to produce a 1-cm thick x 5-cm long slice from the lateral end of the chop that

would be cut perpendicular to the muscle fibers 1-2-cm from the lateral end of the muscle by the Instron Universal Testing Machine (Instron 3365, Instron Corporation, Norwood, Maine, United States of America). Results were reported as kilograms of peak force.

Proximate Composition

Chops used for proximate analysis were powder homogenized and remained frozen at $-20\pm 2^{\circ}\text{C}$ until analysis. Moisture content was determined using AOAC (1990) methods by drying crucibles overnight in an oven at 90°C , placing the crucibles in a glass desiccator for 10 min, weighing the crucibles, weighing 3 g of sample in a crucible, drying the sample at 90°C for 48h, equilibrating in a desiccator for 10 min, and reweighing the sample.

Percentage moisture was determined by the equation: $[\text{sample wt.} - (\text{dried wt.} - \text{crucible wt})] / \text{sample wt.} \times 100\%$.

Ash content was determined by the AOAC (1990) method by placing the dried crucibles from the moisture procedure in an oven at 550°C for 4h. Crucibles were removed from the oven, equilibrated in a desiccator for 10 min., and reweighed. Percentage ash was determined by the equation: $[\text{Dry sample wt.} - (\text{Ash sample wt.} - \text{crucible wt.})] / \text{sample wt.} \times 100\%$.

Total lipid content was determined by chloroform:methanol extraction according to the procedure of Folch, Lees, & Sloane Stanley (1957) with slight modifications.

Homogeneous 2.5-g samples from each of the treatments were weighed into a 50 mL conical centrifuge tube. Methanol (10 mL) and chloroform (5 mL) were added to the sample and it was homogenized on medium speed for 30 s. Samples were allowed to stand in an ice bath for 1 h to extract the lipids. Additional chloroform (5 mL) and 1 M KCl (5 mL) were added to the samples. The tubes were capped, vortexed vigorously, placed in an ice bath for 5 min,

and centrifuged at 2,000 x g at 0°C for 10 min. The top layer of the samples was aspirated off and the bottom layer was poured into pre-weighed aluminum pans which were dried overnight at 100°C. The samples in aluminum pans were evaporated overnight in the fume hood with the fan on and the following morning were placed in a drying oven at 100°C for 15 min. Samples were then placed in a desiccator for 15 min and the pans containing the lipid fraction were weighed. The percent lipid was determined by the equation: (pan with lipid wt. - pan wt.)/ sample wt. x 100%.

Crude protein was determined using a nitrogen analyzer (Leco FP-528, Leco Corporation, Warrendale, Pennsylvania, United States of America). Samples were weighed to 0.10-0.15 g. Sample weight was recorded and samples were folded into the sample tin foil cup into a tear drop shape. Samples were loaded into the carousel and analyzed for nitrogen content. The precision of the values was compared and the relative standard deviation between the duplicates remained under 5.0.

Sodium content was determined by mass spectroscopy on ashed samples. The crucibles that contained the samples from moisture content analysis were ashed at 550°C for 4 h and the oven and crucibles were allowed to cool. The crucibles were placed in a dessicator for 10 min. and allowed to equilibrate. The ashed samples were quantitatively transferred to a 100 mL volumetric bottle by rinsing with 6 N Hydrochloric Acid (25 mL) and 5% Lanthanum solution (25 mL). The samples were brought to the 100 mL volume with deionized water. The silica was allowed to precipitate and the supernatant was removed using a pipette and placed into plastic sample bottles. The supernatant liquid in the plastic sample bottles was delivered to the Center for Applied Isotope Studies Chemical Analysis Laboratory at the University of Georgia in Athens, GA. Samples were analyzed for sodium

content using a Thermo Jarrell Ash Enviro 36 Inductively Coupled Argon Plasma-Optical Emission Spectrograph which burned an aqueous sample in an argon flame. The elements present emitted light at characteristic wavelengths with an intensity directly proportional to the element concentration. Results were analyzed by a computer to determine the concentration ratios among constituent elements in the sample and sodium content was reported in parts per million.

Statistical Analysis

All data were analyzed using SAS 9.2. Proximate data, sodium content, cooking, tenderness, and sensory traits were analyzed using one-way analysis of variance. Microbial data were analyzed using two-way analysis of variance with treatment and storage time as main effects. Retail display data were analyzed using PROC MIXED with loin as a random variable. Main effects and interactions were considered significant at $P < 0.05$.

References

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CHAPTER 4

RESULTS AND DISCUSSION

Initial and Pumped Loin Quality Measures

Initial quality of loins was similar among treatments as determined by objective color, marbling scores, pH, green weight, and initial purge (**Table 4.1**). These results indicate that variation between treatments in pork loin quality post-injection should be attributed to the enhancement brine treatments. Pumped whole loin quality did not differ ($P > 0.07$) between treatments as measured by objective color, marbling, pH, pumped weight, percent pump, and purge loss (**Table 4.2**). Loins were pumped to similar weights and percentage of marinade added. Pumped weight was not different ($P = 0.79$) between treatments with a mean of 4.72 kg and percent pump did not differ ($P = 0.07$) between treatments with a mean of 13.04%. These results also indicate that, if differences between treatments measured post-injection were observed, then those differences would be a result of the differences in composition of the enhancement brines. It is important that pump rate was not different because of it has been shown to influence pH, Warner-Bratzler shear force values, razor shear force values, sensory tenderness, sensory pork fat flavor, sensory off-flavor, and sensory overall acceptability of pork loins in previous studies (Baublits, et al., 2006). Additionally, enhancement at 18% as compared to 12% of beef *biceps femoris* muscles showed higher sensory tenderness scores and pH values (Baublits, Pohlman, Brown & Johnson, 2005).

Pumped objective color including lightness, redness, and yellowness on the sirloin end of the loin did not differ ($P > 0.85$) between treatments. Pumped marbling scores on the sirloin end of the loin were not different ($P = 0.58$) between treatments with a mean of 2.62 which may be associated with the consistency in pump rate and initial marbling. Pumped

pH, which was measured on both the blade and sirloin ends of the loin and then averaged, did not differ ($P = 0.89$) between treatments with a mean of 6.07. Pumped purge did not differ ($P = 0.70$) between treatments with a mean of 1.28%. These results indicate that pork protein solution is a competitive replacement for salt and phosphate brines from a whole muscle perspective, as there are no significant differences in quality or yields between treatments in whole, boneless pork loins. Lawrence et al. (2004) found that enhancing beef *longissimus* muscle with a sodium phosphate plus salt solution resulted in higher pump yields than enhancement with calcium lactate plus non-phosphate water binders plus rosemary extract. However, the present study did not find similar results, which indicates that pork protein solution may show promise as a potential replacement for phosphate brines. Additionally, Lowder et al. (2011) found no statistical differences in purge loss over storage time between a salt and phosphate brine and a salt and dehydrated beef protein brine that were injected into beef strip loins (IMPS #180). These results also indicate that protein solution brines may be an alternative to phosphate brines.

There was a possibility that pH for the salt and phosphate enhanced chops would be higher than the pork protein solution loins as seen in other studies (Baublits et al., 2006; Baublits, Pohlman, Brown & Johnson, 2005; Boles & Shand, 2001; Jensen et al, 2003). However, the pH of the pork protein solution was on the basic side of the isoelectric point at 7.3 and therefore would also raise the overall pH of the loins just as the salt and phosphate solution did. This also may be a result of the form of phosphate used in the present study as compared to the form used in previous studies. Brifisol 85 Instant Phosphate combines Sodium Pyro- (Di) and Sodium Polyphosphates and is agglomerated which results in complete salt compatibility, rapid protein solubilization, and quick dispersion of the injection

solution throughout the muscle even at low processing temperatures. Brifisol 85 Instant Phosphate is very effective in reducing purge loss in both beef and pork products. Lowder et al. (2011) also used Brifisol 85 Instant Phosphate in a salt/phosphate brine at pH 8.44 to compare with dehydrated beef protein brine at a pH of 7.49, which resulted in the salt and phosphate loins having higher ultimate pH values. One major difference between Lowder et al. (2011) and the present study is that Lowder et al.'s control brine contained 3.6% salt, 4.5% Brifisol 85 Instant Phosphate, and 1% Herbalox seasoning type HT-S which is higher for salt, phosphate, and seasoning than the present study. This higher concentration may have resulted in a higher ultimate pH in the final product.

Retail Display Characteristics

Pork loin chops are the most popular cut from the pork loin. Consumers and retailers place significant emphasis on color and retail purge during product selection and therefore it is important to note differences in those traits resulting from enhancement brine composition. Fortomaris et al. (2006) stated that appearance of pork has a great impact on how it is valued by the consumer and that color is the most important factor in consumer decisions within Greece and Cyprus. Romans and Norton (1989) also found that color was an important characteristic in purchasing decisions. However, Romans and Norton (1989) found that leanness was the most important factor in purchasing decisions. Today, most pork loin chops sold at the retail level has been trimmed such that only minor differences in leanness exist at the retail level. Thus, consumer preference is strongly based on color. Results for retail purge, objective color, and subjective color of retail chops are shown in **Table 4.3**. In terms of lean color, whether measured instrumentally or by a trained panel, there were no differences ($P > 0.09$) between chops that had been enhanced with the control or PPS brines.

However, chops from loins injected with either pork protein solution containing brine showed greater retail purge ($P < 0.05$) losses than chops from loins injected with the conventional salt/phosphate brine, which may cause concern to consumers and retailers.

The pork protein solution treatments did not differ ($P = 0.31$) in terms of retail purge. Treatment has been shown to influence purge in previous studies of alternative brines. Jensen et al. (2003) showed that incorporation of organic acids such as buffered vinegar does not aide in water holding capacity as measured by reducing purge loss, which is in accordance with the results of the present study.

Objective retail color was not affected ($P > 0.79$) by brine composition. Display day significantly impacted lightness, redness, and yellowness measurements by the Minolta colorimeter. **Figure 4.1** indicates that even with small differences in lightness, chops significantly became lighter over display time with the exception of d 2 on which chops were the darkest. **Figure 4.2** shows that across treatment groups chops became less red over display time with the exception of d 2 where chops were the most red. **Figure 4.3** shows that within a display day, yellowness did not differ significantly across treatments with the exception of d 0 where chops from salt and phosphate enhanced loins were less yellow than chops from loins enhanced with salt, vinegar, and PPS. There was an interaction ($P < 0.01$) for yellowness between treatment and display day indicating that yellowness of salt/phosphate enhanced chops increased to a greater degree as compared to chops from loins enhanced with either of the PPS containing brines. Viania, Gomide, and Vanetti (2005) noted that retail pork shelf-life is limited by a change in color that occurs prior to microbial storage which is in accordance with the changes in color seen in the present study. Tik, Lindahl, Karlsson, and Anderson (2008) reported that during extended retail display,

discoloration occurs where meat changes from bright cherry-red to grayish-brown which is consistent with the results of this study.

Subjective retail pork color was not affected ($P = 0.94$) by treatment. Display day significantly ($P < 0.01$) impacted subjective pork color. There was an interaction ($P = 0.03$) for subjective pork color between treatment and display day as salt and phosphate enhanced chops showed darker pork color at d 0 from either of the other treatments and at no other display day did pork color differ between treatments (**Figure 4.4**). Subjective discoloration was not affected ($P = 0.09$) by treatment; however, as expected, discoloration scores increased ($P < 0.01$) as display time increased (**Figure 4.5**).

Cooking Characteristics

Cooking characteristics are extremely important to the food service industry. Portion sizes are very important in quality assurance and are directly related to thaw loss, cook loss, and total loss (Dunn et al., 1999). Reduced losses equate to increased salable yield which is desirable to the food service industry, retailers, and consumers. The chops produced from loins injected with salt and phosphate showed reduced thaw, cook, and total loss as compared to chops produced from loins injected with either of the brines containing pork protein solution (**Table 4.4**).

Thaw loss is extremely important when chops are frozen during distribution and storage. Thaw loss was reduced ($P = 0.02$) in salt and phosphate injected chops compared to salt and pork protein solution enhanced chops by 1.00%. Thaw loss was less ($P < 0.01$) in salt and phosphate injected chops than salt, vinegar, and pork protein solution enhanced chops by 1.33%. There were no differences ($P = 0.42$) in thaw loss between salt and pork protein solution injected chops and salt, vinegar, and pork protein solution injected chops.

This may be a result of the ability of the phosphate to bind water and interact with the proteins and inherent water in the meat may be a reason for its ability to retain additional moisture during thawing. It is unknown if the protein solution interacts with the water inherent in the pork loin or only the water in the solution. This could also be related to the differences observed in cook loss.

Cook loss was less ($P < 0.01$) in salt and phosphate injected chops than salt, vinegar, and pork protein solution enhanced chops by 3.67%. Cook loss tended to be less ($P = 0.08$) in salt and phosphate injected chops than salt and pork protein solution enhanced chops by 2.22%. There were no differences ($P = 0.25$) in cook loss between salt and pork protein solution injected chops and salt, vinegar, and pork protein solution injected chops.

Total loss was reduced ($P = 0.01$) in salt and phosphate injected chops than salt and pork protein solution enhanced chops by 2.99%. Total loss was less ($P < 0.01$) in salt and phosphate injected chops than salt, vinegar, and pork protein solution enhanced chops by 4.59%. There were no differences ($P = 0.16$) in total loss between salt and pork protein solution injected chops and salt, vinegar, and pork protein solution injected chops.

Cook time was measured in minutes and showed no difference ($P = 0.35$) between treatments with a mean of 21.20 min per chop. This was expected as cook time is related to the weight and size of the chops. Pumped weight was consistent among treatments and all chops were cut to the same thickness and therefore, cook time would be expected to be similar among treatments.

Proximate Composition

The chops from loins enhanced with pork protein solution showed a significant reduction in sodium content as compared to the chops from loins enhanced with salt and

phosphate while exhibiting similar compositional results in terms of fat, protein, and moisture (**Table 4.5**). There were no differences in moisture ($P = 0.64$), lipid ($P = 0.89$), or protein percentage ($P = 0.49$) between chops from the enhancement treatments. The salt and phosphate injected chops had greater ($P < 0.01$) ash content than salt and pork protein solution or salt, vinegar, and pork protein solution enhanced chops which may be a result of the additional salt in the Brifisol 85 phosphate which was present in the salt and phosphate marinade and absent in the pork protein solution containing brines.

Sodium intake has been linked to high blood pressure and enhanced risk for heart disease, costing the U.S. approximately \$403 billion per year (Desmond, 2006). The addition of sodium chloride is a common practice within the meat industry and creates increased sodium levels in meat products (Desmond, 2006). Engstrom, Tobelmann, & Albertson (1997) showed that meat and meat products contribute up to 21.0% of sodium intake in the U.S. Currently, meat processors have the goal of producing reduced sodium meat products that still have the sensory characteristics and functionality of products containing typical amounts of sodium (Desmond, 2006). As expected, the salt and phosphate injected chops showed greater ($P < 0.01$) sodium content than the salt and pork protein solution or salt, vinegar, and pork protein solution enhanced chops. There were no differences ($P = 0.59$) between the salt and pork protein solution enhanced chops and salt, vinegar, and pork protein solution enhanced chops.

Microbiological Shelf-Life

Pork protein solution and salt and phosphate brines displayed similar results in terms of microbiological quality (**Table 4.6**). Chops from loins injected with salt, vinegar, and pork protein solution showed reduced ($P = 0.03$) APC as compared to chops from loins

injected with either salt and phosphate brine or salt and pork protein solution brine. The APC is a generic test for organisms that grow at mesophilic temperatures under aerobic conditions (Downes & Ito, 2001). There are limitations to the use of APC as an indicator of food safety as they do not directly correlate to the presence of pathogens or toxins (Downes & Ito, 2001). However, APC can be used to provide information regarding sanitary quality and raw food quality (Downes & Ito, 2001). Enhancement solution composition has been shown to influence APC in loin chops in previous studies (Jensen et al., 2003). Jensen et al. (2003) found that pork chops enhanced with either phosphate, potassium lactate, or sodium lactate had significantly greater aerobic plate counts as compared to chops enhanced with either un-pumped or enhanced with sodium acetate or potassium lactate/potassium diacetate.

There were no differences in enterobacteriaceae ($P = 0.09$), *E. coli* ($P = 1.00$), coliforms ($P = 0.54$), Lactic Acid Bacteria ($P = 0.22$), or *Pseudomonas* ($P = 0.38$) counts between treatments.

Sensory and Shear Force Analysis

Sensory and shear force analysis results are reported in **Table 4.7**. There were no differences between treatments in subjective odor ($P = 0.10$), sensory tenderness ($P = 0.69$), overall acceptability ($P = 0.15$), non-pork flavor intensity ($P = 0.22$), and peak force (kgf) ($P = 0.39$). It is important to note that neither instrumental nor sensory tenderness scores differed between treatments, suggesting that similar muscle characteristics are being measured by these methods.

Chops from loins injected with salt and phosphate solution showed greater ($P = 0.02$) juiciness scores as compared to salt and pork protein solution or salt, vinegar, and pork protein solution injected chops. This was expected as the chops from loins injected with salt

and phosphate showed less retail purge loss, thaw loss, and total loss which would result in a greater percentage of retained moisture and juicier chops. Aaslyng et al. (2003) found that initial juiciness in the chewing process depended only on the water content of the meat and juiciness experienced later in the chewing process was determined by a combination of the water and intramuscular fat contents and the saliva produced during chewing. This is consistent with the results as lipid content was consistent among treatments and as losses increase, juiciness sensory scores decreased. A potential method to overcome the issue of moisture retention in pork protein solution enhanced chops is to increase the protein concentration of the pork protein solutions, thus allowing more protein and water interaction to occur which may result in less purge from the product.

Chops from loins injected with salt and phosphate showed greater ($P = 0.01$) pork flavor sensory scores than chops from loins injected with salt and pork protein solution. Chops from loins injected with salt and phosphate showed greater ($P = 0.02$) pork flavor sensory scores than chops from loins injected with salt, vinegar, and pork protein solution. This may be a result of the additional retained moisture in the chops enhanced with salt and phosphate as compared to those with pork protein solution. There were no differences ($P = 0.92$) in pork flavor intensity between chops from loins injected with pork protein solution. Chops from loins enhanced with salt and phosphate showed increased ($P < 0.01$) saltiness sensory scores as compared to either pork protein solution injection brine enhanced chops. There were no differences ($P = 0.38$) in saltiness sensory scores between chops from loins injected with pork protein solution. These sensory scores were expected as increased sodium content which was seen in the chops from loins enhanced with sodium and phosphate exhibited higher saltiness scores which may be related to the increase in pork flavor intensity.

TABLES AND FIGURES

Table 4.1 Initial quality of boneless pork loins

Variable	Enhancement Brine Composition			Pr > F	SEM
	Salt, Phosphate	Salt, PPS	Salt, Vinegar, PPS		
Initial L* ¹	55.28	54.88	53.90	0.28	0.62
Initial a* ²	17.58	17.69	17.25	0.32	0.21
Initial b* ³	7.30	6.95	6.71	0.07	0.18
Initial Marbling	2.50	2.48	2.48	1.00	0.22
Initial pH	5.82	5.81	5.88	0.16	0.03
Initial Weight, kg	4.21	4.14	4.18	0.85	0.08
Initial Percent Purge, % ⁴	0.97	0.72	0.65	0.16	0.12

¹ L* = lightness, where 0 equals black and 100 equals white

² a* = redness, from red (+) to green (-)

³ b* = yellowness, from yellow (+) to blue (-)

⁴ Initial Percent Purge, % was calculated using the formula: $(((\text{Initial wt. in bag} - \text{bag wt.}) - (\text{Initial wt. out of bag})) / (\text{Initial wt. in bag} - \text{bag wt.})) \times 100\%$

Table 4.2 Pumped quality of boneless pork loins

Variable	Enhancement Brine Composition			Pr > F	SEM
	Salt, Phosphate	Salt, PPS	Salt, Vinegar, PPS		
Pumped Weight, kg	4.77	4.68	4.70	0.79	0.09
Percent Pump, % ¹	13.39	13.11	12.62	0.07	0.24
Pumped L* ²	54.78	54.71	54.23	0.86	0.78
Pumped a* ³	17.39	17.28	17.22	0.92	0.28
Pumped b* ⁴	7.12	7.11	7.22	0.93	0.23
Pumped Marbling	2.61	2.83	2.42	0.59	0.28
Pumped pH	6.06	6.08	6.07	0.90	0.03
Pumped Purge, % ⁵	1.20	1.32	1.32	0.70	0.11

¹ Percent Pump, % was calculated using the formula: $(\text{Pumped wt.} - \text{Initial wt.}) / \text{Initial wt.} \times 100\%$

² L* = lightness, where 0 equals black and 100 equals white

³ a* = redness, from red (+) to green (-)

⁴ b* = yellowness, from yellow (+) to blue (-)

⁵ Pumped Purge, % was calculated using the formula: $[(\text{Pumped wt. in bag} - \text{bag wt.}) - (\text{Pumped wt. out of bag})] / (\text{Pumped wt. in bag} - \text{bag wt.}) \times 100\%$

Table 4.3 Retail display quality and yield of enhanced boneless pork loin chops

Variable	Enhancement Brine Composition			Pr > F	SEM
	Salt, Phosphate	Salt, PPS	Salt, Vinegar, PPS		
Retail Purge, % ¹	3.34 ^a	4.44 ^b	4.22 ^b	< 0.01	0.15
Retail L* ²	55.26	55.54	55.40	0.96	0.71
Retail a* ³	15.51	15.67	15.74	0.79	0.25
Retail b* ⁴	7.90	7.92	7.98	0.96	0.21
Subjective Pork Color	2.99	2.94	2.95	0.94	0.11
Subjective Discoloration	6.06	6.08	6.07	0.09	0.03

^{a, b} Means within row with different superscripts differ (P < 0.05)

¹ Retail Purge, % was calculated with the formula: [(Retail wt. day 0 – retail wt. day 5)/retail wt. day 0] x 100%

² L* = lightness, where 0 equals black and 100 equals white

³ a* = redness, from red (+) to green (-)

⁴ b* = yellowness, from yellow (+) to blue (-)

Table 4.4 Thaw loss, cook loss, total loss, and cook time of enhanced boneless pork loin chops

Variable	Enhancement Brine Composition			Pr > F	SEM
	Salt, Phosphate	Salt, PPS	Salt, Vinegar, PPS		
Frozen Weight, g	225.16	216.01	214.14	0.07	3.61
Thawed Weight, g	215.70 ^a	204.59 ^b	202.49 ^b	0.01	3.40
Cooked Weight, g	179.13 ^a	165.56 ^b	160.58 ^b	< 0.01	2.98
Thaw Loss, % ¹	3.18 ^a	4.18 ^b	4.51 ^b	< 0.01	0.29
Cook Loss, % ²	16.84 ^a	19.06 ^{ab}	20.50 ^b	0.02	0.89
Total Loss, % ³	19.50 ^a	22.49 ^b	24.09 ^b	< 0.01	0.80
Cook Time, min.	21.18	20.41	22.01	0.35	0.78

^{a, b} Means within row with different superscripts differ (P < 0.05)

¹ Thaw Loss, % was calculated by the formula: [(Frozen wt. - Thaw wt.)/Frozen wt.] x 100%

² Cook loss, % was calculated by the formula: [(Thaw wt. - Cooked wt.)/Thaw wt.] x 100%

³ Total loss, % was calculated by the formula: [(Frozen wt. - Cooked wt.)/Frozen wt.] x 100%

Table 4.5 Proximate analysis of enhanced pork loins

Variable	Enhancement Brine Composition			Pr > F	SEM
	Salt, Phosphate	Salt, PPS	Salt, Vinegar, PPS		
Moisture, % ¹	76.37	76.64	76.57	0.64	0.21
Ash, % ²	1.79 ^a	1.44 ^b	1.48 ^b	< 0.01	0.02
Lipid, % ³	1.91	1.90	1.83	0.89	0.13
Protein, %	20.05	20.42	20.36	0.49	0.78
Sodium, ppm	61.35 ^a	44.05 ^b	45.56 ^b	< 0.01	1.96

^{a, b} Means within row with different superscripts differ (P < 0.05)

¹ Moisture, % was calculated by the formula: [sample wt. - (dried wt. - crucible wt)] / sample wt. x 100%.

² Ash, % was calculated by the formula: [Dry sample wt. - (Ash sample wt. - crucible wt.)] / sample wt. x 100%.

³ Lipid, % was calculated by the formula: (pan with lipid wt. - pan wt.) / sample wt. x 100%.

Table 4.6 Microbiological quality of enhanced pork loins

Variable	Enhancement Brine Composition			Pr > F	SEM
	Salt, Phosphate	Salt, PPS	Salt, Vinegar, PPS		
APC	5.24 ^a	5.25 ^a	5.02 ^b	0.03	21305.69
Enterobacteriaceae	2.68	3.05	2.14	0.09	311.22
<i>E. coli</i>	0.70	0.70	0.70	1.00	0.00
Coliforms	1.38	1.42	1.10	0.54	9.29
Lactic Acid Bacteria	4.99	4.23	4.17	0.22	37188.95
<i>Pseudomonas</i>	0.70	0.70	0.73	0.38	0.24

^{a, b} Means within row with different superscripts differ (P < 0.05)

* All microbiological counts are reported as log CFU/mL

Table 4.7 Sensory and tenderness evaluation of enhanced pork loins

Variable	Enhancement Brine Composition			Pr > F	SEM
	Salt, Phosphate	Salt, PPS	Salt, Vinegar, PPS		
Subjective Odor ¹	1.18	1.18	1.35	0.10	0.06
Tenderness ²	5.53	5.35	5.28	0.69	0.22
Juiciness ³	5.03 ^a	4.33 ^b	4.34 ^b	0.03	0.20
Pork Flavor ⁴	5.20 ^a	4.81 ^b	4.82 ^b	0.03	0.11
Saltiness ⁵	1.83 ^a	1.34 ^b	1.25 ^b	< 0.01	0.07
Overall Acceptability ⁶	5.18	4.92	4.71	0.15	0.17
Non-Pork Flavor ⁷	1.35	1.20	1.40	0.22	0.08
Slice shear force, kgf	9.89	10.44	9.28	0.39	0.59

^{a, b} Means within row with different superscripts differ (P < 0.05)

¹⁻⁷ All sensory evaluations were completed using a hedonic scale.

¹ Subjective Odor: 1 equals no off-odor detected and 6 equals extremely strong off-odor detected

² Tenderness: 1 equals extremely tough and 8 equals extremely tender

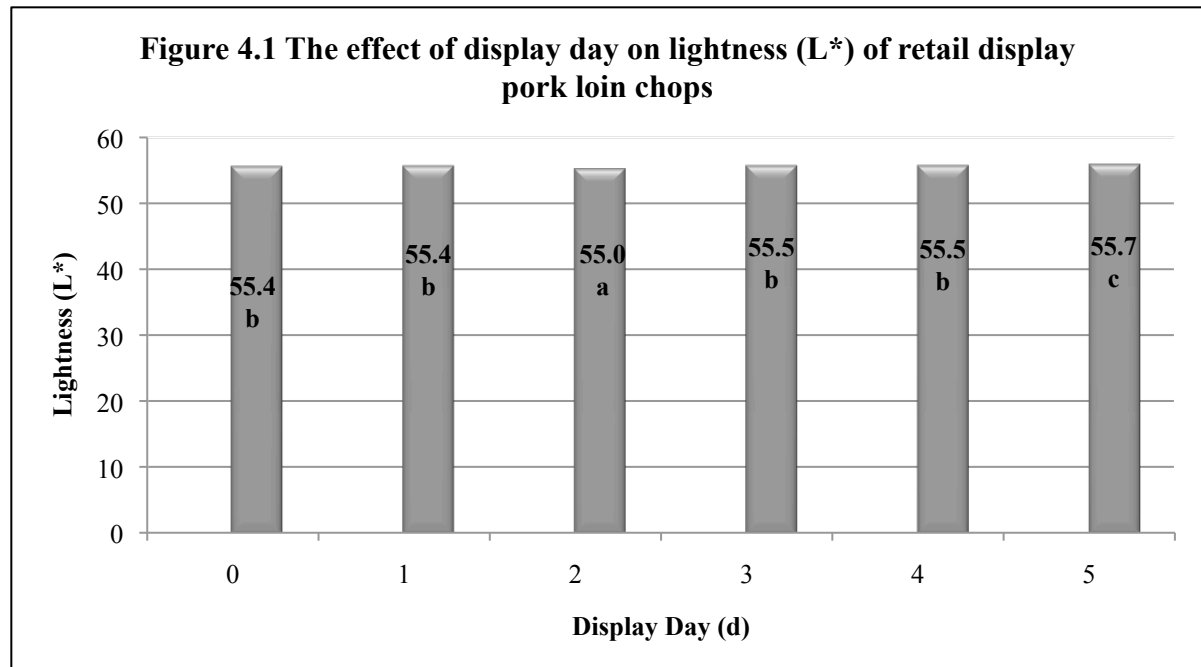
³ Juiciness: 1 equals extremely dry and 8 equals extremely juicy

⁴ Pork Flavor: 1 equals extremely bland and 8 equals extremely intense

⁵ Overall Acceptability: 1 equals disliked extremely and 8 equals liked extremely

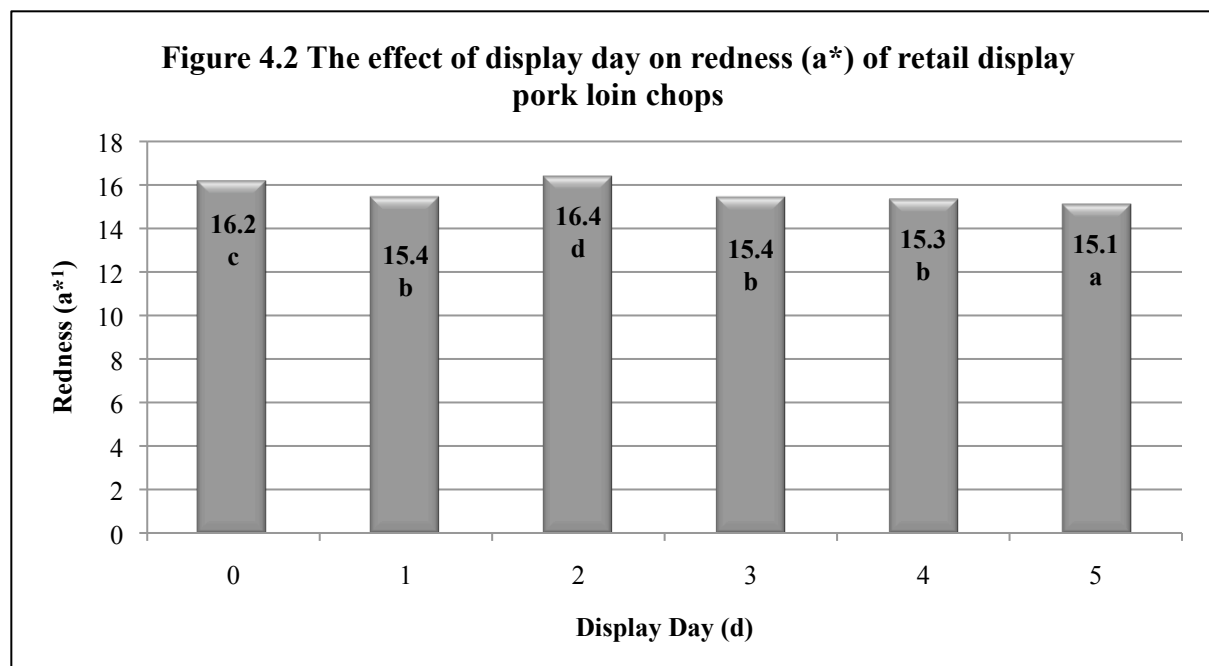
⁶ Saltiness: 1 equals no salty flavor detected and 6 equals extreme salty flavor

⁷ Non-pork Flavor scores: 1 equals no non-pork flavor detected and 6 equals extreme non-pork flavor



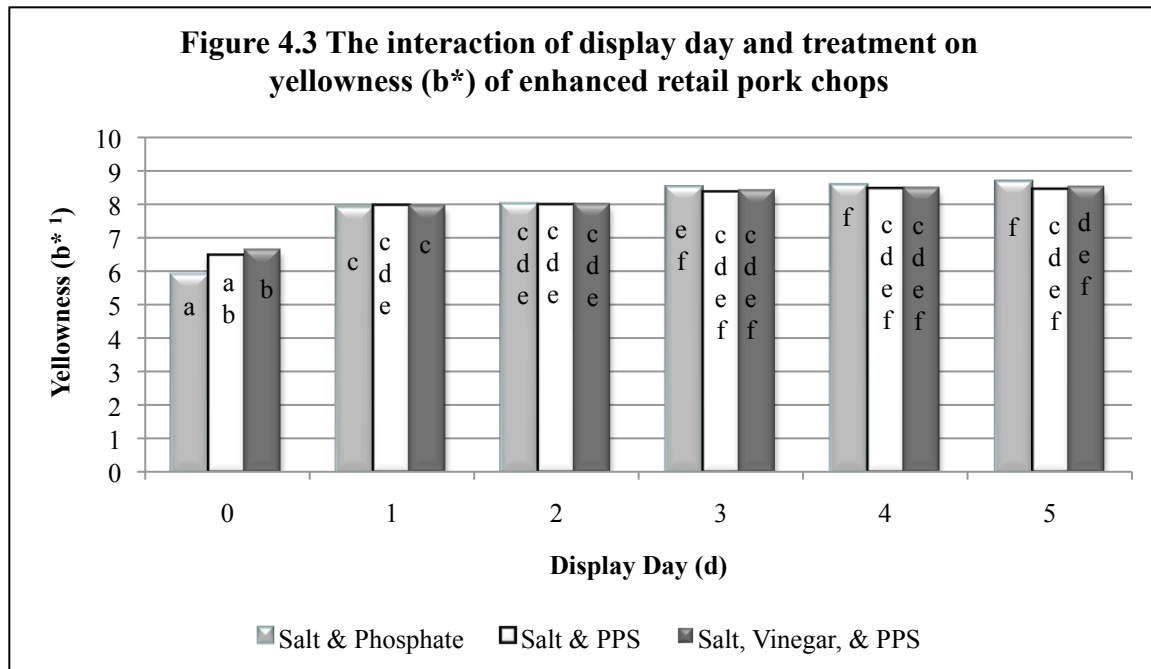
a, b, c Means within figure with different labels differ ($P < 0.05$)

¹ L* = lightness, where 0 equals black and 100 equals white



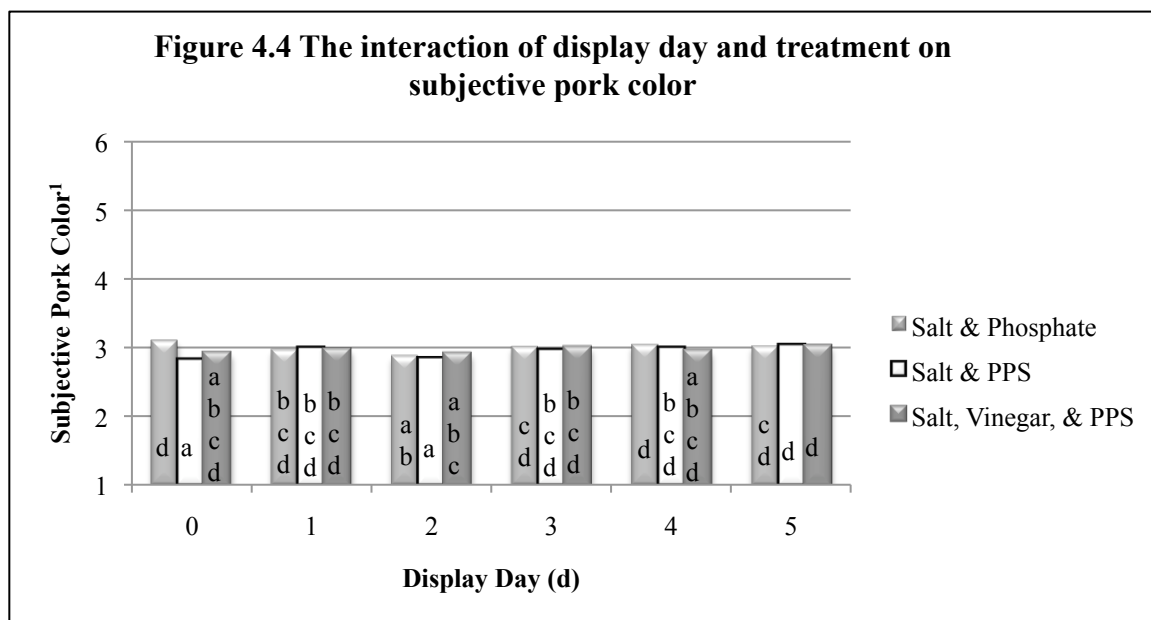
a, b, c, d Means within figure with different labels differ ($P < 0.05$)

¹ a* = redness, from red (+) to green (-)



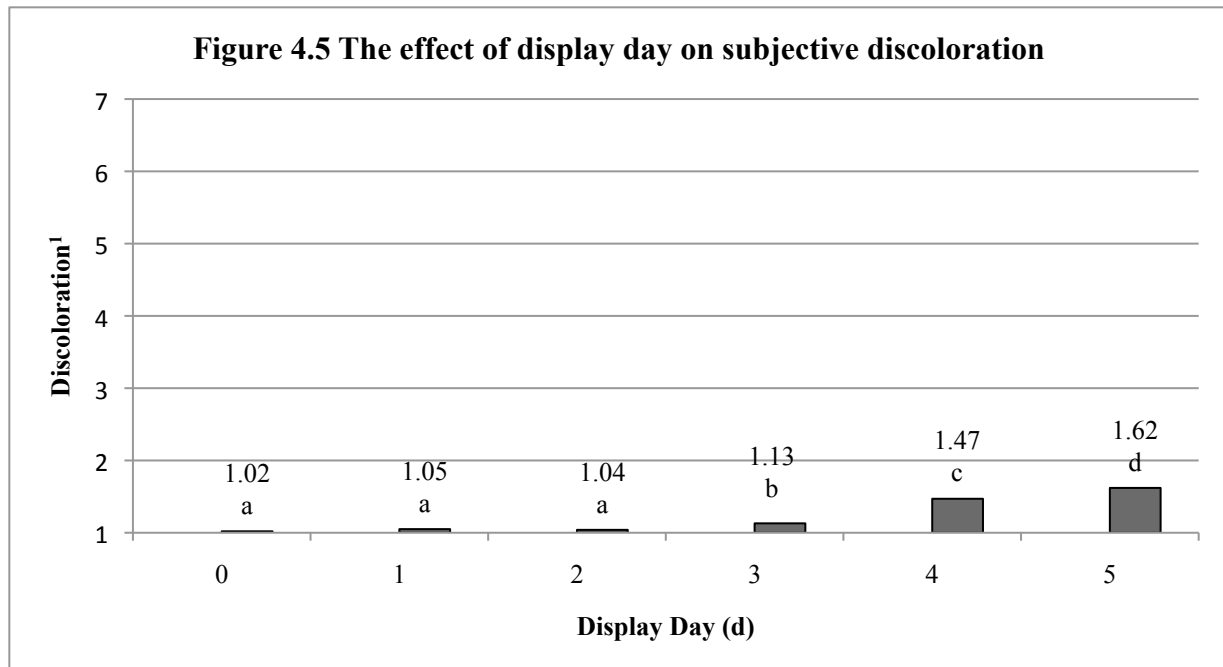
a, b, c, d, e, f Means within figure with different labels differ ($P < 0.05$)

¹ b* = yellowness, from yellow (+) to blue (-)



a, b, c, d Means within figure with different labels differ ($P < 0.05$)

¹ Subjective pork color was evaluated using the following scale: 6=Dark purplish red, 5=Purplish red, 4=Reddish pink, 3=Pink, 2=Grayish pink, 1=Pale purplish gray according to the American Meat Science Association's Guidelines for Meat Color Evaluation.



a, b, c, d Means within figure with different labels differ ($P < 0.05$)

¹ Surface discoloration was determined with the following scale: 7=Total discoloration (100%), 6=Extensive discoloration (88-99%), 5=Moderate discoloration (60-79%), 4=Modest discoloration (40-59%), 3=Small discoloration (20-39%), 2=Slight discoloration (1-19%), 1=No discoloration (0%).

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CHAPTER 5

CONCLUSIONS

This study compared the ability of a pork protein solution to substitute for a salt and phosphate brine in enhanced pork loins by measuring quality, yield, shelf-life, tenderness, and sensory traits. Three solutions were compared including a salt and phosphate brine; a salt and pork protein solution brine; and a salt, vinegar, and pork protein solution brine.

Brines containing pork protein solution showed advantages over traditional salt and phosphate enhancement brines in terms of reduced sodium content in loin chops and cleaner labels. Loins enhanced with pork protein solution have labeling advantages as the product is natural and the ingredients labeled potentially include pork protein solution and salt as compared to products containing salt and phosphates which must be labeled as such. There is even potential for products containing pork protein solution to be labeled as all natural and not contain the term “pork protein solution” as long as the pH is in the range that USDA considers normal for pork loins. Consumer trends are moving away from enhanced products, especially those containing phosphates. There is even potential for chops from loins enhanced with pork protein solution to be labeled as “made with all natural ingredients and minimally processed” as processing is minimal and citric acid and sodium bicarbonate are natural ingredients and are considered processing aides that would not necessitate incorporation into the label. These benefits to consumer health and perception are significant and show desirable characteristics of pork protein solution enhancements.

Loins enhanced with salt and phosphate displayed similar results in terms of objective color, marbling, pH, and pumped purge to loins injected with brines containing pork protein solution. Additionally, on a retail level, all treatments showed similar retail objective color,

subjective pork color, and subjective discoloration scores. In terms of microbiological shelf-life, salt and phosphate enhanced loins displayed similar results to the loin enhanced with pork protein solution. These results indicate that use of pork protein solution containing brines in enhanced pork loins results in similar visual quality and food safety characteristics as compared to traditional salt and phosphate brines. Consumer perception at the retail level will not be impacted by color or color stability due to treatment with any of the tested brines.

However, traditional salt and phosphate enhancement brine showed yield advantages over the pork protein solution containing brines. Chops from loins enhanced with salt and phosphate did show advantages in reduced retail purge as compared to chops enhanced with either of the pork protein solution containing brines. Additionally, chops from salt and phosphate enhanced loins showed less thaw loss and total loss than chops injected with either of the pork protein solution containing brines. The chops from loins enhanced with salt and phosphate showed reduced cook loss as compared to those produced from loins enhanced with salt, vinegar, and pork protein solution. Yields are major driving factors in processing decisions and significantly influence income. Therefore, this is a concern for the viability of pork protein solution as replacement for salt and phosphate brines. Furthermore, chops from the salt and phosphate injected loins exhibited higher juiciness, pork flavor, and saltiness scores as compared to chops enhanced with either of the pork protein solutions. Consumers tend to prefer more palatable products and salt and phosphate enhanced loins showed advantages in juiciness and pork flavor which is another concern regarding the ability of pork protein solution to replace salt and phosphate brines.

In conclusion, further analysis should be conducted in order to improve the yield characteristics of pork protein solution which should positively influence juiciness and pork

flavor intensity scores. With improvements, pork protein solution may be a viable replacement for traditional salt and phosphate brines and help to fight the war on hypertension and cardiovascular disease while making consumers feel more comfortable with their meat choices.

APPENDICES

A. Original Abstract

Clean labels and sodium reduction are two primary concerns for today's consumers. This study compared the ability of a pork protein solution (PPS) to substitute for a salt/phosphate (CTL) marinade in enhanced pork loins by measuring quality, yield, shelf-life, tenderness, and sensory traits. Pork protein solutions were made by chopping lean pork trim in water (20% w/w) and then lowering the pH to 3.8. The fat was skimmed from the solution and the pH was raised to 7.3. Loins ($n = 78$) were sorted by weight, pH, marbling score, and objective color into three groups of similar initial quality. Loins were injected to approximately 113.0% of initial weight with either CTL brine (0.35% salt, 0.35% phosphate), salt and PPS (0.35% salt in PPS), or salt, vinegar, and PPS (0.35% salt and 0.13% dried vinegar in PPS). Loins ($n = 14$ per treatment) were then sliced and retail display characteristics ($n = 3$ chops per loin) were measured during a 5-d retail display. Cooking, tenderness, and sensory attributes (d 12 post-fabrication) were evaluated on four 2.5-cm chops. Proximate analysis and sodium content were measured. Finally, aerobic plate count and counts for coliforms, pseudomonas, generic *E. coli*, lactic acid bacteria, and enterobacteriaceae were measured after 28, 30, or 32 d of storage (4°C , $n = 4$ per treatment/storage time). Proximate data, sodium content, cooking, tenderness, and sensory traits were analyzed using one-way ANOVA. Microbial data were analyzed using two-way ANOVA with treatment and storage time as main effects. Retail display data were analyzed using PROC MIXED with loin as a random variable. Objective color, marbling, pH and purge loss did not differ ($P > 0.10$) between treatments. Chops injected with CTL brine showed less ($P < 0.01$) retail purge than chops injected with either PPS. Retail color was not

affected ($P > 0.10$) by brine composition. Cook time, slice shear force (kgf), raw odor, sensory tenderness, and non-pork flavor intensity did not differ ($P > 0.10$) between treatments. Thaw loss and total loss were greater ($P < 0.05$) in chops from PPS loins compared to chops from CTL loins; however, cook loss was only greater in chops from loins injected with salt, vinegar and PPS compared to CTL. Sensory juiciness, pork flavor intensity and saltiness scores were higher ($P < 0.05$) in CTL than either PPS. Moisture and lipid content did not differ ($P > 0.10$) between treatments. As expected, loins enhanced with CTL brine had greater ($P < 0.01$) sodium content (ppm) than loins injected with either PPS. Loins injected with salt, vinegar and PPS had decreased ($P < 0.03$) aerobic plate counts than loins injected with either the CTL brine or the salt and PPS. Enterobacteriaceae counts were reduced ($P < 0.04$) in loins enhanced with salt, vinegar, and PPS compared to those enhanced with salt and PPS. There were advantages in microbial shelf-life of loins enhanced with salt, vinegar and PPS compared to loins injected with CTL or salt and PPS. With consumer trends towards reduced-sodium meat products, PPS injection appears to have advantages over traditional enhancement technologies. However, additional research should be conducted to improve the yield characteristics of PPS-injected pork products.

KEYWORDS: Pork, Enhancement, Protein solution

B. Retail Subjective Color Score Sheet

Name: _____

Date: _____

Pork Color

6 = Dark purplish red

5 = Purplish red

4 = Reddish pink

3 = Pink

2 = Grayish pink

1 = Pale purplish gray

Surface Discoloration

7 = Total discoloration (100%)

6 = Extensive discoloration (80-99%)

5 = Moderate discoloration (60-79%)

4 = Modest discoloration (40-59%)

3 = Small discoloration (20-39%)

2 = Slight discoloration (1-19%)

1 = No discoloration (0%)

[illegible]

C. Raw Odor Evaluation Score Sheet

**Marinade-Injected Pork Loin Chop
Raw Odor Evaluation Score Sheet
Miller/Pringle 2012**

Panelist Initials: _____

Date: _____

Fresh (raw) Odor
6 – Extremely strong off-odor detected
5 – Very strong off-odor detected
4 – Moderate off-odor detected
3 – Slight off-odor detected
2 – Threshold off-odor detected
1 - No off-odor detected

I D	Fresh Odor	Descriptor
1		
2		
3		
4		
5		
6		
7		

D. Cooked Sensory Evaluation Score Sheet

**Marinade-Injected Pork Loin Chop Sensory Evaluation Score Sheet
Miller/Pringle 2012**

Panelist Initials: _____

Date: _____

Tenderness	Juiciness	Pork Flavor Intensity
8 – Extremely tender	8 – Extremely juicy	8 – Extremely intense
7 – Very tender	7 – Very juicy	7 – Very intense
6 – Moderately tender	6 – Moderately juicy	6 – Moderately intense
5 – Slightly tender	5 – Slightly juicy	5 – Slightly intense
4 – Slightly tough	4 – Slightly dry	4 – Slightly bland
3 – Moderately tough	3 – Moderately dry	3 – Moderately bland
2 – Very tough	2 – Very dry	2 – Very bland
1 – Extremely tough	1 – Extremely dry	1 – Extremely bland

Saltiness	Overall Acceptability	Non-Pork Flavor
----	8 – Liked Extremely	----
----	7 – Liked Very Much	----
6 – Extreme salty flavor	6 – Liked Moderately	6 – Extreme non-pork flavor
5 – Very strong salty flavor	5 – Liked Slightly	5 – Very strong non-pork flavor
4 – Moderate salty flavor	4 – Disliked Slightly	4 – Moderate non-pork flavor
3 – Slight salty flavor	3 – Disliked Moderately	3 – Slight non-pork flavor
2 – Threshold salty flavor	2 – Disliked Very Much	2 – Threshold non-pork flavor
1 – No salty flavor detected	1 – Disliked Extremely	1 – No non-pork flavor detected

Please Wait 20 seconds between samples

I D	Tenderness	Juiciness	Pork Flavor Intensity	Saltiness	Overall Acceptability	Non-Pork Flavor Intensity	Descriptor
1							
2							
3							
4							
5							
6							