EFFECTS OF PLUM CONCENTRATE, POTATO STARCH, AND RICE STARCH AS A PHOSPHATE REPLACEMENT ON QUALITY AND SENSORY ATTRIBUTES OF WHOLE MUSCLE HAMS

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WILLIAM RICHARD MEYER

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by

WILLIAM RICHARD MEYER

APPROVED:

Dr. Loree A. Branham

Dr. John D. Kellermeier

Dr. Chase A. Runyan

Dr. Karen Cody

May 2018

APPROVED:

Dr. Susan E. Keith
Dean, College of Graduate Studies and Research

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ABSTRACT

This study was conducted to determine the functionality of plum concentrate (PC), potato starch (PS), and rice starch (RS) as phosphate replacements in whole muscle hams, determined by the industry significant attributes of smokehouse yields, sensory analysis, lipid oxidation, and color scores. Clean label treatment hams (CLT) were evaluated in conjunction with a traditional processed ham control (CON). Hams treated with PS had the highest cooking and overall yield ($P < 0.05$), PC hams had the lowest cooking and overall yield ($P < 0.05$), and RS hams were comparable to CON. The CON had decreased tenderness compared to CLT ($P < 0.05$). For all other sensory attributes CLT was comparable to CON. Both CON and CLT had TBARS values acceptable for lipid oxidation. The CLT were darker and less red than CON ($P < 0.05$). Both PS and RS should be considered acceptable phosphate replacements in natural curing brines.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS iii

ABSTRACT iv

TABLE OF CONTENTS v

LIST OF TABLES vi

INTRODUCTION 1

LITERATURE REVIEW 3

Consumer Demand for Clean Labels 3

Phosphates 4

Alternatives to Phosphates 5

MATERIALS AND METHODS 7

Ham Production 7

Cooking Loss and Purge Determination 11

Subjective Color Measurements 12

Lipid Oxidation Values 12

Sensory Evaluation 13

Statistical Analysis 14

RESULTS AND DISCUSSION 15

Color 15

Product Yield 17

Lipid Oxidation 20

Sensory Analysis 22

CONCLUSION 25

LITERATURE CITED 27

LIST OF TABLES

Table 1. Control Brine Formulation....8

Table 2. Natural Curing Brine Formulation Utilized for Potato, Plum, and Rice Treatments...8

Table 3. Overall pick-up % by treatment including pump weights, tumble weights, phosphate replacement and added brine 10

Table 4. Smokehouse Cycle for Hams....10

Table 5. Least squares means for Minolta color values (lightness L*, redness a*, yellowness b*) of Control, Potato Starch, Rice Starch, and Plum Concentrate 16

Table 6. Least squares means (± SEM)) and percentages for Cook Loss, Chill Loss, Purge Loss, Overall Loss and Product Yield of Control, Potato Starch, Rice Starch, and Plum Concentrate Hams....18

Table 7. Least squares means (± SEM) for trained sensory components of Control, Potato Starch, Rice Starch, and Plum Juice Concentrate Hams....23

INTRODUCTION

Within the processed meats industry, shifting consumer preference has called for the removal of traditional processing ingredients and has increased the marketability of organic, natural, and clean label meat products. These ingredients include salt, sugar, sodium nitrite, sodium phosphate, antioxidants, and cure accelerators, which all play a vital role in processed meat production. Salt is the most important cure ingredient; imparting flavor, protein binding capabilities, and is an antimicrobial agent. A second ingredient, sodium nitrite is essential in the development of cured meat color, and acts as an antimicrobial agent as well. Sodium phosphates increase water retention, affecting overall meat yield positively. Cure accelerators, typically sodium erythorbate or ascorbic acid, increase the rate at which cured meat color is developed. These ingredients are standard within traditional processed meat production. However, due to consumer pressure on processors to produce cleaner labeled products, processors are attempting to identify natural sources of these traditional cure ingredients. For instance, sodium nitrite is commonly replaced with celery powder (a natural form of nitrite), table salt is replaced with sea salt, sugar is replaced with raw sugar or honey, and cure accelerators with fruit powders. Many of these alternatives are well researched: Sindelar et al., (2007) showed similar cured meat color for a variety of products containing either sodium nitrite or celery juice powder as the curing ingredient. Additionally, Sebranek, (2015) discovered cherry powder contained high levels of ascorbic acid which is commonly used as a cure accelerator. Furthermore, both salt and sugar are commonly replaced with less commercially processed forms. Little research however, has been conducted on different

clean label replacements for phosphates. Similarly to phosphates, PC, RS, and PS are all ingredients added to curing brines to increase yields, shelf life, and color stability (Rourke, 2016). Moreover, these ingredients are well accepted in clean label, natural, and organic processed meat products. The purpose of this study was to evaluate the functionality and acceptability of PC, PS, and RS as phosphate replacements in whole muscle ham production.

LITERATURE REVIEW

Consumer Demand for Clean Labels

The term "clean label" in food products is often associated with natural or organic production. For the purpose of this study a clean label product is synonymous with natural and organic production, and is defined as any product produced without synthetic ingredients or chemical preservatives. In 2016, there was a total of $43 billion in organic food sales accounting for 5.3 percent of the entire market share (Organic Trade Association, 2016). According to the USDA-ERS, (2015) report, there have been increases in the organic food market share annually from 2005-2014. Additionally, natural meat sales in the United States improved 23.5% from 2014-2015. Moreover, 38% of all retail meat products have clean label claims (Kelly, 2016). Even more compelling, processed meats are the fastest growing category of clean label foods (Mitchell, 2007) and are available in three out of four conventional grocery stores nationally. Nielsen, (2015) stated consumers believed products with chemical sounding ingredients were less healthy than clean label products. Additionally Zink, (1997) conducted a survey reporting consumers wanted less processed, healthier, cleaner labeled products. Consumer demands are influencing the production of cleaner labeled products, but processors are seeing benefits as well. Premiums for clean labeled food products at the consumer level can increase sales price 40% (Winter and Davis, 2006). Additionally, natural and organically produced meat can reach premiums over 100% (Bacus, 2006).Within the meat industry, products containing a natural or organic label must be free of any artificial ingredients, artificial colors, and chemical preservatives (which most traditional curing ingredients fall under) (USDA, 2017). Additionally, all natural and organic meat products must be produced with no sodium nitrite or potassium nitrite (Bacus, 2006). With a

growing trend for cleaner labels, ingredients from natural sources are replacing the synthetic ingredients found in traditional curing formulations. The USDA and FDA currently have not defined what ingredients fall under clean labeling in food products. Nevertheless, sodium nitrite and potassium nitrite, phosphates, and cure accelerators are chemical preservatives not considered fit for clean labels. As stated by Resconi et al. (2015), over 70 percent of consumers surveyed stated phosphates either sounded unhealthy or artificial. Rourke (2016), identified clean label replacements for common curing ingredients showing plum concentrate, potato starch, and rice starch as possible replacement for phosphates. As more clean-label ingredients are identified, their functionality in processed meats production needs to be researched further.

Phosphates

Phosphates are commonly added to a variety of curing formulations to increase water holding capacity, directly increasing cooking yields. Products injected with a curing brine containing phosphates can often retain 100% of the products' green weight (fresh weight before processing) after cooking. Phosphates raise the pH of meat products' which inherently increase the products ability to retain moisture. Additionally, phosphates unfold complex protein structure allowing for ease of binding with added water (Pearson and Gillet, 1996). Increased moisture content in cooked products increases the overall palatability of meat products. Generally, cured meat containing phosphates have higher yields, slice more easily, and have more retention of flavor (Pearson and Gillet, 1996). Additionally, the inclusion of phosphates decreases warmed over flavor (WOF) through decreased lipid oxidation (Pegg, 2004). Even still, consumers' unfamiliarity with the ingredient, coupled with health concerns, has brought the use of phosphates under scrutiny. Many non-published articles as well as

growing peer-reviewed research heighten consumer concerns over phosphates. A study conducted by Ritz et al., (2012) linked the ingestion of processed foods containing phosphate to hyperphosphatemia, a disease which causes kidney failure. Although little published research indicates health problems from ingestion of phosphates, as consumer concerns increase alternative ingredients need to be evaluated.

Alternatives to Phosphates

Research identifies PC, PS, and RS as ingredients having multiple processing characteristics similar to phosphates. Person and Gillet (1996) identify both potato and rice starches as hydrocolloids. More specifically, rice and potato starches are modified food starches (MFS) which are mainly carbohydrate in structure. Moreover, MFS are affordable substitutions to phosphates and increase the water holding capabilities of meat similarly. Rice and potato starch increase water holding capacity individually, but are more effective when combined with low levels of phosphates in restructured ham products (Resconi et al., 2016). Moreover, as the level of comminution increases within a meat product, the more effective MFS become. In an additional study, Resconi et al., (2015) utilized rice starch as a replacement for phosphates in whole muscle hams and noted decreased sensory attributes for juiciness, saltiness, as well as a less desirable appearance. Interestingly enough, the same survey suggested consumers would be more apt to purchase ham products containing dietary fiber (Rice Starch) compared to phosphates based on clean label aspects. Nuñez de Gonzalez et al., (2009) evaluated different sources' of plum ingredients (plum powder, plum juice concentrate, or sprayed plum powder) on quality characteristics in hams compared to a traditional ham brine control. Although each plum ingredient decreased sensory attributes ($P < 0.05$), dried plum powder had the highest overall acceptability sensory value (when

compared to other plum treatments). Moreover, the study revealed plum powder as having similar color attributes to the control, and all treatments had similar lipid oxidation values. Jarvis et al., (2012) showed plum powder was statistically similar to phosphates for pickup percentage (moisture retention before cooking) in poultry marinades, suggesting the most important functional use of phosphates (water retention) can be achieved using alternative ingredients. Additionally, multiple studies suggest plum ingredients have antioxidant effects, increasing the shelf life of meat products (Ahmad et al., 2013; Karre et al., 2013; Nuñez de Gonzalez et al., 2009; Yildiz-Turp et al., 2010).

MATERIALS AND METHODS

Ham Production

Fresh inside ham pieces (*Semi membranosus* + *Adductor*) (n= 80), USDA-IMPS # 402F, were purchased from a USDA inspected pork harvesting facility. The product was received at the Angelo State University Food Safety and Product Development Laboratory (FSPD) and held in refrigeration (4°C). The ham pieces were denuded (removal of fat and connective tissue), split into equal halves, and considered "pump ready". A total of 160 inside ham pieces were created, allowing for 40 within each brine treatment group. Inside ham pieces were randomly assigned to one of four brine treatments including: a control (Table 1) containing traditional curing ingredients (CON), and three treatments with natural curing alternatives (Table 2) containing either plum concentrate (PC), potato starch (PS), or rice starch (RS) as phosphate replacement. Regardless of treatment, all ingredients used were commercially available, generally recognized as safe (GRAS) products, contained at the FSPD laboratory. Brine treatments were made separately, and injectors were cleaned and sanitized between each injection period. Unlike phosphates, PC, PS, and RS cannot readily dissolve in water, and consequently cannot be injected into meat products. Therefore, the control brine was made with the addition of phosphate; whereas, the three clean label treatment brines received phosphate replacement inclusion via the vacuum tumbler. Vacuum tumblers apply extreme pressure on meat products, forcing the interaction of meat with curing ingredients. Both injecting and tumbling are widely practiced processing steps for processed meats. The ham pieces from all treatments were injected to approximately 125% of their fresh weight (GW) using a multi- needle injector (KOCH günter pökelinjektor Model PI 9/17 – Kansas City, MO). After injection, hams were weighed (PW) and pump percent was

Table 1. Control Brine Formulation *

Ingredient	Percent Ingredient in Brine	Pounds of Ingredient in Brine
Water	80.70	80.70
Salt	9.80	9.80
Sugar	6.60	6.60
Phosphate	1.40	1.40
Sodium Erythorbate	0.22	0.22
Sodium Nirtite	1.28	1.28

*Control brine was formulated at 100lbs

Table 2. Natural Curing Brine Formulation Utilized for Potato, Plum, and Rice Treatments*

Ingredient	Percent Ingredient in Brine	Pounds of Ingredient in Brine
Water	81.29	121.90
Salt	9.87	14.80
Sugar	6.65	10.00
Cherry Powder	1.26	1.90
Veg Stable 506	0.94	1.4

*Treatment brine was formulated at 150lbs

recorded. Hams were placed into a vacuum tumbler (KOCH Model LT-15 – Kansas City, MO). Targeting a post tumble weight of 130% (of GW), the following the formula was used to determine the amount of brine and phosphate replacement (PR) added to the tumbler: [(GW*1.3)-PW] - PR. Phosphate replacements were formulated based on manufactures' recommendations. Inclusion rates for treatments included 2.25% (PS, RS) and 1.1 % (PC) of the projected final meat block weight (130% of GW). The control group received only brine while each clean label treatment received phosphate replacement in addition to brine. Table 3 displays PR weights, and the amount of added brine to reach 130% of GW after tumbling (typical % for hams) for all treatments. Hams were then tumbled for 2 hours at -15 mm Hg and 12 RPM (industry standard). Between each tumble cycle, the tumbler was clean and sanitized to prevent cross contamination of ingredients across products. After tumbling, tumbled weights (TW) and pick-up percentages were recorded (Table 3). The following formula was used to calculate pick-up percent: (TW/GW)*100.

After injection and tumbling, hams were loaded onto smoke house racks and cooked in a smokehouse (Alkar Model 700 HP – Lodi, WI) to an internal temperature of 62.7°C without the addition of smoke, all utilizing identical smokehouse cycles (Table 4). To achieve a steam cook, the smoke house cycle maintained even wet and dry bulb temperatures for 100% humidity. Additionally, fan speed was set at 5 (a neutral setting) to evenly distribute heat without excessive drying. Each treatment group was cooked on different smokehouse cooking runs to prevent contamination of ingredients across products. Immediately after cooking, hot weights of hams were recorded, and 24 h post cooking chilled weights

Table 3. Overall pick-up by treatment including pump weights, tumble weights, phosphate replacement and added brine

	Control	Potato Starch	Rice Starch	Plum Concentrate
Fresh Weight, lb	91.25	88.70	86.80	85.10
Pump Weight[a], lb	113.75	110.60	107.45	105.35
Pump Percent	1.25	1.25	1.24	1.24
Phosphate Replacement, lb	0.00	2.88	2.83	1.21
Added Brine, lb	4.87	1.89	2.94	4.32
Tumble Weight[b], lb	115.89	113.30	111.80	109.90
Tumble Percent	1.27	1.28	1.29	1.29

[a] Pump weight was recorded immediately after injection period
[b] Tumble weight was recorded after 2 hr. tumbling period

Table 4. Smokehouse Cycle for Hams

Step	Hr	Min	Dry Bulb (°F)	Wet Bulb (°F)	Internal Temp (°F)	Fan (MB) Speed	H_20 Humidity
1	0	45	130	130	0	5	ON
2	1	30	145	145	0	5	ON
3	0	45	155	155	0	5	ON
4	0	1	175	175	158	5	ON

were recorded. Cooking and chilling of ham products was conducted in accordance with USDA-FSIS Appendix A and B which have established proper protocols for pathogen reduction in specific processing categories of meat. Heating guidelines established by Appendix A require whole muscle hams to reach an internal temperature of 70°C during cooking for instant pathogen lethality (USDA-FSIS, 2017b). In addition, Appendix B guidelines mandate stabilization (chilling) must reduce product temperatures from 57.22°C to below 21.11°C in 2 hours and below 5°C within 6 total hours (USDA-FSIS, 2017a). After chilling, hams were vacuum packaged and held under refrigeration (4°C) in bulk boxes for each treatment. Storage of hams was performed to mimic the commercial meat industry. At 21d post cooking, hams were removed from vacuum packaged bags, dried, and final product weight (FPW) was recorded to determine purge loss. Hams were then sliced (Berkel Model 827 Gravity Feed Meat Slicer- Troy, OH) into 6.35mm thick slices. Hams slices were given unique identification, vacuum packaged, and held under refrigeration (4°C). After an additional 7d of storage, hams were subject to multiple quality and sensory tests. Slices utilized for quality and sensory test had specific identification to ensure each slice came from the same anatomical section of the ham.

Cooking Loss and Purge Determination

Cooking loss was determined by recording the post tumble weight (TW) of the hams and the hot weight of the hams after cooking (HW). After chilling, the chilled weight (CW) was recorded. The following formula was used to determine cook loss and chill loss: Cook Loss (%) = (TW- HW) / TW × 100, Chill Loss (%) = (HW-CW) / HW × 100. Additionally, CW was utilized in determining purge loss of refrigerated storage. Ham products were stored in refrigeration (4°C) for 21d. After the 21d refrigeration period, products were removed

from the packaging material, dried of excess moisture, and weighed (FPW). Purge loss was calculated as: (CW-FPW) / CW × 100.

Subjective Color Measurements

At 28d post cooking, ham slices were evaluated for L*, a*, b* color space values using a Minolta Colorimeter (Model CR-300, Minolta Corp., Ramsey NJ). The colorimeter was standardized using a plain white calibration tile. Values for the calibration tile were Y= 94.6, x = .3133, and y= .3195. Ham pieces and calibration tile were read through vacuum packaged bags. L* value determined lightness, a* values determined redness, and b* values determined yellowness. Each slice was visually separated into three section, and color values were recorded for each section within the *Semi membranosus* muscle. L*, a*, and b* values were averaged to create one set of values for each slice.

Lipid Oxidation Values

Lipid oxidation for each treatment after 28d refrigerated storage period was determined by 2-thiobarbituric acid-reactive substances procedures (TBARS). Procedures are outlined by Texas Tech University TBARS Protocol, modified from Beuge and Aus (1978). The day prior to TBARS evaluations, trichloroacetic acid/ thiobarbituric acid (TBA/TCA), butylated hydroxyanisole (BHA), and Tetra-ethoxypropane (TEP) chemical reagents were made and stored in refrigeration (4°C). After a 28d refrigeration period, individual ham slices from each treatment were cubed into a 10g sample, frozen in liquid nitrogen, and then crushed into a powder. The sample was then placed in a sterile conical vial with 30mL of distilled deionized water (DDI). Samples were homogenized for 2 min allowing for complete homogenization. After homogenization, samples were centrifuged at 2000G for 10 min. The

remainder of the procedure was completed in duplicate. Initially, 2mL of supernate (liquid separated from meat particles within sample) was removed and placed in a 15mL conical vial. Secondly, 100µl of BHA was added to each vial. Lastly, 4mL of TCA/TBA solution was added to each vial and vortexed thoroughly. The vortex solution was heated in a boiling water bath (100°C) for 15 min and then cooled for 10 min in ice water (4°C). The solution was then centrifuged at 200G for 10 min and then read using a spectrophotometer (Thermo-Scientific Evolution 201). Absorbance values for the supernatant of the samples were determined using a standard. The standard was created by adding a descending concentration of TEP to vials containing 4mL of TCA/TBA and 100 µL of BHA. TEP concentrations ranged from 0.0 - 0.1 ml and allowed for recordable color variation (very dark pink to clear). Absorbance values were determined for each concentration of TEP and the standard established. Each sample's absorbance was compared to the standard to determine the level of TEP present. TEP concentrations were recorded as nmol malondialdehyde/gram and then converted to mg malondialdehyde/ kg. The following conversion was used: (nmol/g)*72/100

Sensory Evaluation

All sensory panel testing was completed according to an Institutional Review Board approved protocol (ASU-BRA- 013018). A trainer was appointed based on most sensory experience, and panelists were trained within the FSPD laboratory sensory evaluation room. During training, all panelists evaluated similar ham pieces and gave feedback to the trainer over sensory attributes. Each sensory attribute was evaluated individually, and adjustments were made based on findings until the trainer approved panelist for the trial. Ham slices were removed from the vacuum package material, assigned randomly to different sensory panels, and cut into 1cm³ pieces for sensory evaluation. Trained panels were conducted in

accordance with AMSA, (1995) procedures. Ham slices were not heated to mimic traditional ham consumption at the consumer level. Each sample was evaluated for the following attributes: initial and sustained juiciness, initial and sustained tenderness, off flavors, ham flavor intensity, mouth feel and overall acceptability. In between samples, panelist were provided water, unsalted crackers, and apple juice to cleanse their palates. In total, 100 samples were evaluated during 7 sensory panels over 1 wk. The first 6 sensory panels consisted of 12 samples and the last consisted of 8 samples.

Statistical Analysis

All data were analyzed utilizing the mixed model (PROC MIXED) procedure of SAS (SAS Inst. Inc., Cary, NC). The dependent variables consisted of cook loss, purge loss, color scores, lipid oxidation, and trained sensory responses. Among treatments, each individual inside ham piece served as the experimental unit and significant ($P \leq 0.05$) treatment effect means was separated using Fisher's protected LSD.

RESULTS AND DISCUSSION

Color

Color values were determined using a Minolta Colorimeter and were reported as L*, a*, and b* values. L* values measure lightness and are scaled from 0 = black to 100 = white, a* values measure redness whereas negative values = green and positive values = red, b* values measure yellowness whereas blue = negative values and positive values = yellow. All Least Squares Means for colorimeter values are presented in Table 5. When analyzing L* values, the CON had the highest value indicating the lightest overall color. Hams treated with PS, RS, and PC were all similar and darker in color compared to CON samples ($P < 0.05$). Similarly, CON had the highest a* value ($P < 0.05$) indicating a significant redder color compared to PS, RS, and PC. A less important measure in cured meat, b*, also indicated CON having the highest value for yellowness ($P < 0.05$) compared to clean label treatments. Lightness (L*) and redness (a*) most directly relate to cured meat color quality. Variation in these values directly affects how consumers perceive the quality of cured meat products. Color remains the most important factor influencing consumer preference in meat purchasing (AMSA, 2012). Although acceptable ranges for Minolta values have not been documented for whole muscle hams, all hams were considered acceptable for color by the trained panel during quality analysis. The darker, less red, less yellow hues exhibited by each treatment group may be attributed the individual treatments themselves, or the curing brine used across all clean label treatments. Sindelar et al., (2007) showed hams produced with vegetable powder have similar color attributes as hams produced with sodium nitrite. These results indicate the color differences within this experiment can likely be attributed to individual treatments rather than the natural curing brine.

Table 5. Least Square Means for Minolta color values (lightness L*, redness a*, yellowness b*) of Control, Potato Starch, Rice Starch, and Plum Concentrate treated hams

Color Reading	Control	Potato	Rice	Plum
L*	52.43[a]	49.95[b]	49.02[b]	49.28[b]
a*	56.96[a]	50.94[b]	51.89[b]	51.64[b]
b*	39.91[a]	35.65[b]	34.82[b]	34.85[b]

[ab]Values within a color reading with a different superscript differ ($P < 0.05$)

Product Yield

Product yield was determined by four measurements taken at different steps during the production of the ham products. All product yield measurement Least Squares Means are reported in Table 6. Cook loss is determined by taking the post tumble weight (TW) of the product and comparing it to the cooked weight (HW) of the product. Cook loss is the most important factor in processed meat yield as the greatest amount of weight loss occurs during cooking. Cook loss was determined by the following formula: Cook Loss (%) = (TW- HW) / TW × 100. For cook loss, PS had the lowest value ($P < 0.05$) indicating the highest yield, both CON and RS were similar, and PC had the greatest cooking loss ($P < 0.05$) compared to all other treatments. Chill loss is determined by comparing the hot weight and chilled weights (CW) of ham products. Ham products were chilled for 24 h before weights were recorded. Chill loss is determined by following formula: Chill Loss (%) = (HW-CW) / HW × 100. Potato starch had the greatest value for chill loss ($P < 0.05$) as it had more weight retention and therefore more weight available to loose. The CON, RS, and PC were all similar for chill loss. Purge loss was determined by the following formula: Purge Loss = (CW-FPW) / CW × 100. Final product weight (FPW) was determined by drying excess moisture from ham product after 21d storage and recording the weight. The RS and PC treatments had similar values for purge loss and were the lowest amongst treatments ($P < 0.05$). The CON had greater purge loss than RS and PC but less purge loss than PS which had the greatest value ($P < 0.05$). The final weight measurement, overall loss, was determined by comparing TW and FPW using the following formula; Overall Loss = (TW-FPW) / TW × 100. Potato Starch had the lowest value ($P < 0.05$) for overall loss indicating the highest yield.

Table 6. Least Square Means (± SEM) and percentages for Cook Loss, Chill Loss, Purge Loss, Overall Loss and Product Yield of Control, Potato Starch, Rice Starch, and Plum Concentrate Hams

Weight Attribute		Control	Potato	Rice	Plum
Cook Loss[d]	Weight	0.32 ± 0.009^{a}	0.18 ± 0.009^{b}	0.33 ± 0.009^{a}	0.54 ± 0.009^{c}
	%	11.43	6.59	11.96	19.97
Chill Loss[e]	Weight	0.11 ± 0.005^{a}	0.14 ± 0.005^{b}	0.12 ± 0.005^{a}	0.12 ± 0.005^{a}
	%	4.41	5.58	4.88	5.51
Purge Loss[f]	Weight	0.04 ± 0.004^{a}	0.10 ± 0.004^{b}	0.02 ± 0.004^{c}	0.02 ± 0.004^{c}
	%	1.88	4.16	1.12	1.26
Overall Loss[g]	Weight	0.48 ± 0.012^{a}	0.43 ± 0.012^{b}	0.48 ± 0.012^{a}	0.69 ± 0.012^{c}
	%	16.91	15.47	17.21	25.34
Product Yield[h]	%	104.71	107.72	106.394	96.41

[a,b,c] Values within a weight trait which have different superscripts differ ($P \leq 0.05$)
[d]Cook Loss (%) = (GW- HW) / GW × 100
[e]Chill Loss (%) = (HW-CW) / HW × 100
[f]Purge Loss = (CW-FPW) / CW × 100
[g]Overall Loss = (GW-FPW) / GW × 100.
[h]Product Yield= (GW/FPW) × 100
GW=Green Weight, HW = Cooked Weight, CW= Chilled Weight, and FPW= Final Product Weight

The CON and RC were similar, while PC had the highest value ($P < 0.05$) indicating the lowest yield.

Results for PC are comparable to results by Nuñez de Gonzalez et al., (2009), who discovered the addition of plum ingredients reduces over yield of processed meat products. Contradicting previous research by Resconi et al, (2016) inside ham pieces containing RS had similar yields to a traditional control, and PS outperformed a traditional control. Product pH is the most influential factor affecting water holding capacity and moisture retention in processed meat (Huff and Lonergan, 2005). Plum Concentrate had the highest yield among treatments for tumbling percent, indicating the greatest initial moisture retention. Nevertheless, PC has an acidic pH (2.0-4.8) and inherently decreases the pH of the final product. Decreased pH coupled with a heating process results in decreased product yield (Bouton et al., 1971). Potato and rice starches are near neutral in pH, therefore there product yields are less affected by heating. Based on results of product yield alone RS and PS can be substituted for phosphates in natural curing brines.

Lipid Oxidation

Lipid oxidation values were determined by using Thiobarbituric Reactive Substance Assay (TBARS). The TBARS measures malondialdehyde, the secondary bi-product of oxidative rancidity in fats. Values for TBARS were recorded as mg malondialdehyde per kg of ham sample. Formulation of processed meats with nitrites, cure accelerators, phosphates, and other ingredients aiding in the stabilization of cured meat decrease overall lipid oxidation. Even still, a measure of lipid oxidation can be recorded as predictor of shelf life and product quality in processed meats. With increased lipid oxidation, processed meat products deteriorate and unacceptable flavors, colors, and aromas persist reducing quality and value. All TBARS least square means are recorded in Figure 1. The PC treatment had the highest TBARS values ($P < 0.05$), compared to CON, PS, and RS which were all similar. All samples for each treatment group and control contain nitrite, which greatly reduces lipid oxidation of meat products (Alahakoon et al., 2015; Shahidi and Pegg., 1992). Additionally, inclusion of processing ingredients and nitrite alters the effectiveness of lipid oxidation test such as TBARS (Jo et al., 2003). Generally, the lowered final pH of products contain plum ingredients reduces spoilage bacteria responsible for product deterioration. The PC treatment having the highest TBAR value directly opposes a multitude of previous research (Ahmad et al., 2015; Karre et al., 2013; Nuñez de Gonzalez et al., 2009; Yildiz-Turp et al., 2010).These results are likely a product of either nitrite interference, or sampling errors exaggerating extremely low TBARS values. Even still, the highest TBAR value measurement was .23 mg mal/ kg ham (PC) which remains below the level detectable for lipid oxidation during sensory analysis (Melton, 1983). Therefore, all treatments and the control were effective in inhibiting lipid oxidation.

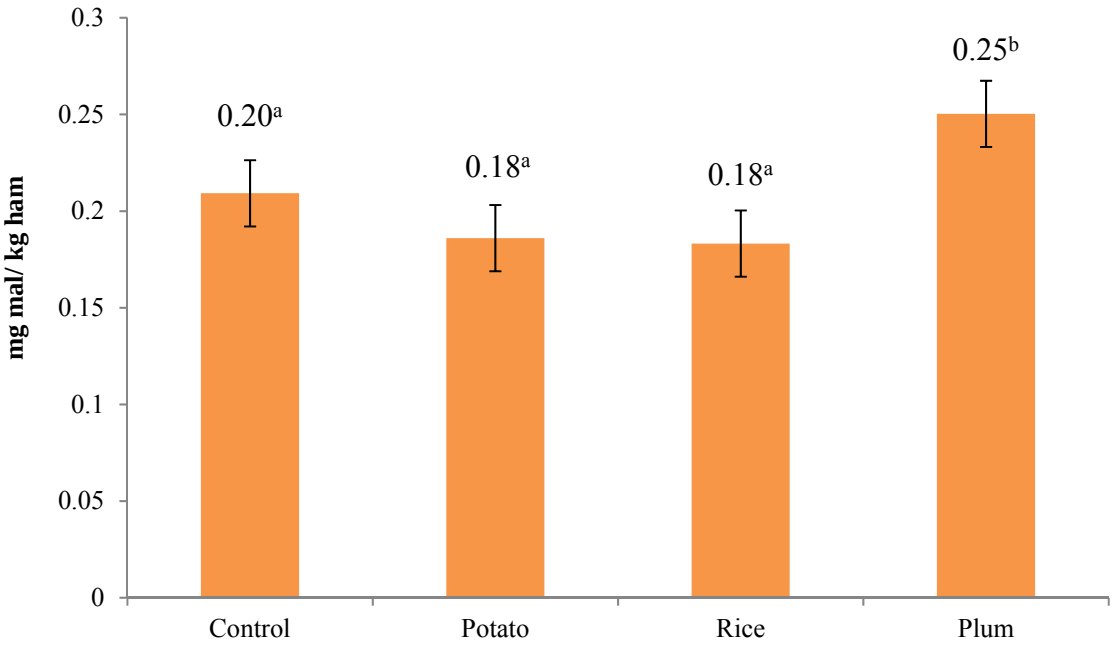

Figure 1. Least Squares Means of Thiobarbituric Reactive Substance Assay Values for control, potato starch, rice starch, and plum juice concentrate treated hams.
Error bars represent the standard error of the least squares means.
[a,b] values which have different superscripts differ ($P \leq 0.05$).

Sensory Analysis

Sensory data was collected via trained sensory panels evaluating initial juiciness, sustained juiciness, initial tenderness, sustained tenderness, ham flavor intensity, off flavors, mouthfeel, and overall acceptability. Each sensory attribute was scaled to the following; juiciness: 8 = extremely juicy, 1 = extremely dry, tenderness: 8 = extremely tender, 1 = extremely tough, ham flavor intensity: 8 = extremely intense ham flavor, 1 = extreme non-ham flavor, mouthfeel: 8 = extreme ham like mouthfeel, 1 = extreme non-ham like mouthfeel, off flavors: 1 = extreme off flavor, 4 = no off flavors, and overall acceptability: 1 = dislike extremely, 8 = like extremely. Each sample was evaluated by eight panelists and an average for each sensory attribute was created.

The Least Squares Means of sensory attributes are presented in Table 6. There were no treatment effects on initial and sustained juiciness amongst treatments. All products had similar values and were considered slightly juicy (5-6) for both initial and sustained juiciness. A treatment effect was observed for both initial and sustained tenderness. The CON was considered less tender than clean label treatments for both initial and sustained tenderness ($P < 0.05$). All clean label treatments were similar for initial tenderness and were considered moderately tender (6-7) whereas the control was slightly tender (5-6). Although CON was considered less tender than treatments, they were all considered moderately tender for sustained tenderness (6-7). There were no treatment effects seen on ham flavor intensity, and all values were considered to have a moderately intense ham flavor (6-7). Similarly, there were no treatment effects for off flavor, mouthfeel, and overall acceptability. All treatments and control were considered to have no off flavors (4), a moderate ham like mouthfeel (6-7),

Table 7. Least Square Means (± SEM) for trained sensory components of Control, Potato Starch, Rice Starch, and Plum Juice Concentrate Hams

Traits	Control	Potato	Rice	Plum
Initial Juiciness[a]	5.63 ± 0.06	5.70 ± 0.06	5.63 ± 0.06	5.60 ± 0.06
Sustained Juiciness[a]	6.15 ± 0.06	6.08 ± 0.06	6.17 ± 0.06	6.08 ± 0.06
Initial Tenderness[b]	5.48 ± 0.05[y]	6.01 ± 0.05[z]	6.13 ± 0.05[z]	6.01 ± 0.05[z]
Sustained Tenderness[b]	6.20 ± 0.05[y]	6.53 ± 0.05[z]	6.59 ± 0.05[z]	6.54 ± 0.05[z]
Ham Flavor Intensity[c]	6.37 ± 0.06	6.32 ± 0.06	6.34 ± 0.06	6.33 ± 0.06
Off Flavor[d]	3.98 ± 0.01	3.98 ± 0.01	3.98 ± 0.01	3.99 ± 0.01
Mouth Feel[e]	6.34 ± 0.06	6.20 ± 0.06	6.26 ± 0.06	6.23 ± 0.06
Overall Acceptability[f]	6.15 ± 0.06	6.15 ± 0.06	6.33 ± 0.06	6.22 ± 0.06

[a]Sensory scale for juiciness was 1- extremely dry, 8- extremely juicy
[b]Sensory scale for tenderness was 1- extremely tough, 8- extremely tender
[c]Sensory scale for ham flavor intensity was 1- extremely bland, 8- extremely intense
[d]Sensory scale for off flavor was 1- extreme off flavor, 4- none
[e]Sensory scale for mouth feel 1- extreme non ham mouth feel, 8-extreme ham mouth feel
[f]Sensory scale for overall acceptability 1- dislike extremely, 8- like extremely
[y,z]values within a sensory trait which have different superscripts differ ($P \leq 0.05$)

And were moderately liked overall (6-7). Nuñez de Gonzalez et al., (2009) saw decreased juiciness and tenderness with addition of plum concentrate and correlated it to decreased cooking yields. Similarly within the results, PC had the lowest cooking yields; however, had similar attributes for juiciness and improved tenderness. In addition, RS, PS, and CON having similar juiciness values in the current study, conflict Resconi et al., (2015) findings, who saw decreased juiciness with the inclusion of RS and PS as a phosphate replacement. The CON having the lowest value for tenderness can likely be attributed to increased springiness. Although springiness is considered a defining characteristic of cured ham, it does increase toughness. As the level of phosphate increases, springiness increases linearly (Resconi et al., 2016). Therefore the decrease in tenderness for CON is likely attributed to phosphate.

CONCLUSION

The purpose of this study was to evaluate the functionality of potato starch, rice starch, and plum concentrate as a replacement for phosphates in clean label curing brines. Shifting consumer demands have allowed for increased growth of natural and organic meat products which restrict chemical preservatives. Research has identified replacements for nitrites (Vegetable Powder) and cure accelerators (Cherry Powder) but a suitable phosphate replacement has not been identified. Although plum concentrate, potato starch, and rice starch have all been researched individually, they have not been researched simultaneously under the same processing conditions. A comparison was conducted utilizing natural curing ingredients and three potential phosphate replacements to determine functionality as compared to a control.

Although color differences were determined, visual assessments determined all phosphate replacements as having acceptable cure color. Additionally, trained sensory analysis determined all phosphate replacements maintained or improved sensory attributes over the control. The PC treatment had the highest TBARS value but was still under the threshold of detectable levels for lipid oxidation. Cooking yields were improved by PS, held similar by RS, and decreased significantly by PC when compared to the control. Based on research presented, PS and RS are suitable replacement for phosphates in natural curing brines based upon similar or improved yields, and similar or improved sensory attributes. Due to its extreme cooking loss PC is not a recommended phosphate replacement.

Before implementation of RS and PS as sole phosphate replacements in meat curing brines, further research needs to be conducted. The processed meats industry would greatly

benefit from consumer sensory data associated with these replacements. Consumer sensory data will give companies a better idea of actual consumer acceptance of products containing PS and RS. Additionally, it might be beneficial to understand how PS and RS work in cooperation within the same curing system. Furthermore, shear force values might help further define differences in tenderness between PS, RS, and CON. Finally, hams only represent a small subset of all processed meats containing phosphates. Future research could identify the functionality of PS and RS in other processed meats products as phosphate replacement.

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