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

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Abstract: Experiments were conducted to determine the efficacy of replacing phosphates in marinated chicken and chunked and formed deli ham using alternative ingredient blends. For the marinated chicken study, broiler breasts were marinated with a 13% solution of 1.0% NaCl, water and either 0.35% sodium tripolyphosphate or a phosphate alternative. Treatment variables consisted of (1) 0.35% sodium tripolyphosphate (STP), (2) negative control (no phosphate, NP), (3) 0.83% Whey protein concentrate (WPC), (4) 0.83% Oat fiber (OF, marinated chicken only), or (5) 1.05% Oat fiber with dry vinegar (OF-DV). The WPC, OF, and OF-DV treatments also included 1,000 ppm of a natural flavor that served as an antioxidant. The STP treatment yielded breast meat with less ($P < 0.05$) cooking loss and a higher pH ($P < 0.05$) than the NP and alternative ingredient treatments. On average, no differences were observed ($P > 0.05$) in consumer acceptability for chicken breast appearance, texture and overall acceptability. For the ham study, each treatment formulation consisted of approximately 77% pork, 20% water, common commercial curing ingredients, and the following treatment effects: STP (0.4% STP), NP (no phosphate, NP), 1.3% OF-DV, and 1.1% WPC. STP had less cooking loss than all other treatments ($P < 0.05$). The STP treatment had greater protein bind ($P < 0.05$) than all other treatments, and the OF-DV treatment had greater protein bind than the WPC and NP treatments. The NP, STP, and WPC treatments were preferred ($P < 0.05$) over the OF-DV treatment. Application of WPC or OF-DV may help meat processors meet current clean label trends if the decrease in yields for chicken breast and deli hams and the decrease in firmness of texture in deli hams is acceptable to processors and consumers.

Keywords: consumer acceptability, deli ham, marinated chicken, phosphate alternative
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Introduction

Phosphates function by increasing pH and opening up the meat protein structure such that there is more space for water in meat products, which leads to increased water holding capacity (WHC; Huynh et al., 2011). Sodium tripolyphosphate (STP) is hydrolyzed by alkaline phosphatases in meat to form pyrophosphate which dissociates actomyosin. Myosin is solubilized by alkaline pyrophosphate and swells with added moisture to form a solution and subsequently a gel when heated (Xiong, 1998). Though phosphates provide meat functionality that results in desirable sensory properties, there is a trend for meat processors to replace phosphates in their formulations to create cleaner labels (Fuhrman, 2018). Countries such as Italy and France have decreased the usage of phosphates in poultry products due to negative consumer perception (Petracci et al., 2013).

To meet consumer demand, several ingredients have been investigated as potential alternatives for phosphates. Prabhu and Husak (2014) evaluated sodium carbonate in combination with native potato starch. Native potato starch was able to replace the water binding and texture provided by phosphate but was ineffective at disassociating the actin-myosin

Table 1. Percentage of each ingredient included for the marinated chicken treatment formulations

Treatment[1]	Chicken	Water	Salt	Sodium phosphate	WPC blend	Oat fiber blend	Oat fiber vinegar blend
NP	88.415	10.70	0.885	–	–	–	–
STP	88.415	10.35	0.885	0.35	–	–	–
OF	88.485	9.80	0.885	–	–	0.83	–
OF-DV	88.465	9.60	0.885	–	–	–	1.05
WPC	88.485	9.80	0.885	–	0.83	–	–

[1]NP = negative control, no phosphate; STP = positive control, sodium tripolyphosphate; OF = oat fiber blend; OF-DV = oat fiber blend-dry vinegar; WPC = whey protein concentrate blend.

complex. Whey protein concentrate (WPC) at levels of 1.5 to 3.3% enhanced emulsion stability, pH, and yields in smoked chicken sausage (Rao et al., 1999), and enhanced yields and texture of injected pork loins (Hayes et al., 1998). WPC has also been used to improve texture and color and inhibit lipid and oxymyoglobin oxidation in meatballs (Ulu, 2004). Whey protein has an isoelectric point that is similar to meat protein so it has an overall negative charge, which improves WHC and texture in processed meat products (Horne, 2017).

β- glucan in oat fiber binds water in meat products (Talukder and Sharma, 2010). Incorporating oat bran (15%) in chicken patties made from finely minced chicken meat increased WHC (from 40.5 to 52%), emulsion stability (from 74.2 to 98.2%), and cooking yields (70.2 to 96.0%) when compared to the control (Talukder and Sharma, 2010). Carrageenan and oat fiber (2%) were effective at increasing WHC and enhancing emulsion stability in reduced fat frankfurters (Hughes et al., 1997). In addition, Meat Kofta, an Indian meat product, had greater yields and softer texture when oat flour (8%) and 0.5 and 1.5% carrageenan were used in the formulation (Modi et al., 2007). Since WPC and oat fiber improve functionality in processed products, these ingredients may have some viability as phosphate replacers. Since phosphate also functions as an antioxidant, an antioxidant system should also be included in a phosphate replacement system. Therefore, the objective of the present study was to evaluate whey protein concentrate, oat fiber, and oat fiber with vinegar and an antioxidant system as potential STP alternatives in marinated whole chicken breasts and chunked and formed deli ham.

Materials and Methods

Broiler breast

Sample treatments. Broiler breast meat (0.19 to 0.25 kg per fillet) was obtained from a local poultry processor 24 h after deboning. Samples were stored at 2 to 4°C and marinated within 24 h after arrival. Marinade formulations were targeted to include 1.0% NaCl (salt, Culinox 999, Morton Salt, New York, NY) and either 0.35% sodium tripolyphosphate (STP New, ICL Performance Products, St. Louis, MO) or a phosphate alternative treatment and water on a finished product basis (FPB). The treatment variables consisted of (1) 0.35% STP (STP); (2) Negative Control, 0% STP (NP); (3) 1.3% Whey Protein Concentrate (WPC; NatBind Seasoning WPA-C100 [WPC, chicken broth, natural flavor as an antioxidant]), Hawkins, Roseville, MN); (4) 1.3% Oat Fiber (OF; NatBind Seasoning FPA-C100 [oat fiber, chicken broth, natural flavor as an antioxidant], Hawkins); and (5) 1.3% Oat Fiber with Dry Vinegar (OF-DV; 1.1% OF and 0.2% dried vinegar, NatBind Seasoning FPA-C100-C [oat fiber, vinegar, chicken broth, natural flavor as an antioxidant] Hawkins). Formulations for each marinated chicken treatment are included in Table 1. Dry ingredients were blended (Oster hand blender with blending cup, Oster, Racine, WI) with water and ice (0 to 2°C) and the final temperatures of the brine solutions were –6 to –7°C. The experiment was conducted on 3 separate occasions, such that there were 3 independent replications of the 5 treatments. For brine uptake, there was 1 subsample per treatment. For cooking loss, pH, instrumental color, and shear force, there were 8 subsamples from each treatment within each replication. Therefore, for the study, 24 individual breasts were evaluated for cooking loss, pH, color, and shear force for each treatment.

Processing. For marinated chicken, a Biro Vacuum Tumbler (two 9.1 kg drums, 825 mm long × 393.7 mm wide, 16 L volume, VTS-44, Marblehead, OH) was placed in a walk-in cooler (2 ± 2°C) 24 h prior to tumbling. The brine marinade (1.02 kg) was placed in the tumbler with 7.8 kg of chicken (13% marinade). The expected marinade pick-up was 12% based on previous experience. The drums were closed and a vacuum (25 mm hg) was pulled on the drum prior to tumbling for 30 min at 8 rpm. After tumbling, the chicken was placed on racks for 10 min to allow the samples to drip prior to cooking.

Brine retention. After allowing 10 min for drip losses and immediately prior to cooking, all chicken breasts were weighed and brine pick-up was recorded as the difference in weight of the marinated chicken breast meat and non-marinated chicken, divided by the raw weight and multiplied by 100:

$$\text{Brine Pickup } (\%) = \frac{\begin{pmatrix}\text{tumbled weight}\\ -\text{raw weight}\end{pmatrix}}{\text{Cooking yield }\%} \times 100$$

Cooking loss. Chicken breasts were placed in a Hobart Steam Oven (Hobart) at a dry bulb temperature of 177°C until an internal temperature of 74°C was reached. Temperature was monitored using TruTemp thermometers (Taylor). Eight chicken breasts from each treatment, within each replication were used to determine cooking loss. The equation is as follows:

Cooking loss (%) = [(marinated raw weight – cooked weight)/(marinated raw weight)] × 100

Cooked weight was measured 15 min after cooking.

Added sodium concentration. Added sodium concentration in the chicken was estimated based on the amount of STP and salt added to the formulation, the molecular weight of sodium in the STP and salt, the pick-up of the marinade and the cook yield as:

$$\frac{\left[\left(\frac{115}{367}\right)\times\begin{pmatrix}\text{STP }\% \text{ in}\\ \text{marinade}\times\text{pickup}\end{pmatrix}\right]+\left(\frac{23}{58}\right)\times\begin{pmatrix}\text{NaCl }\% \text{ in}\\ \text{marinade}\times\text{pickup}\end{pmatrix}}{\text{Cooking yield }\%}$$

For the STP treatment for chicken (Table 1), this is ([{115/367} × {0.35/11.585} × {0.0088}] + [23/58] × [0.885/11.585] × [0.0088])/0.78 = 4,486 ppm sodium

In the above equation, 115 is the molecular weight of phosphate, 367 is the molecular weight of STP, 23 is the molecular weight of sodium, and 58 is the molecular weight of sodium chloride. For the treatments with proprietary treatment blends, the amount of sodium (less than 50 ppm in each blend) was included in the final concentration for those treatments. There is approximately 50 ppm indigenous sodium in meat. This was not accounted for since it was not measured.

pH. Instrumental pH measurements (n = 8) were taken 24 h after vacuum tumbling of breast meat. The pH was measured with a Portable pH meter (Model AP61, Acumet, Fisher Scientific, Pittsburgh, PA) by inserting a penetrating probe (model 05998–20, Cole Palmer, Vernon Hills, IL) 2.5 cm below the pectoralis major muscle at approximately 2.5 cm from the top of the breast, and 2.5 cm from the breastbone.

Instrumental color evaluation. Instrumental color measurements (CIE L*, a*, and b*) of raw (24 h after marination) and cooked (24 h after cooking) breast fillets (n = 8) for each treatment were measured using the Hunter Lab MiniScan 45/0° color spectrophotometer EZ (model 4500L; Hunter Laboratories, Reston, VA) with illuminant D65, an observer angle of 10°, and an aperture size of 3 cm on raw chicken 24 h after marinating and cooked chicken 24 h after cooking. The instrument calibration was performed using a standard white Hunter MiniScan calibration plate.

Instrumental tenderness. Breast meat samples from cooking loss determinations were also used for shear force determinations (n = 8 for each treatment within a replication). Cooked chicken breasts were cut parallel to the muscle fiber into 6 adjacent 1 cm (width) × 1 cm (thickness) × 2 cm (length) strips, according to Meek et al. (2000). Each strip was sheared perpendicular to the muscle fibers. The Warner-Bratzler shear force apparatus was attached to an Instron Universal Testing machine (Model 3345, Instron Corp., Canton, MA) with a 50-kg transducer and a crosshead speed of 200 mm/min. Shear force (N) was reported as the maximum peak force required to shear through each sample.

Consumer acceptability. Three consumer sensory panels (IRB approval number 15–401), 1 panel for each of 3 replications (n = 180 total panelists), were conducted to evaluate the acceptability of appearance, aroma, texture, and flavor and overall acceptability of chicken breast treatments. Panelists consisted of 18 to 65 old male and female consumers that liked baked chicken breast. These consumers were recruited through campus-wide emails. Testing was performed based on Example 13.2 in the Civille and Carr (2015) textbook in which a 9-point hedonic scale was used to evaluate the liking of breakfast cereal. Chicken breasts were placed in a Hobart Steam Oven at a dry bulb temperature of 177°C until an internal temperature of 74°C was reached. Cooked chicken breast fillets were cut into 2.5 × 2.5 × 2.5 cm cubes and kept warm (60 to 70°C) using 7.6 L covered chafer dishes (Model 53042, Polarware Co., Kiel, WI) for approximately 10 to 15 min. Three-digit numbers were randomly assigned to identify samples, and sample order was randomized. Panelists were provided with water, apple juice, and unsalted crackers to cleanse their palates. Each panelist was asked to evaluate 5 coded chicken breast samples for the acceptability of appearance, aroma, texture, and flavor and overall acceptability using a 9-point hedonic scale where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely (Civille and Carr, 2015).

Table 2. Percentage of each ingredient[1] included for chunked and formed deli ham treatment formulations

Treatment[2]	Pork	Water	Sodium chloride	Sodium phosphate	Evaporated cane sugar	WPC blend	Oat fiber vinegar blend
NP	77.1	20.2	1.8	–	0.90	–	–
STP	77.1	19.8	1.8	0.40	0.90	–	–
OF-DV	77.1	18.9	1.8	–	0.90	–	1.3
WPC	77.1	19.1	1.8	–	0.90	1.1	–

[1]Sodium nitrite and sodium erythorbate were included in all formulations at 120 ppm and 450 ppm, respectively.

[2]NP = negative control, no phosphate; STP = positive control, sodium tripolyphosphate; OF-DV = oat fiber blend-dry vinegar; WPC = whey protein concentrate blend.

Chunked and Formed Ham

Sample treatments. Porcine *semimembranosus* muscles were obtained from Plumrose (Tupelo, MS) and made into deli ham 1 d postmortem. Brine formulations (22.94% of formulation) consisted of 7.84% NaCl (salt, Culinox 999, Morton Salt, New York, NY), 0.096% Prague powder (6.25% sodium nitrite) for a final concentration of 120 ppm in the product formulation (Double Cure, Bloomfield Farms, Bardstown, KY), 0.0401% sodium erythorbate (Magnolia Seasoning Company, West Point, MS), 3.92% evaporated cane sugar (Florida Crystals, West Palm Beach, FL), and either 1.74% sodium tripolyphosphate (STP New, ICL Performance Products, St. Louis, MO) or a phosphate substitute and water. The treatment variables included the following ingredient combinations using the same proprietary blends that were used for chicken: (1) 0.4% STP; (2) NP; (3) 1.3% WPC (NatBind Seasoning WPA-P100 [WPC, pork broth, natural flavor as an antioxidant], Hawkins); and (4) 1.3% OF-DV (1.1% OF and 0.2% DV, NatBind Seasoning FPA-P100-C [Oat fiber, vinegar, chicken broth, natural flavor as an antioxidant], Hawkins). Formulations for each boneless deli ham are included in Table 2. Dry ingredients were incorporated into a mixture of water and ice (0 to 2°C; hand blender with blending cup, Oster). Final temperatures of the brine solutions were –6 to –7°C (TruTemp thermometer, Taylor). The experiment was conducted on 3 separate occasions, such that there were 3 independent replications of the 4 treatments. There was 1 subsample per replication for cooking loss and slice integrity. There were 6 subsamples for instrumental color and protein bind, and 8 subsamples for pH, instrumental color, and shear force within each of the 3 replications.

Processing. For chunked and formed deli ham, porcine *semimembranosus* muscles were cut into 2.54 × 2.54 × 2.54 cm cubes. Each treatment batch weighed 6.75 kg and contained 5.2 kg of meat and 1.55 kg of brine (29.8% marinade). A 0.78-kg portion of the meat block was finely ground in a food chopper (Model 3002 1.5-cup, Rival, Kansas City, MO) and added to the meat block in the tumbler to increase protein bind. A total of 0.23 kg of brine solution was included with the 0.78 kg of finely ground meat and added in the last part of the tumbling process. The ham muscles were tumbled in the same tumbler described in the chicken marinating section, using a 4 cycle intermittent pattern that consisted of 20 min periods of tumbling followed by 10 min rest periods. After the last 10 min rest period, the vacuum was released and 0.78 kg ground meat and 0.24 kg of the brine solution prepared previously were added to the tumbler to increase protein bind. The ham muscles, brine solution, and ground meat were then vacuum-tumbled for an additional 20 min.

Regular fibrous pre-stuck casings (Reg Fibrous CSG 5*25 Light PT, Viskase, Chicago, IL) with a 12.7-cm diameter were soaked in warm water for 2 to 3 min prior to stuffing the chunked and formed cubes. A pneumatic clipping machine (Model PTNV, Tipper Tie, Apex, NC) was used to tie and clip one end of the casing. A modified stuffing horn was used to keep the casing open as the meat was fed inside until the casing contained 1.5 to 1.75 kg of meat, which was approximately 4 loaves per treatment. The open end of the casing was then pulled tight and clipped with the pneumatic clipping machine. The stuffed ham samples were placed in between 2 ham mold racks with 4 springs to place pressure on the hams. The hams were then cooked in a smokehouse (Model 100XLT, Kemtec, Charlotte, NC) with the following smokehouse program: (1) drying cycle for 45 min with a 60°C dry bulb and 42°C wet bulb; (2) cook cycle for 60 min with 66°C dry bulb and 46°C wet bulb with smoke; (3) cook cycle for 60 min with 77°C dry bulb and 62°C wet bulb, with smoke; (4) cook cycle until an internal temperature of 71°C at 82°C dry bulb and 62°C wet bulb; and (5) cold shower for 15 min. After completion of the smokehouse cycle, hams were placed in a walk-in cooler (2 to 3°C) for 16 h.

Hams were sliced (Model 3100, Hobart manual meat slicer, Troy, OH) into 12.7-mm thick slices for cooked color determinations and protein bind, 25.4-mm thick slices for sensory analysis, and 1.58 mm thick slices for slice integrity. Slice integrity was defined as the number of slices out of 100 that contained

no holes, tears, or cracks in the meat texture. The ham slices were then vacuum packaged (Model 75840157, Vacuum Pouches, Koch Supplies Inc, Kansas City, MO) with 1 slice per package and stored at 2 to 3°C until evaluations were completed.

Cooking loss. Cooking loss was determined for restructured hams by recording the raw and cooked weights of all loaves of restructured ham within each treatment and using the same equation that was used for marinated chicken.

Added sodium concentration. Added sodium concentration in the ham was estimated based on the amount of STP and salt added to the formulation, the molecular weight of sodium in the STP and salt and the cook yield as:

$$\frac{\left[\left(\frac{115}{367}\right)\times\begin{pmatrix}\text{STP \% in}\\ \text{marinade}\end{pmatrix}\right]+\left[\left(\frac{23}{58}\right)\times\begin{pmatrix}\text{NaCl \% in}\\ \text{marinade}\end{pmatrix}\right]}{\text{Cooking yield \%}}$$

For the STP treatment for ham, this is [(115/367) × (0.4) + (23/58) × (1.8)]/0.904 = 9,282 ppm sodium. In the above equation, 115 is the molecular weight of phosphate, 367 is the molecular weight of STP, 23 is the molecular weight of sodium, and 58 is the molecular weight of sodium chloride. For the treatments with proprietary treatment blends, the amount of sodium (less than 50 ppm in each blend) was included in the final concentration for those treatments. There is approximately 50 ppm indigenous sodium in meat. This was not accounted for since we did not measure it.

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

Instrumental color evaluation. Instrumental color measurements (CIE L*, a*, and b*) of ham slices (n = 6) for each treatment were measured 24 h after smoking using the Hunter Lab MiniScan 45/0° color spectrophotometer EZ (model 4500L; Hunter Laboratories, Reston, VA) with illuminant D65, an observer angle of 10°, and an aperture size of 3 cm. The instrument calibration was performed using a standard white Hunter MiniScan calibration plate.

Protein bind. Protein-protein bind of ham slices was evaluated utilizing the Instron Universal Testing Machine. For ham protein to protein bind, a steel ball (25.0 mm diameter) was attached to a rod that was secured in a 50 kg load cell with a chuck and used at a crosshead speed of 100 mm/min to penetrate through the center of 6 randomly selected ham slices from each treatment within each replication (Field et al., 1984). Protein-protein bind was reported as the peak force (N) required for the steel ball to penetrate through the center of each ham slice.

Consumer acceptability. Three consumer sensory panels (IRB–15–401, n = 172 panelists) were conducted to evaluate the acceptability of appearance, aroma, texture, and flavor and overall acceptability of chunked and formed restructured ham. Panelists consisted of 18 to 65 old male and female consumers that liked deli ham. These consumers were recruited through campus-wide emails. Testing was performed based on Example 13.2 in the Civille and Carr (2015) textbook in which a 9-point hedonic scale was used to evaluate the liking of breakfast cereal. Restructured, cooked smoked 25.4-mm thick ham slices were cut into 2.5 × 2.5 × 2.5 cm cubes and kept cold (2 to 3°C) in 56.7 mL plastic portion containers (Model 200pc, Dart, Mason, MI) until panelists evaluated the samples. Each panelist was asked to evaluate 4 coded ham samples for the acceptability of appearance, aroma, texture, and flavor and overall acceptability using a 9-point hedonic scale where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely (Civille and Carr, 2015).

The rest of the panel regarding randomization, scale, and testing were identical to that of the marinated chicken study.

Statistical analysis. Randomized Complete Block designs with 3 replications serving as blocks were used to test the effects of adding whey protein concentrate, oat fiber (chicken only), and oat fiber with dry vinegar on quality parameters and sensory acceptability of both chicken breast and chunked ham (SAS version 9.2, SAS Inst. Inc., Cary, NC). Duncan's multiple range test was utilized to separate the treatment means when differences ($P < 0.05$) occurred among treatments. For overall acceptability data, agglomerative hierarchical clustering (ACH) using Wards method (XLSTAT version 2016, Addinsoft USA, New York, NY) was performed to group consumers together based on their preference of broiler breast meat and deli ham from different treatments.

Results and Discussion

Marinated chicken

Marinade retention. No differences ($P > 0.05$) in marinade pickup percentage were observed among treatments (Table 3), ranging from 8.2% (OF) to 8.8% (STP). Pick-up percentage did not reach the target of 12%. This is most likely due to the use of a small tumbler and the 10 min drip time after tumbling. The tum-

Table 3. Marinade retention, cooking loss, shear force, and pH of broiler breasts[1] that were vacuum-tumble marinated with sodium tripolyphosphate and phosphate substitutes

Treatment[2]	Marinade pick-up, %	Cooking loss[2], %	Raw pH after marinating[2]	Shear force[2], N	Calculated sodium, ppm
NP	8.4	26.5[b]	5.85[b]	20.5	3,400
STP	8.8	22.0[a]	5.98[a]	15.5	4,500
OF	8.2	25.9[b]	5.80[b]	19.5	3,300
OF-DV	8.3	26.5[b]	5.83[b]	18.1	3,300
WPC	8.5	26.9[b]	5.85[b]	14.8	3,300
Pooled SEM[3]	0.18	0.80	0.01	1.42	NA

[a,b]Means within a column with different superscripts are significantly different ($P < 0.05$).

[1]n = 6–8 subsamples per treatment (t = 5) for each replication (r = 3).

[2]NP = negative control, no phosphate; STP = positive control, sodium tripolyphosphate; OF = oat fiber blend; OF-DV = oat fiber blend-dry vinegar; WPC = whey protein concentrate blend.

[3]SEM = standard error mean.

bler barrels have a volume of minimum capacity of (7 kg) whereas the amount of chicken used in this study was (7.8 kg). With such a small amount of meat in a tumbler, a loss of protein adhering to the inside surface of the tumbler may contribute to the total weight loss.

Cook loss, sodium, and pH and color evaluation. STP had less ($P < 0.05$) cooking loss and a higher pH than all other treatments (Table 3). This indicates that phosphate was able to shift meat pH further away from its isoelectric point, thus increasing the amount of water that could be trapped within proteins. Lampila (2013) reported that phosphates restore the WHC of meat, which decreased with the onset of rigor mortis. Therefore, less water was lost during the cooking process with the addition of STP to chicken formulations. The STP treatment included NaCl at a target of 1.0%, which is the same percentage that was included in other treatments. Previous research by Lopez et al. (2012) indicated that broiler breast meat that was marinated with 1.0% NaCl and 0.4% STP retained more moisture than STP with lower concentrations of salt and that phosphate alone did not improve cooking yield. All other treatments did not differ ($P > 0.05$) in cooking loss. Final added sodium concentrations of broiler breast samples were calculated as approximately 3,300 to 3,400 ppm for the NP, WPC, OF, and OF-DV treatments and close to 4,500 ppm for the STP treatment (Table 3). There was no difference ($P > 0.05$) in color among treatments with respect to raw and cooked marinated chicken breast (data not presented).

Shear force. No difference ($P > 0.05$) in shear force (Table 3) was observed. Lack of difference may be attributed to a large standard error due to the high variability in shear force from 10 to 40 N. Schilling et al. (2003) indicated that chicken breast meat with shear values that were observed in the current study would be considered highly acceptable with respect to tenderness. The disruption of meat fibers during tumbling might also have sufficiently increased tenderness in all treatments. Szerman et al. (2007) demonstrated that injection of whey protein concentrate and sodium chloride into sous vide beef lowered shear force in *semitendinosus muscles* when compared to non-injected sous vide beef from the same muscle.

Consumer acceptability. No differences were observed ($P > 0.05$) in appearance, texture and overall acceptability of marinated chicken breasts (Table 4). The lack of difference between samples may have been due to all samples being tender as indicated by shear force (Schilling et al., 2003) and lack of color differences between samples. STP and WPC had greater ($P < 0.05$) aroma acceptability than all other treatments. Moreover, the flavor of STP was preferred ($P < 0.05$) over the OF,

Table 4. Effects of vacuum-tumbling chicken breast meat with salt and phosphate or salt and phosphate substitutes on the sensory acceptance[1] of appearance, aroma, texture, flavor, and overall liking (n = 180)

Treatment[2]	Appearance	Aroma	Texture	Flavor	Overall acceptability
NP	6.4	6.1[b]	6.3	6.2[b]	6.1
STP	6.5	6.4[a]	6.4	6.6[a]	6.4
OF	6.2	6.1[b]	6.5	6.2[b]	6.3
OF-DV	6.3	6.1[b]	6.2	6.3[b]	6.2
WPC	6.2	6.4[a]	6.3	6.4[ab]	6.3
Pooled SEM[3]	0.11	0.09	0.17	0.14	0.14

[a,b]Means within a column with different superscripts are significantly different ($P < 0.05$).

[1]Consumer acceptability was based on a 9-point scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

[2]NP = negative control, no phosphate; STP = positive control, sodium tripolyphosphate; OF = oat fiber blend; OF-DV = oat fiber blend-dry vinegar; WPC = whey protein concentrate blend.

[3]SEM = standard error mean.

Table 5. Mean scores for overall consumer acceptability of broiler breasts (n = 180) that were marinated with salt and phosphate or salt and phosphate substitutes according to different clusters of consumer segments using a hedonic scale[1]

Cluster	Panelist, %\)	NP[2]	STP[2]	OF[2]	OF-DV[2]	WPC[2]
1	17.5	4.1^{c}	4.6^{bc}	6.1^{a}	5.2^{b}	4.9^{b}
2	18.7	7.3^{b}	7.7^{a}	7.8^{a}	7.6^{ab}	7.7^{a}
3	40.9	6.9^{a}	6.4^{b}	6.3^{b}	6.2^{b}	6.6^{ab}
4	8.8	7.7^{a}	6.7^{ab}	4.0^{c}	6.0^{b}	4.8^{c}
5	14.1	3.8^{c}	6.9^{a}	5.6^{b}	3.5^{c}	6.6^{a}
Percentage of panelists that rated the treatment like slightly (6) or greater (%)		68	82	77	68	74

$^{a–c}$Means within a column with different superscripts are significantly different ($P < 0.05$).

[1]Consumer acceptability was based on a 9-point scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

[2]NP = negative control, no phosphate; STP = positive control, sodium tripolyphosphate; OF = oat fiber blend; OF-DV = oat fiber blend-dry vinegar; WPC = whey protein concentrate blend.

OF-DV, and NP treatments. Previous research by Saha et al. (2009) reported greater consumer acceptability when chicken fillets were enhanced with salt and phosphate in comparison to a non-enhanced chicken breast.

Cluster analysis. Panelists in cluster 1 (17.5%) rated chicken breast samples between dislike slightly and like slightly, and preferred ($P < 0.05$) OF over other treatments (Table 5). Cluster 2 (18.7% of panelists) rated chicken breast between like moderately and like very much. Consumers in this cluster preferred ($P < 0.05$) STP, WPC, and OF ($P < 0.05$) over NP. Cluster 3 consisted of 40.9% of panelists who liked all chicken breast treatments "slightly", as indicated by a 6 on the hedonic scale. These panelists preferred ($P < 0.05$) NP over STP, OF, and OF-DV. Cluster 4 consisted of 8.8% of panelists, who preferred ($P < 0.05$) the NP and STP over all other treatments. Cluster 5 consisted of 14.1% of panelists. These panelists preferred ($P < 0.05$) STP and WPC over other treatments. STP was rated at least liked slightly by 82% of the panelists. The OF was liked slightly or greater by 77% of the panelists, while 74% of panelists rated WPC at least like slightly or greater. Both the OF-DV and NP treatments were rated as "like slightly" or greater by 68% of the panelists. These findings indicated that incorporating oat fiber or whey protein concentrate into chicken marinades increased the percentage of panelists that like chicken breast as compared to the negative phosphate treatment.

Chunked and formed ham

Cooking loss. Similar to breast samples, hams with STP had less cooking loss ($P < 0.05$) than all other treatments (Table 6). This is expected since phosphate shifts meat pH away from its isoelectric point, which allows more space for water to reside within the myofibrillar protein structure (Xiong and Kupski, 1999). The WPC treatment had less cooking loss than the NP treatment ($P < 0.05$), but no difference was observed ($P > 0.05$) between NP and DV or WPC and DV treatments. It was likely that these treatments did not increase ionic strength and pH enough to improve protein functionality, which is an important attribute of a phosphate alternative. Added Sodium concentrations in hams were calcu-

Table 6. Cooking loss, protein bind, sliceability, L*, a*, and b* color of 12.7 and 1.578 mm thick ham slices with salt and phosphate or salt and phosphate substitutes

Treatment[1]	Cooking loss[2], %	Calculated added sodium, ppm	CIE L*[2]	CIE a*[2]	Protein bind[2], N	Intact slices (0–100)
STP	9.6^{c}	9,300	65.6^{ab}	10.8	19.6^{a}	60^{a}
NP	18.4^{a}	8,700	67.3^{a}	10.5	10.3^{b}	2^{d}
OF-DV	17.3^{ab}	8,600	65.5^{ab}	10.0	13.2^{b}	5^{c}
WPC	15.5^{b}	8,400	64.8^{b}	10.4	10.4^{b}	6^{b}
Pooled SEM[2]	0.68	NA	0.64	0.28	0.92	0.08

$^{a–d}$Means within a column with different superscripts are significantly different ($P < 0.05$).

[1]NP = negative control, no phosphate; STP = positive control, sodium tripolyphosphate; OF-DV = oat fiber blend-dry vinegar; WPC = whey protein concentrate blend.

[2]n = 6–8 subsamples per treatment (t = 4) for each replication (r = 3).

[3]SEM = standard error mean.

Table 7. Consumer acceptability[1] of deli ham (n = 172 panelists, 3 replications) that was formulated with salt and phosphate or salt and phosphate substitutes on the sensory evaluation for appearance, aroma, texture, flavor, and overall acceptability

Treatment[2]	Appearance	Aroma	Flavor	Texture	Overall acceptability
STP	7.1[a]	7.0[a]	6.5[a]	6.5[a]	6.7[a]
NP	6.5[b]	6.6[b]	6.7[a]	6.5[a]	6.8[a]
OF-DV	6.4[b]	6.6[b]	6.2[b]	5.9[b]	6.2[b]
WPC	6.6[b]	6.6[ab]	6.7[a]	6.6[a]	6.6[a]
Pooled SEM[3]	0.01	0.09	0.01	0.12	0.01

[a,b]Means within a column with different superscripts are significantly different ($P < 0.05$).

[1]The hedonic scale was based on a 9-point scale (9 = like extremely; 5 = neither like nor dislike; 1 = dislike extremely).

[2]NP = negative control, no phosphate; STP = positive control, sodium tripolyphosphate; OF-DV = oat fiber blend-dry vinegar; WPC = whey protein concentrate blend.

[3]SEM = standard error mean.

lated as approximately 9,300 ppm for the STP treatment and 8,300 to 8,700 ppm for all other treatments (Table 6). This is greater than an 8 to 10% reduction in sodium, but there is a still a need for ingredient technology to impart the various functions of phosphates (Brouilette, 2007). Previous research done by Fernández-Ginés et al. (1998) indicated that oat fiber increased the cooking yield on meat products due to its ability to bind fat and water. Steenblock and Sebranek (2001) reported a 3% purge reduction when oat fiber was used in bologna and frankfurter formulations. In the production of the current product, additional ingredients are needed to increase the negative charges of the oat fiber and whey protein concentrate to decrease cooking loss.

pH. There was no difference ($P > 0.05$) in pH (6.1 to 6.2) among ham treatments. The lack of pH difference among treatments was unexpected because it has been reported that sodium tripolyphosphate increases the pH of deli meats (Pearson and Gillett, 1996). According to MSDS, the pHs of the proprietary treatment ingredients were 6.0, and the pH of the raw pork used in the formulation was 5.8 to 6.0.

Color evaluation. There was no difference ($P > 0.05$) in L* between STP, OF-DV, and WPC treatments (Table 6). NP ham slices were darker ($P < 0.05$; lower L*) than ham slices from WPC. No differences ($P > 0.05$) were observed with respect to a* among all treatments. All treatments contained nitrite at an equal concentration which imparted equal reddish/pinkish cured color to the hams.

Protein bind and slice integrity. The STP treatment had greater bind strength ($P < 0.05$) than all other treatments (Table 6). This is due to the synergistic effect that phosphate and sodium chloride have on meat proteins, particularly myosin and the ability to improve the efficiency of protein solubilization and dissociation which enhances the extracted protein's ability to coat the meat pieces and gel when heated. Siegel and Schmidt (1979) reported that phosphate dissociates actomyosin, and salt solubilizes myosin, which frees the myosin up to participate in protein-protein interactions. This increase in protein-protein binding produces greater gel strength. In addition to phosphates and sodium chloride, the mechanical action of tumbling increases protein extraction. This creates a tacky surface that is composed of the solubilized protein matrix, which forms a gel during heating that binds the individual chunks into deli meat that resembles a whole muscle product (Pearson and Gillett, 1996). Treatments formulated with NP, OF-DV, and WPC did not differ ($P > 0.05$) in protein bind. Aleson-Carbonell et al. (1998) and Imeson et al. (1977) suggested that the low binding strength of oat fiber was caused by polysaccharides that hinder the formation of a strong protein-protein network. Wit (1988) reported low binding strength for whey protein when heated to 95°C, because the whey proteins do not aggregate until subsequent cooling. It is evident from these results that other ingredients would need to be included, in addition to the ones evaluated in this study, to increase the protein bind so that it is similar to that of ham with STP.

The STP treatment had a greater number of intact slices ($P < 0.05$) than all other treatments (Table 6). This is due to the synergistic ability of phosphate and sodium chloride to solubilize myosin and strengthen a protein gel. This results demonstrate how important phosphate is in the production of thinly sliced deli meat, which is a high volume product. Ham formulated with WPC had more intact slices ($P < 0.05$) than OF-DV. This may be due to glucan, a polysaccharide in oat fiber which might have decreased the aggregation of meat proteins. The NP treatment had fewer intact slices ($P < 0.05$) than any other treatment. This treatment consisted of salt and water, and without additional functional ingredients incorporated into the formula, was not able to extract enough proteins to create a strong protein-protein network. Though statistical differences were observed in the slice integrity of WPC, OF-DV, and NP, all of these treatments were ineffective at imparting a texture that would allow the deli ham to be sliced thinly. Therefore, if WPC or OF-DV were used in chunked and formed deli ham, additional ingredients such as native food starch or carrageenan may need to be included to add gel strength and set up a matrix to

Table 8. Mean scores for overall consumer acceptability of deli ham (n = 172) that were marinated with salt and phosphate or salt and phosphate substitutes according to different clusters of consumer segments using a hedonic scale[1]

Cluster	Panelist, %	NP[2]	STP[2]	OF-DV[2]	WPC[2]
1	28.9	6.3[ab]	6.7[a]	5.9[b]	6.4[a]
2	13.9	6.2[a]	3.9[b]	6.4[a]	6.3[a]
3	39.4	7.6	7.6	7.6	7.3
4	10.0	4.7[b]	6.9[a]	3.1[c]	4.3[b]
5	7.8	7.8[a]	6.7[b]	3.1[c]	7.4[ab]
Percentage of panelists that rated the treatment like slightly (6) or greater (%)		90	86	53	90

[a–c]Means within a column with different superscripts are significantly different ($P < 0.05$).

[1]The hedonic scale was based on a 9-point scale (9 = like extremely; 5 = neither like nor dislike; 1 = dislike extremely).

[2]NP = negative control, no phosphate; STP = positive control, sodium tripolyphosphate; OF-DV = oat fiber blend-dry vinegar; WPC = whey protein concentrate blend.

maintain slicing properties for deli ham products such as that which is provided by phosphates.

Consumer acceptability. On average, all hams were rated between "like slightly" and "like moderately" for all acceptability attributes (Table 7). The appearance of STP was liked more ($P < 0.05$) than that of all other treatments. No difference in appearance was observed ($P > 0.05$) among hams formulated with WPC, OF-DV, and NP. The aroma of ham slices from STP was liked more ($P < 0.05$) than that of ham slices from OF-DV and NP, and no difference in aroma acceptability ($P > 0.05$) was observed between WPC and all other treatments. The OF-DV was liked less ($P < 0.05$) than other treatments with respect to flavor, texture, and overall acceptability. It is unknown whether this decrease in acceptability was caused by the vinegar, oat fiber, or the combination of the two. However, some panelists indicated that they did not like OF-DV due to a soft, crumbly, loose, and dry texture. The lack of differences between STP and the NP treatments may be because the sensory samples were served as cubes and all had very good ham flavor. This indicates that a case could be made for removing phosphate from the formulation since no negative impacts on flavor were found. However, economic and practical constraints suggest that the product would not be able to be sliced thin, and would have lower yields and limited packaging and processing options, which would impact the processors more than the consumers.

Cluster analysis. Panelists in cluster 1 (28.9%) rated all deli ham treatments like slightly (Table 8). These panelists preferred ($P < 0.05$) WPC and STP over OF-DV and NP. Cluster 2 panelists (13.9%) preferred ($P < 0.05$) WPC, OF-DV, and NP over STP. Cluster 3 panelists (39.4%) had no preference ($P > 0.05$) for any of the treatments and all deli hams were rated "like moderately". Panelists in cluster 4 (10%) preferred ($P < 0.05$) the STP treatment over all treatments, and WPC and NP were preferred ($P < 0.05$) over OF-DV. Cluster 5 panelists (7.8%) preferred ($P < 0.05$) the NP treatment over STP and OF-DV. STP and WPC were also preferred ($P < 0.05$) over OF-DV. Out of these panelists, 90% liked the STP and WPC treatments, 86% liked the NP treatment, and 53% liked the OF-DV treatment, which was indicated by hedonic ratings of 6 and greater.

Conclusions

Oat fiber and whey protein concentrate have been reported in the literature and evaluated in research as potential phosphate alternatives in processed meat products. In the current study, these ingredients were minimally effective at providing the marinated chicken breast and chunked and formed deli ham with similar yields to sodium tripolyphosphate. In addition, both ingredients were ineffective at increasing meat pH, lowering cooking loss, and providing adequate texture to the chunked and formed deli ham. It is unlikely that these ingredients are efficacious in the production of clean label, or no phosphate meat as stand-alone alternatives to phosphate. However, with the incorporation of additional technologies to increase meat and poultry pH and selecting the best properties of these clean label functional systems, improved formulations could be developed. Future research is needed to explore what additional ingredients need to be coupled with whey protein concentrate and/or oat fiber to replace phosphate in meat products, with minimal quality differences between the STP and clean label product. In addition, ingredients need to be evaluated that can increase ionic strength and negative charges on myofibrillar proteins to maximize yield and functionality and/or function as a chelating agent or antioxidant that can be used in conjunction with oat fiber and/or whey protein concentrate to enhance these ingredients' functionality as phosphate replacers in meat systems.

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