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Postrigor tumble marination strategies for improving color and water-holding capacity in normal and pale broiler breast fillets

Postrigor tumble marination strategies for improving color and water-holding capacity in normal and pale broiler breast fillets

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ABSTRACT Pale or pale, soft, and exudative-like meat can be caused by a decline in pH early postmortem while carcass temperatures are still high. This decrease in pH leads to protein denaturation, attributing to the pale color and poor water-holding capacity that is characteristic of this lesser quality meat. Marination with NaCl and phosphates has been shown to improve protein functionality, thereby reducing lost meat yield and improving meat quality. However, there are few studies relating marination with phosphates to improvements in pale meat. Therefore, the purpose of this experiment was to determine if meat quality improvements could be obtained in pale meat via marination with various phosphate and NaCl treatments without altering the quality and stability of normal or pale meat. The treatments used in this study were 1) sodium tripolyphosphate, an industry control; 2) a high pH phosphate (11.9); 3) a sodium tripolyphosphate and high pH mixture; 4) an agglomerated phosphate; and 5) a nonagglomerated phosphate. The marinades used in this study increased the pH, decreased the L* values of the pale fillets, and improved water-holding capacity. There were no significant differences in overall flavor preference for any of the 5 phosphate treatments. There was also no difference in oxidation or shelf-life trends in either the pale or normal fillets marinated with each of the 5 treatments. The results of this study were that marination with phosphates can be used to marinate pale meat without altering flavor, increasing the development of oxidation, or reducing shelf life.

Key words: pale meat, marination, color, water-holding capacity, broiler

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INTRODUCTION

Recently, the poultry industry has been faced with the increasing problem of pale meat. Pale meat has been associated with antemortem stressors such as rapid growth, extreme environmental temperatures, transportation stress, and preslaughter handling practices (McKee and Sams, 1998; Sams, 1999; Owens and Sams, 2000; Alvarado and Sams, 2002). Pale meat is the result of accelerated postmortem (**PM**) glycolysis and protein denaturation. The combination of rapid pH decline in PM muscle with high carcass temperatures early PM can lead to the development of meat with a pale color, low water-holding capacity (**WHC**), and soft texture (Barbut, 1993; Allen et al., 1998; Sams, 1999). This poor quality meat is often referred to as pale, soft, and exudative (**PSE**) meat. Specifically, pale poor-quality meat causes an increase in purge, resulting in reduced yield for processors. It has been estimated that PSE-like meat can cost a processor $2 to 4 million per year in lost meat yield alone (Owens et al., 2000; Alvarado, 2001; Woelfel et al., 2002). This estimate does not consider repackaging and increased labor costs.

The genetic causes of PSE meat in poultry are not yet fully understood, but the poultry industry is taking steps to determine how closely PSE development in pork is related to the same condition in poultry. The cause of this pale condition is an inability to regulate the flow of calcium ions in the different compartments of the muscle cell (Louis et al., 1992). Calcium is a key regulator of muscle contractions and relaxation; therefore, calcium imbalances can substantially alter muscle activity and energy metabolism. The cause of this imbalance in some swine is a single point mutation that occurs in the calcium channel gatekeeper protein (ryanodine receptor) that controls the flow of calcium from storage compartments to the fluid surrounding the contraction proteins, actin and myosin (Fujii et al., 1991; Sams, 1999). When this mutation in the amino acid sequence occurs, the protein gate leaks, or is even locked open, at which point the contraction apparatus is flooded with calcium, the metabolism accelerates, and the body temperature increases (Sams, 1999).

The development of poor-quality and pale meat is directly related to biochemical changes occurring in the muscle during rigor mortis development. The rate of pH decline is a determining factor in the development

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of meat with poor WHC. A decrease in muscle pH can cause reduced net protein charge, resulting in fewer charges to bind water. Also, the decline in pH early PM, while carcass temperatures are still elevated, can cause protein denaturation, resulting in additional loss of WHC (Offer, 1991).

Pale, soft, and exudative meat has been shown to cause its greatest problems in products to which no or low amounts of NaCl and phosphates are added (Sams, 1999). Marination of broiler breast fillets has been used as a means to improve protein functionality, flavor, and tenderness. Marinades containing NaCl and phosphates, specifically sodium tripolyphosphates (**STP**), are the most common (Barbut et al., 1989). Both NaCl and STP have been shown to improve WHC and yield (Hamm, 1960; Young and Lyon, 1986; Lemons et al., 1999). Salt and STP used in marinades work synergistically to increase water binding by increasing pH and ionic strength as well as dissociating actinomyosin, which exposes more water-binding sites (Wong, 1989). If the pH of the meat can be increased by ingredients during the marination process, the potential yield losses and quality problems due to pale meat can be minimized. Therefore, this study was conducted to determine if marination with phosphates can increase pH and improve WHC, color, and texture of pale meat.

MATERIALS AND METHODS

Tumble Marination

A total of 320 (160 in each of 2 trials) pale and normal broiler breast fillets were collected at deboning [12 h PM] from a commercial processor. Broiler breast fillets were screened (Gorsuch, 2003) using L* values (Minolta Chroma Meter Model CR-200, Minolta Corp., Ramsey, NJ) to determine whether they were pale or normal. The fillets were considered to be pale if they had an L* value (measured on medial surface of each fillet by averaging 3 readings) of 57 or higher and normal if the L* value was less than 53. The pH values (pH range 5.95 to 6.18 for normal; pH range 5.62 to 5.85 for pale) were also recorded upon initial collection using a pH meter and piercing probe pH (pH 26-SS, IQ Scientific Instruments Inc., San Diego, CA). The fillets were tagged, bagged, and placed in a cooler full of ice for transportation back to the Muscle Foods Laboratory (2 h) and stored in a 4°C cooler overnight.

At 24 h PM, the weight of each fillet was recorded. The samples were then divided into 5 groups of 16 fillets, 8 pale and 8 normal. The total weight of each group was calculated and a 20% marinade (wt/wt) with a final concentration of 0.45% phosphates and 0.70% NaCl was used. Each group was placed separately into a vacuum tumbler along with the marinade solution. The fillets were tumble-marinated at 4°C with 65 to 70 mmHg for 30 min at 12 rpm. The following phosphates were tested: 1) STP (pH 9.7), 2) high pH phosphate (pH 11.9), 3) STP + high pH phosphate blend (pH 11.0), 4) agglomerated STP (pH 9.0), and 5) nonagglomerated STP (pH 9.0).

After tumble marination, each fillet was weighed again to determine marinade pickup (%). The fillets were then placed in a covered container in a 4°C cooler for 3 h to allow for marinade equilibration (based on preliminary data, unpublished). After 3 h of equilibration, half of the pale and half of the normal marinated fillets of each group were again weighed to determine marinade retention (%) using the following equation:

$$\text{postmarination fillet weight} - \text{premarination fillet weight}/\text{postmarination fillet weight} \times 100.$$

The L* values and pH values were again recorded postmarination for each fillet. The samples were then placed on aluminum-lined pans on raised wire racks. The fillets were cooked in a convection oven to an internal temperature of 73°C and allowed to cool according to the procedures of Sams (1990). Cook loss (%) was determined after cooling.

Total moisture was also determined using the procedure of Urbin et al. (1962). Basically, 3 to 5 g of cooked center cut fillet pieces were placed in preweighed aluminum pans and then dried in a drying oven overnight. The following day, all aluminum pans were placed in a desiccator for an hour and then weighed using an analytical balance. These same procedures were repeated with the remaining fillets that were allowed to equilibrate in a 4°C cooler for 24 h to determine any differences in equilibration of marinade over time.

TBA Reactive Substances

A modified method for TBA reactive substances (**TBARS**), as described by Spanier and Traylor (1991), was performed on these fillets at 0, 2, and 4 d after cooking. Cooked fillets were stored at −78°C until analysis. Estimated TBARS values of stored cooked meat tend to be high so a standard curve was prepared with 0.0, 2.5, 5.0, 7.5, and 10.0 mL of standard tetramethoxypropane solution. The fillets were thawed at room temperature for about 1 h. The chicken was then minced and a 5.0 ± 0.1 g sample was homogenized with 85.0 mL of distilled water, 0.1 mL of 10% SDS, and 10.0 mL of antioxidant and chelator solution. All samples and standards were placed in ice until all homogenization was complete. The homogenate was stirred with a glass bar and 1.0 mL of each sample homogenate and standard solution was transferred to 15-mL centrifuge tubes. Four milliliters of solution I (0.375% TBA, 0.506% SDS, and 9.370% acetic acid adjusted to pH 3.4) was added to each tube, which was then vortexed, capped loosely, and incubated in a 95°C water bath for 60 min. The tubes were then cooled in tap water and 1.0 mL of 4°C water and 5.0 mL of solution II (15:1 *n*-butanol and pyridine) were added to each tube and vortexed under a hood for approximately 10 s. The tubes were

then centrifuged at room temperature (25°C) at 2,180 × *g* for 15 min. The top layer was pipetted off and the absorbance of the organic solution was read at 532 nm under a hood. Time from cook to freeze until TBARS was conducted was standardized for 1 h.

Sensory Evaluation

Fillets for sensory evaluation were cooked according to the procedures of Sams (1990). Cooked fillets were evaluated by an untrained consumer sensory panel to determine overall preference for flavor of the fillets. Because the goal of the sensory evaluation was to determine if any of the 5 marinades (STP, high pH, blended, agglomerated, and nonagglomerated) imparted a poor flavor onto the marinated samples, only marinated (24 h) normal fillets were evaluated in 2 trials (d) with 125 consumers each day. Pale meat was not used because it can have a poor texture after cooking, which might confuse the nontrained panelists. After cooking, breast meat was cut into 2.54 cm^2 center cut pieces. The breast fillet pieces were individually placed in a zip-top plastic bag, sealed, and labeled with 3-digit computer randomized numbers that corresponded to each of the 5 marinades. To maintain constant breast meat temperature throughout evaluation, a small hole was punctured in the top corner of each zip-top plastic bag and the bags were strung along a small metal rod. The metal rod was suspended above a 52°C water bath with the covered breast meat samples immersed in the water to maintain temperature. The samples were removed from the water bath as needed, placed on a small white paper plate numbered with the corresponding random number, and served to the panelists sitting opposite a breadbox sensory panel setup. Panelists were asked to evaluate each sample for overall flavor preference using a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely).

Shelf Life

A shelf-life study (64 fillets in 2 trials) was also included on samples using standard aerobic plate count (**APC**). After marination, both pale (n = 32) and normal (n = 32) breast fillets were tray-packed separately in the Virginia Tech Muscle Foods Laboratory (Blacksburg) and stored in a 4 to 5°C cooler. Standard APC was determined on both pale and normal packaged fillets at 0, 3, 6, and 9 d. A sterile cotton swab was rubbed over each treatment section of breast meat in 2 similar locations per treatment inside a 10-cm^2 template. After testing, the swab was placed into 9 mL of peptone water and broken off. This allowed the cotton on the swab to soak in the peptone water and create a 10^0 dilution. Appropriate dilutions were performed according to the day (0, 3, 6, or 9) and the solution was pipetted onto Petrifilm (3M Health Care, St. Paul, MN). The Petrifilm was incubated at either 35°C for 48 h to determine APC or 4°C for 7 d to determine psychrotrophic count. Petrifilm containing between 25 and 250 cfu was enumerated to determine colony-forming units per gram.

Statistical Analysis

The completely randomized experimental design consisted of 5 treatments (STP, high pH, blended, agglomerated, and nonagglomerated), 2 types of meat (pale and normal), and 2 replications in each of 2 trials. Statistical analysis was performed using the GLM procedure (SAS Institute, 2002) to determine significance of independent variables. The means were separated using Duncan's multiple range test at a significance level of $P < 0.05$. Because there were no trial × treatment interactions, the data were pooled by treatment and fillet type. Because the sensory data are ordinal, it was analyzed using the ANOVA procedures of JMP (SAS Institute, 2001). Significance was determined at $P < 0.05$. The shelf-life experiment was a 5 × 2 factorial design with 10 treatments (combinations of fillet type and day of storage). Effect of fillet type (pale or normal) and days of storage (0, 3, 6, and 9) was determined by performing a log transformation of the data followed by statistical analysis using the GLM procedures of SAS (SAS Institute, 2002). Because significance between fillet type and each day of storage was found, the means were separated using Duncan's multiple range test at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

Ultimate pH can be an indicator of functionality of the breast fillets and was measured in this study to determine pale fillets and possible increased protein functionality in marinated fillets. As expected, the pale fillets collected at the processing plant had significantly lower pH and higher L* values when compared with the normal fillets before marination (Table 1). After marination with the 5 treatments, the pH values of the pale fillets increased but were still significantly lower than the pH values of the marinated normal fillets, indicating that the treatments did not increase pH of the pale fillets to that of the normal fillets. When comparing treatments on pale fillets only (Table 2), treatment 1 (STP) worked significantly better than the other treatments at increasing pH. When comparing marinated normal fillets (Table 2), treatment 1 (STP) again significantly increased pH of the fillets when compared with the remaining treatments, whereas pH in treatments 3 (blend) and 4 (agglomerated) was significantly lower when compared with treatment 1 (STP).

The color of a fillet is a reflection of muscle quality status, with pale meat having higher L* values (increased lightness) due to the denaturation of the sarcoplasmic proteins (Offer, 1991). The L* values of the pale fillets decreased (appeared darker) after marination with each of the 5 treatments, which indicated

Table 1. Comparison of means of meat quality parameters in pale and normal fillets marinated with NaCl (0.7%) and different phosphates (0.45%)[1]

Treatment[2]	Marinade pH	pH (before)	pH (after)	L*[3] (before)	L* (after)	a*[4] (before)	a* (after)	b*[5] (before)	b* (after)
Treatment 1 (STP)									
N	11.9	$6.06^{a,x}$	$6.26^{a,y}$	52.0^{b}	51.1^{b}	$3.6^{a,x}$	2.3^{y}	3.8^{b}	3.4
P		$5.83^{b,x}$	$6.05^{b,y}$	$59.6^{a,x}$	$54.9^{a,y}$	2.2^{b}	2.1	4.6^{a}	4.2
Treatment 2 (high pH)									
N	9.7	6.08^{a}	6.04^{a}	$52.0^{b,x}$	$54.6^{b,y}$	$3.4^{a,x}$	2.3^{y}	$3.7^{b,x}$	5.5^{y}
P		$5.80^{b,x}$	$5.92^{b,y}$	$60.0^{a,x}$	$56.0^{a,y}$	2.2^{b}	2.5	$5.0^{a,x}$	5.6^{y}
Treatment 3 (blend)									
N	9.0	6.06^{a}	5.99^{a}	$52.0^{b,x}$	55.3^{y}	$3.5^{a,x}$	2.3^{y}	$3.9^{b,x}$	$5.8^{a,y}$
P		$5.74^{b,x}$	$5.82^{b,y}$	$60.3^{a,x}$	54.8^{y}	$2.6^{b,x}$	2.0^{y}	$4.9^{a,x}$	$4.1^{b,y}$
Treatment 4 (agglomerated)									
N	9.0	$6.11^{a,x}$	$5.97^{a,y}$	$51.8^{b,x}$	54.6^{y}	$3.7^{a,x}$	2.7^{y}	$3.9^{b,x}$	$5.3^{a,y}$
P		5.76^{b}	5.83^{b}	$59.5^{a,x}$	54.3^{y}	2.4^{b}	2.3	4.5^{a}	4.4^{b}
Treatment 5 (nonagglomerated)									
N	11.0	6.07^{a}	6.11^{a}	$51.6^{b,x}$	$54.1^{b,y}$	$3.9^{a,x}$	$2.8^{a,y}$	3.7^{b}	4.1^{b}
P		$5.79^{b,x}$	$5.79^{b,x}$	$60.3^{a,x}$	$57.3^{a,y}$	2.4^{b}	2.1^{b}	4.8^{a}	5.1^{a}
Pooled SEM		0.34	0.34	3.1	3.1	0.2	0.2	0.3	0.4

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

[x,y]Means with different superscripts within a row and a parameter are significantly different ($P < 0.05$).

[1]n = 32 fillets.

[2]N = normal; P = pale; STP = sodium tripolyphosphate.

[3]L* value indicates the lightness of the fillet.

[4]a* value indicates the redness of the fillet.

[5]b* value indicates the yellowness of the fillet.

improved color, whereas normal marinated fillets, with the exception of treatment 1 (STP), increased in lightness (Table 1). This increase in lightness of the normal fillets is expected and possibly due to the increase in extracellular water as a result of the marination process. Young et al. (1996) and Allen et al. (1998) have reported that marination with STP and NaCl showed no color improvements and actually increased the lightness of the fillets, respectively. Treatments 3 (blend) and 4 (agglomerated) increased the L* value of the normal fillets and decreased the L* value of the pale fillets so that there was no significant difference between color of pale and normal fillets after marination (Table 1).

The a* value is a measurement of the redness of the fillet. There were no significant differences in a* value in any of the normal or any of the pale fillets before marination or after marination (Table 2). However, by treatments, the pale fillets had a significantly lower a* value when compared with the normal fillets in each treatment before marination (Table 1). After marination, the a* values for the pale fillets marinated with each treatment (except treatment 5 nonagglomerated) were not significantly different from those of the normal fillets, indicating improved color of the pale fillets to that of the normal fillets. The normal marinated fillets decreased in a* value after marination in all of

Table 2. By treatment comparisons of pH and color in pale and normal broiler breast fillets marinated with NaCl (0.7%) and different phosphates (0.45%)[1]

Item	pH (before)	pH (after)	L*[2] (before)	L* (after)	a*[3] (before)	a* (after)	b*[4] (before)	b* (after)
Pale treatment								
1 (STP[5])	5.83	6.05^{a}	59.6	54.9^{bc}	2.2	2.1	4.6	4.2
2 (high pH)	5.80	5.92^{b}	59.8	56.0^{ab}	2.2	2.5	5.0	5.6^{b}
3 (blend)	5.75	5.82^{c}	60.3	54.8^{bc}	2.6	2.0	4.9	6.1
4 (agglomerated)	5.76	5.83^{c}	59.5	54.3^{c}	2.4	2.3	4.5	4.4
5 (nonagglomerated)	5.79	5.89^{bc}	60.3	57.3^{a}	2.4	2.1	4.8	5.1^{b}
Normal treatment								
1 (STP)	6.06	6.26^{a}	52.0	51.1^{c}	3.6	2.3	3.8	3.4^{c}
2 (high pH)	6.08	6.04^{bc}	52.0	54.6^{ab}	3.4	2.3	3.7	5.5^{a}
3 (blend)	6.06	5.99^{c}	52.0	55.3^{a}	3.5	2.3	3.9	5.8^{a}
4 (agglomerated)	6.11	5.97^{c}	51.8	54.6^{ab}	3.7	2.7	3.9	5.3^{a}
5 (nonagglomerated)	6.07	6.11^{b}	51.6	54.1^{b}	3.5	2.8	3.7	4.1
Pooled SEM	0.34	0.34	3.1	3.1	0.2	0.2	0.3	0.4

[a–c]Means in a column within a parameter and within fillet type (pale or normal) with different superscripts are significantly different ($P < 0.05$).

[1]n = 32 fillets.

[2]L* value indicates the lightness of the fillet.

[3]a* value indicates the redness of the fillet.

[4]b* value indicates the yellowness of the fillet.

[5]STP = sodium tripolyphosphate.

Table 3. Comparison of means of water-holding capacity parameters in pale and normal broiler breast fillets marinated with NaCl (0.7%) and different phosphates (0.45%)[1]

Treatment[2]	Pickup (%)	Retention (%)	Cook loss (%)
1 (STP)			
N	17.7^{xy}	97.9	16.7^{z}
P	17.3	99.7	20.5^{z}
2 (high pH)			
N	17.3^{xy}	99.0	21.7^{xy}
P	17.7	99.2	29.9^{x}
3 (blend)			
N	15.7^{z}	97.0	22.0^{xy}
P	16.8	98.9	21.7^{yz}
4 (agglomerated)			
N	16.2^{yz}	99.7	22.9^{x}
P	15.8	99.6	24.9^{y}
5 (nonagglomerated)			
N	18.1^{x}	99.3	19.8^{y}
P	17.1	99.7	23.6^{yz}
Pooled SEM	0.4	0.1	0.5

$^{x–z}$Means with different superscripts within a column and fillet type (pale or normal) are significantly different ($P < 0.05$).

[1]n = 32 fillets.

[2]N = normal; P = pale; STP = sodium tripolyphosphate.

the treatments as did the pale fillets with the exception of treatment 2 (high pH). Allen et al. (1998) found that marination decreased both the a* and b* values of both pale and normal fillets. Young and Lyon (1997) reported that treatment with STP significantly reduces a* value, or redness, of broiler breast fillets.

The b* value measures the yellowness of the fillet. There were no significant differences in b* value in any of the pale or any of the normal fillets before marination (Table 2). After marination, treatment 3 (blend) significantly increased the yellowness of the pale fillets and treatments 2 (high pH), 3 (blend), and 4 (agglomerated) significantly increased the yellowness of the normal fillets compared with the other treatments. Treatment 1 (STP) significantly decreased the yellowness of both pale and normal fillets, whereas treatment 4 (agglomerated) significantly decreased the yellowness of the pale fillets only. By treatments, the pale fillets had significantly higher b* values than the normal fillets premarination (Table 1). After marination with treatments 1 (STP) and 2 (high pH), pale and normal fillets were not significantly different in yellowness, indicating improved color of pale fillets to that of normal fillets. Treatments 3 (blend) and 4 (agglomerated) significantly decreased b* values of pale fillets to lower than normal fillets. Treatment 5 (nonagglomerated) increased the b* value of the pale fillets significantly more than the normal fillets. As a note, lightness of the fillet (L* value) is an important quality attribute for consumers and is more discernable than changes in a* or b* values.

Water-holding capacity parameters of marinade pickup and retention as well as cook loss were also determined. The polyelectrolyte behavior of phosphates promotes water retention. This characteristic of phosphates allows them to attach themselves to positively charged sites of proteins so that they increase water binding (Molins, 1991). All treatments performed equally for marinade pickup and retention of pale and normal fillets, indicating that marination with these 5 treatments improved pickup and retention of pale fillets to that of normal fillets (Table 3). Comparing treated normal fillets, treatment 5 (nonagglomerated) increased marinade pickup significantly when compared with treatments 3 (blend) and 4 (agglomerated). There were no differences, by treatment, in marinade retention for normal fillets. However, with regard to cook loss (%), treatment 1 (STP) tended to decrease cook loss (trend) in pale fillets, whereas treatment 1 (STP) alone significantly decreased cook loss in normal fillets when compared with other treatments. Table 3 also compares WHC measurements in pale to normal fillets. Treatments 3 (blend), 4 (agglomerated), and 5 (nonagglomerated) improved cook loss of pale fillets to that of normal fillets as indicated by no significant differences, indicating that marination with these treatments will increase the yield of pale fillets to that of normal fillets due to decreased cooking losses (Table 4). Treatments 1 (STP) and 2 (high pH) resulted in significantly higher cook loss values in pale fillets compared with normal fillets. The differences in cook loss with treatment 1 were possibly due to the major reduction in cook loss of the normal fillets.

Table 4. Sensory scores on a 9-point hedonic scale for overall preference of normal fillets marinated with NaCl (0.7%) and different phosphates (0.45%)[1]

Treatment[2]	Hedonic scale value[3]
1 (STP)	5.6
2 (high pH)	5.2
3 (blend)	5.6
4 (agglomerated)	5.6
5 (nonagglomerated)	6.0

[1]n = 250 panelists.

[2]STP = sodium tripolyphosphate.

[3]1 = dislike extremely; 9 = like extremely.

Table 5. Comparisons of TBA reactive substances (TBARS) (mg/kg) in pale and normal fillets marinated with NaCl (0.7%) and different phosphates (0.45%)[1]

	TBARS		
Item[2]	Day 0	Day 2	Day 4
Pale treatment			
1 (STP)	2.17	3.22	4.78
2 (high pH)	2.78	4.12	4.61
3 (blend)	2.07	4.06	3.93
4 (agglomerated)	1.68	2.93	4.01
5 (nonagglomerated)	2.02	3.50	4.94
Normal treatment			
1 (STP)	1.76	3.92	3.7
2 (high pH)	2.18	4.6	4.62
3 (blend)	1.99	4.17	6.63
4 (agglomerated)	2.02	4.24	6.79
5 (nonagglomerated)	1.73	4.02	6.46
Pooled SEM	0.13	0.20	0.2

[1]n = 80 fillets.

[2]STP = sodium tripolyphosphate.

Sensory

Sensory perception is of utmost importance in determining consumer satisfaction. Poor-quality pale meat is characterized by poor texture and low moisture that is a result of a decrease in pH early PM that leads to protein denaturation. Marinating pale meat with a combination of NaCl and phosphates has been shown to increase WHC and tenderness (Lyon and Lyon, 2000). The phosphate-NaCl combination has been shown to improve tenderness, juiciness, flavor, and overall sensory impression of tumble-marinated breast meat (Lyon, 1983; Lyon and Hamm, 1986). In this experiment, panelists could discern no significant differences between treatments for normal marinated fillets (Table 4). These results are similar to those found in Garcia et al. (1999). It has been theorized that poor-quality meat due to low pH is very evident in raw samples; however, when cooked, the differences from a sensory perspective are not noticeable. This is probably due to the pH adjustment during cooking. The breast fillet samples for all treatments ranged from 5.2 to 6.0 on a 9-point hedonic scale for overall flavor preference. These results indicate that all 5 treatments were between "neither like nor dislike" (5) and "like slightly" (6). The rankings may seem low compared with other studies. This could be due to the lack of flavorings added to these chicken breast fillets. In addition, the fillets were baked in covered pans and there may have been texture and flavor differences compared with how consumers usually cook chicken in an oven with added flavors or uncovered to brown slightly. Xiong and Kupski (1999) conducted a taste panel that detected little differences between high and low level phosphate treatments and considered tripolyphosphate $\geq$ polyphosphate $>$ hexametaphosphate at improving juiciness, saltiness, and overall flavor intensity at $P < 0.10$.

TBARS

Cooked meats can develop oxidative off-flavors during refrigerated storage (Ang and Young, 1987). One factor affecting the deterioration of meat and the subsequent off-flavors is lipid oxidation. Polyphosphate salts have been shown to hinder these oxidative changes (Ang and Young, 1987) by exhibiting antioxidant activity as metal-sequestering agents. There was no significant difference in any of the 5 treatments for pale or normal fillets for TBARS values for d 0, 2, or 4 (Table 5). Lipid oxidation occurs at a faster rate at low WHC, and because pale meat has lower pH and WHC than normal fillets, it can be insinuated that the treatments improved the oxidative stability (and indirectly shelf life) of pale fillets to that of normal fillets.

Shelf Life

Microbial load of raw broiler meat can have a significant effect on shelf life. Conflicting results have been

Table 6. Log transformation (log cfu/cm^2) aerobic plate counts for pale and normal fillets marinated with NaCl (0.7%) and different phosphates (0.45%)[1]

Treatment[2]	Day 0	Day 3	Day 6	Day 9
1 (STP)				
N	3.41^b	5.05^a	6.34	7.05
P	4.18^a	4.21^b	5.57	7.04
2 (high pH)				
N	3.85^a	3.66^b	5.51	6.89
P	3.55^b	4.32^a	5.44	7.28
3 (blend)				
N	2.97^a	4.00	5.99^a	6.67^b
P	2.58^b	4.03	5.16^b	7.09^a
4 (agglomerated)				
N	3.05^a	3.72	5.56	6.51^b
P	2.56^b	3.98	5.47	7.47^a
5 (nonagglomerated)				
N	3.28^a	3.77^b	5.04	6.26^b
P	2.91^b	4.27^a	5.42	6.95^a

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

[1]n = 64 fillets.

[2]N = normal; P = pale; STP = sodium tripolyphosphate.

obtained concerning the shelf-life-enhancing properties of phosphates on gram-negative microflora of poultry (Allen et al., 1998). It is believed that phosphates act as growth inhibitors of certain food spoilage microorganisms due to their ability to sequester calcium, magnesium, and iron-3, all minerals essential for microbial growth (Molins, 1991). In this study, there was no obvious trend for either treatment for pale or normal fillets in decreasing or enhancing microbial growth (Table 6). There are a variety of factors involved that interact to affect microbial growth rate: type of phosphate used, meat pH, ionic strength, other inhibitors, temperature, and presence of metal ions (Allen et al., 1998). Perhaps this is why there was no obvious trend with any marinade. Newton and Gill (1981) found that increased pH reduces the lag phase time needed for growth of spoilage microorganisms. Davies and Board (1998) also reported that meat with high ultimate pH (>6.0) favors rapid microbial growth. By d 9, all treatments were considered spoiled ($>10^7$ cfu/cm^2 of meat). The psychrotrophic counts were excluded from the results of this experiment because after 7 d of storage at 4°C, there was no growth for all 5 treatments for either fillet type. Perhaps results would have been different if storage time was increased from 7 to 10 d.

In conclusion, all of the phosphates showed some improvement in pale fillets compared with normal fillets. Therefore, phosphates such as high pH phosphates and agglomerated and nonagglomerated phosphates can be used in addition to STP to improve poor meat quality without altering flavor, oxidation, and shelf life.

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