Pork Quality is Affected by Early Postmortem Phosphate and Bicarbonate Injection

E.J. WYNVEEN, B.C. BOWKER, A.L. GRANT, J.W. LAMKEY, K.J. FENNEWALD, L. HENSON AND D.E. GERRARD

ABSTRACT: The ability of sodium polyphosphate (P) to alter postmortem pH declines and pork quality was investigated. Hams from electrically stimulated carcasses were injected 18 min postmortem with P or sodium bicarbonate (SB). P and SB reduced ($P < 0.001$) pH decline and improved ($P < 0.05$) color. P and SB administration improved water-holding capacity as indicated by reductions ($P < 0.05$) in drip loss, thaw loss, and cooking loss values. P and SB also reduced ($P < 0.001$) shear values. These data showed delivery of P and SB was effective in altering postmortem pH declines and improving the quality of pork.

Keywords: PSE, phosphate, pH, muscle, water-holding capacity, bicarbonate

Introduction

PALE, SOFT, EXUDATIVE (PSE) PORK IS OF GREAT CONCERN TO the pork industry. PSE can be attributed to over $100 million in losses to the pork industry annually (Carr and others 1997). PSE meat is characterized as having a low water-binding capacity, soft texture, and pale color. Light or pale meat causes problems during the manufacture of oven-cooked products by increasing purge, resulting in dry products with poor texture, off-flavors, and an overall low eating quality. Due to these quality problems, PSE meat is undesirable for both consumers and meat processors.

PSE develops due to adverse pH and temperature conditions within the muscle early postmortem. A low pH combined with a high carcass temperature results in denaturation of muscle proteins (Briskey and Wismer-Pedersen 1961; Sayre and others 1963; Bendell and Swatland 1988). This protein denaturation is associated with the poor characteristics of PSE meat.

Since PSE is a temperature and pH related phenomenon, it is plausible that reducing carcass temperature could prevent PSE development. However, previous studies have shown that reducing carcass temperatures reduces the magnitude of the problem, but does not eliminate PSE development (Borchert and Briskey 1964; Long and Tarrant 1990). Buffering pH decline is another approach to reducing the occurrence of PSE development. Recently it was shown that infusion of sodium bicarbonate (SB) early postmortem buffers muscle pH and reduces the meat quality problems associated with the PSE condition (van Laack and others 1996, 1998; Kauffman and others 1998). However, SB is not widely used or accepted in the meat industry.

Polyphosphates (P) have great potential to buffer early postmortem pH decline because of their excellent buffering capacities (Ellinger 1972). In addition, multiple forms of P are used widely throughout the meat, poultry, and seafood industries because they improve the functional characteristics of processed meats (Knipe and others 1985). These benefits result from at least four different phenomena: increased pH, increased ionic strength, partial elimination of alkali earth metals, and/or dissociation of actomyosin complexes (Hamm 1971). Because phosphates can alter pH, it can be hypothesized that early addition of phosphate to muscle may be a useful means of inhibiting PSE development. Unfortunately, little data exists regarding the benefits of using polyphosphates during the transformation of muscle to meat. Therefore, the objective of this study was to determine the efficacy of injecting phosphate and sodium bicarbonate-based solutions early postmortem to inhibit PSE development.

Materials and Methods

Harvesting pork carcasses

Three replications (15 pigs each) of this study were conducted using a total of 45 market weight (108-118 kg) gilts. Pigs for replicate 1 were obtained from the Purdue Univ. Research and Education Center and pigs for replicates 2 and 3 were obtained from Pig Improvement Co. (PIC, Franklin, Ky., U.S.A.). All animals were fed freely prior to harvesting at the Purdue Univ. Meat Science Research and Education Center. Pigs were immobilized according to industry standards and exsanguination was considered 0 min postmortem. To accelerate postmortem pH decline and simulate PSE-like conditions, each carcass was subjected to electrical stimulation (26 pulses, 60 Hz, 500 V, 1 sec on and 1 sec off) at 3 min postmortem as described by Bowker and others (1999). Carcasses were then immediately dehaired following scalding and processed according to normal processing procedures. At 18 min postmortem, after carcasses were split and washed, the ham from each carcass side was removed 5 cm anterior the aitch bone perpendicular to the shank. Hams were trimmed to remove skin, weighed, and by 20 min postmortem were subjected to predetermined randomly assigned treatments.

Treatments

Four treatment solutions were formulated using sodium phosphate (MB387, FMC Corp., Philadelphia, Pa., U.S.A.) and a fifth solution was formulated using sodium bicarbonate (Mallinckrodt Baker, Inc., Paris, Ky.,, U.S.A.). Each ham was injected to 110% of green weight using a multi-stitch injector (Presto Precision Products, Inc., Farmingdale, N.Y., U.S.A.) to include 0.2%, 0.3%, 0.4%, or 0.5% phosphate or 0.23% sodium bicarbonate (0.3 M) in the muscle (wt./wt.). Phosphate (P) treatments were formulated to also include 0.3% NaCl in the muscle. The sodium bicarbonate (SB) treatment was formulated to also include 0.07% salt in the muscle. Solutions were formulated to meet the U.S. federal guidelines such

© 2001 Institute of Food Technologists

Table 1—Early postmortem pH measurements of the *Biceps femoris* muscle (LS mean +/- SE)

	Treatment									
Time	0.2% P	0.2% D	0.3% P	0.3% D	0.4% P	0.4% D	0.5% P	0.5% D	0.23% SB	0.23% D
18 min	6.07±0.06	6.03±0.05	6.13±0.04	6.15±0.04	6.12±0.04	6.14±0.03	6.20±0.05	6.14±0.05	6.16±0.06	6.14±0.06
Δ-18 min	-0.04±0.05		0.02±0.03		0.02±0.02		-0.05±0.03		-0.02±0.01	
23 min	6.68±0.12	5.90±0.06	6.92±0.09	5.91±0.04	6.94±0.08	5.92±0.04	6.94±0.09	5.91±0.05	7.12±0.12	5.99±0.05
Δ-23 min	-0.78±0.13*		-1.01±0.11*		-1.02±0.07*		-1.03±.10*		-1.13±0.14*	
30 min	6.41±0.09	5.75±0.06	6.64±0.09	5.83±0.03	6.70±0.08	5.82±0.03	6.85±0.09	5.78±0.07	6.87±0.09	5.87±0.06
Δ-30 min	-0.66±0.10*[a]		-0.81±0.08*[ab]		-0.88±0.07*[ab]		-1.07±0.08*[b]		-1.00±0.11*[b]	
37 min	6.28±0.09	5.72±0.05	6.51±0.04	5.73±0.04	6.58±0.08	5.78±0.04	6.66±0.09	5.71±0.05	6.71±0.06	5.81±0.04
Δ-37 min	-0.56±0.07*[a]		-0.78±0.05*[ab]		-0.80 ± 0.08*[b]		-0.95 ± .10*[b]		-0.90 ± 0.07*[b]	
44 min	6.15±0.10	5.70±0.06	6.32±0.04	5.71±0.02	6.45±0.06	5.72±0.04	6.53±0.10	5.70±0.06	6.54±0.06	5.73±0.04
Δ-44 min	-0.45±0.08*[a]		-0.61±0.04*[ab]		-0.73±0.07*[bc]		-0.83±0.11*[c]		-0.81±0.05*[c]	
52 min	6.15±0.09	5.65±0.04	6.25±0.03	5.70±0.02	6.33±0.03	5.71±0.05	6.38±0.08	5.70±0.02	6.41±0.04	5.67±5.67
Δ-52 min	-0.50 ± 0.07 *[a]		-0.55 ± 0.03 *[ab]		-0.62 ± 0.05 *[abc]		-0.68 ± 0.08 *[bc]		-0.74 ± 0.04 *[c]	
58 min	6.08±0.09	5.63±0.05	6.12±0.03	5.64±0.03	6.23±0.03	5.64±0.02	6.24±0.09	5.63±0.04	6.30±0.04	5.61±0.04
Δ-58 min	-0.45 ± 0.10 *[a]		-0.48 ± 0.03 *[a]		-0.59 ± 0.04 *[ab]		-0.61 ± 0.07 *[ab]		-0.69 ± 0.04 *[b]	

*Indicates differences ($P < 0.05$) between treatment and paired control (N=45/treatment).
[a]Treatment-control differences within a row with different superscripts indicate treatments differ significantly ($P < 0.05$).
D- dextrose; P- phosphate; SB- sodium bicarbonate

that alkaline phosphates, either alone or in various combinations, did not to exceed 0.5% in the finished product (Code of Federal Regulations, Title 9). The sodium bicarbonate treatment was formulated using methods of Kauffman and others (1998) and served as a positive control. For each carcass, one ham was injected with one of the five treatments and the contralateral ham was similarly injected with a control solution comprised of dextrose and salt. Control solutions were formulated to have equivalent solids content and salt levels as their respective treatment solutions. All solutions were heated to 38 °C prior to injection.

In each ham, pH and temperature of the *biceps femoris* (BF) muscle were recorded at 18, 23, 30, 37, 44, 52, and 58 min postmortem. Additionally, pH was measured 24 h (pHu) postmortem. pH was measured using a Beckman Φ 110 ISFET pH meter with a spear-tipped KCI- gel probe (Fullerton, Calif., U.S.A.) which compensated for temperature differences. The probe was inserted approximately 5 cm into the BF at a perpendicular angle to the ham face to ensure measurements were taken near the center of the muscle. Temperature was measured using a VWRbrand™ Traceable Digital Thermometer (Friendswood, Tex., U.S.A.) in the same location. At 60 min postmortem hams were placed in a chill cooler (4 °C) for 24 h.

At 24 h postmortem, hams were sliced (2.54 cm) and the BF, *quadriceps femoris* (QF), and *semimembranosus* (SM) muscles were removed for the evaluation of water-holding capacity, ultimate pH (pHu), CIE L*a*b*color values, thaw loss, cook loss, and Warner-Bratzler shear values.

Water-holding capacity

Triplicate samples from the BF, QF, and SM were removed from one slice and water-holding capacity was determined using the drip loss method (Rasmussen and Stouffer 1996).

CIE L*, a*, b*

Individual BF, QF, and SM muscles were removed from an adjacent ham slice and CIE L*a*b*color values were obtained from three randomly selected locations using a Hunter Lab 45°/0° D25-PC2Δ Colorimeter (Hunter Assoc. Laboratory Inc., Reston, Va., U.S.A.).

Thaw loss

Individual BF, QF, and SM muscles were excised from an adjacent ham slice, individually weighed and vacuum packaged. Samples were stored at –20 °C for 3 mo, thawed at 4 °C for 48 h, removed from the vacuum package, blotted dry, and reweighed. Thaw loss was calculated by expressing thawed weight as a percentage of frozen sample weight.

Cooking

Thawed muscle samples were broiled to an internal temperature of 71.1 °C, blotted dry, and weighed. Cooking loss was determined by expressing cooked weight as a percentage of precooked sample weight.

Shear force

Cooked muscles were allowed to cool to 25 °C and three 1.27-cm core samples oriented parallel to the muscle fiber structure of the meat were excised. Warner-Braztler shear force, perpendicular to muscle fiber orientation, was determined for each core using a Q-Test Universal Testing Machine Model III (Division of MTS Systems Corporation, NC, U.S.A.), equipped with a 45.35 kg load cell at a crosshead speed of 50 mm/min. Data are reported as maximum force tension (kg).

Statistical analysis

Differences for pH, temperature, and quality measurements between each treatment and respective control were calculated and analyzed by paired-comparison procedures using the general linear model procedure of SAS (1985). Treatment-control pair differences were separated using t-tests.

Results

NO DIFFERENCES WERE OBSERVED BETWEEN 15-PIG REPLICATES and no significant ($P > 0.05$) interactions were observed between treatment and muscle for any of the measured traits. No muscle differences were significant for b*, pHu, thaw loss, cook loss, or shear value; therefore, these quality parameters were pooled across muscles. Muscle differences existed for L*and drip loss and are reported by muscle.

The pH and temperature declines of the BF muscle for each treatment and its control are shown in Table 1 and 2, respectively. To compare treatment effects, differences in pH and temperature between the treated and control hams were compared across treatment groups. As expected, both pH

Table 2—Early postmorten tempertature measurements of the Biceps femoris muscle (LS mean ± SE)

	Treatment									
Time	**0.2% P**	**0.2% D**	**0.3% P**	**0.3% D**	**0.4% P**	**0.4% D**	**0.5% P**	**0.5%D**	**0.23% SB**	**0.23%D**
18 min	40.6 ± 0.2	40.4 ± 0.2	40.7 ± 0.3	40.9 ± 0.2	40.9 ± 0.2	40.8 ± 0.2	40.6 ± 0.2	40.3 ± 0.2	40.8 ± 0.2	40.9 ± 0.2
Δ-18 min	-0.2 ± 0.19		0.2 ± 0.24		-0.1 ± 0.12		-0.3 ± 0.43		0.1 ± 0.15	
23 min	38.6 ± 0.4	38.3 ± 0.3	39.2 ± 0.2	39.5 ± 0.3	38.4 ± 0.3	38.8 ± 0.4	38.7 ± 0.4	39.0 ± 0.5	38.9 ± 0.3	39.0 ± 0.4
Δ-23 min	-0.3 ± 0.55		0.5 ± 0.21		0.4 ± 0.35		0.3 ± 0.65		0.1 ± 0.47	
30 min	38.7 ± 0.3	38.4 ± 0.4	38.9 ± 0.2	39.4 ± 0.2	38.2 ± 0.2	38.7 ± 0.3	38.6 ± 0.4	38.7 ± 0.4	38.9 ± 0.2	39.2 ± 0.4
Δ-30 min	-0.3 ± 0.31		0.5 ± 0.25		0.5 ± 0.38		0.1 ± 0.52		0.3 ± 0.41	
37 min	38.5 ± 0.2	38.3 ± 0.3	38.8 ± 0.2	39.2 ± 0.3	38.3 ± 0.2	38.8 ± 0.3	38.7 ± 0.3	38.6 ± 0.3	38.9 ± 0.2	38.7 ± 0.2
Δ-37 min	-0.2 ± 0.20		0.4 ± 0.12		0.5 ± 0.22*		-0.1 ± 0.38		-0.2 ± 0.35	
44 min	38.3 ± 0.3	38.3 ± 0.3	38.6 ± 0.2	39.3 ± 0.2	38.1 ± 0.2	38.8 ± 0.3	38.5 ± 0.3	38.5 ± 0.3	38.6 ± 0.2	39.0 ± 0.4
Δ-44 min	0.0 ± 0.27		0.7 ± 0.12*		0.7 ± 0.28*		0.0 ± 0.22		0.4 ± 0.48	
52 min	38.1 ± 0.3	38.2 ± 0.3	38.3 ± 0.2	39.1 ± 0.3	37.9 ± 0.2	38.7 ± 0.3	38.3 ± 0.3	38.4 ± 0.3	38.4 ± 0.2	38.8 ± 0.3
Δ-52 min	0.1 ± 0.26		0.8 ± 0.24*		0.8 ± 0.20*		0.1 ± 0.32		0.4 ± 0.34	
58 min	37.6 ± 0.4	37.9 ± 0.4	37.9 ± 0.3	38.5 ± 0.4	37.7 ± 0.3	38.4 ± 0.2	37.9 ± 0.3	38.0 ± 0.2	38.3 ± 0.3	38.5 ± 0.3
Δ-58 min	0.3 ± 0.23		0.6 ± 0.19*		0.7 ± 0.34*		0.1 ± 0.30		0.2 ± 0.34	

* Indicates differences ($P < 0.05$) between treatment and paired control.
D-dextrose, P-phosphate; SB-sodium bicarbonate

and temperature at 18 min (prior to treatment) did not differ between any treatment and its control, or among treatments. However, after injection, each treatment resulted in a higher pH ($P < 0.05$) than its control at 23, 30, 37, 44, 52, and 58 min.

No temperature differences were observed among treatments at any of the time points or between any treatment-control comparison at 18, 23, and 30 min. However, at 37, 44, 52, and 58 min some temperature differences were evident. Curiously, the 0.3% P and 0.4% P treatments were slightly (0.5 to 0.8 °C) lower than their respective control side between 37 and 58 min.

The 0.3%, 0.4%, 0.5% P and SB treatments decreased ($P < 0.05$) CIE L*(lightness) values in all muscles compared to controls (Figure 1). The 0.2% P treatment decreased the CIE L*value only in the SM. In each muscle, the reduction in L*did not differ by treatment dose. However, there was a larger reduction ($P < 0.02$) in L*for the SM than either the BF or QF muscles.

In the SM and the QF muscles, all phosphate doses and the SB treatment reduced ($P < 0.05$) drip loss compared to controls (Figure 2). In the BF muscle, only the 0.4% P, 0.5% P, and SB treatment had less ($P < 0.05$) drip loss than controls. No differences among treatments were observed with regards to drip loss when comparing across an individual muscle. However, there was a larger reduction ($P < 0.0001$) in drip loss (%) in the SM than in BF or QF muscles.

Each treatment resulted in a higher ($P < 0.05$) pHu compared with controls (Figure 3). Differences among treatments were similar to the early postmortem pH decline measurements. SB treatment resulted in the highest ($P < 0.0001$) pHu across all treatments whereas the 0.4% and 0.5% P treatments resulted in the highest ($P < 0.0001$) pHu among P treatments.

Compared with controls, each treatment decreased ($P < 0.0001$) thaw loss (Figure 4). Differences were detected among treatments as the 0.4% P and 0.5% P treatments reduced ($P < 0.01$) thaw loss to a greater extent than the 0.2% P treatment. Each treatment reduced ($P < 0.0002$) cooking loss when compared with controls (Figure 5). The 0.5% P treatment reduced ($P < 0.05$) cooking loss more than either the 0.2% P, 0.3% P, or the SB treatments. Warner-Bratzler

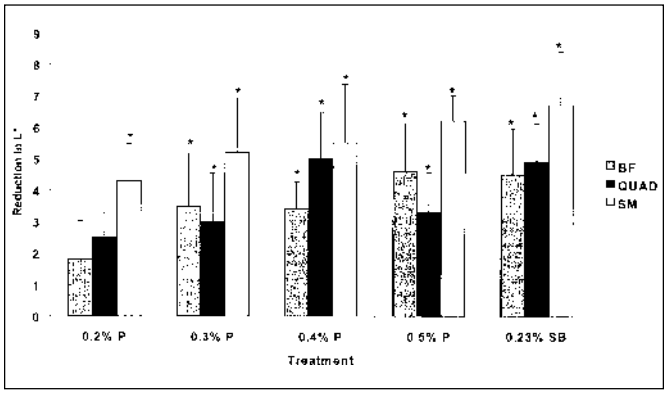

Figure 1—Reduction in CIE L*(control – treated ham) of sodium phosphate and sodium bicarbonate treated muscle (Mean +/- SE). *Indicates differences (P < 0.05) between treatment and paired control (N=45/muscle/treatment). P- sodium phosphate; SB- sodium bicarbonate; BF- *biceps femoris*; QUAD- *quadriceps femoris*; SM- *semimembranosus.*

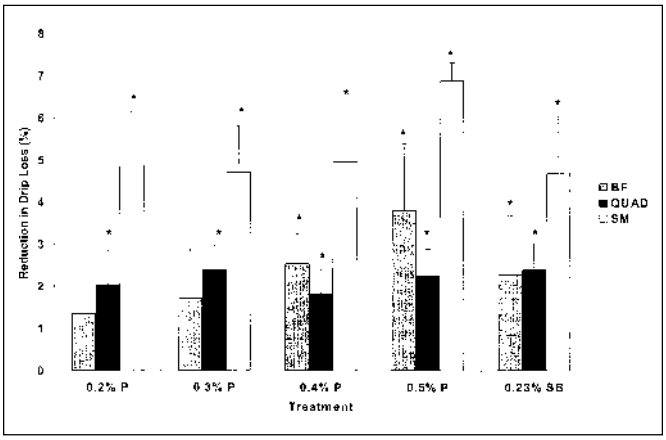

Figure 2—Reduction in drip loss percentage (control vs treated ham) of sodium phosphate and sodium bicarbonate treated muscle (Mean +/- SE). *Indicates differences (P < 0.05) between treatment and paired control (N=45/muscle/treatment). P- sodium phosphate; SB- sodium bicarbonate; BF- *biceps femoris*; QUAD- *quadriceps femoris*; SM- *semimembranosus.*

shear values (Figure 6) revealed that all phosphate and the SB treatments reduced ($P < 0.001$) shear value over controls. No differences were observed among treatments.

Discussion

BECAUSE PSE IS A PH AND TEMPERATURE DEPENDENT PHENOMENON early postmortem, phosphate was injected early postmortem in an attempt to buffer pH decline that is thought to lead to protein denaturation and PSE meat. To simulate the PSE condition, electrical stimulation was used to accelerate the rate of postmortem metabolism. The pH and temperature declines of controls were consistent with the early postmortem declines in PSE. The pH of the various controls did not differ at any time, and the average pH at 23 min was 5.93 at a temperature of 38.9 °C for control sides. Thus, all controls were predisposed to the adverse conditions that develop PSE meat (Offer 1991). The fresh meat quality measurements confirm that the control hams developed PSE-like meat.

In general, injection of phosphate early postmortem resulted in muscle pH between 0.45 to 1.07 pH units higher for treated versus controls during the first hour postmortem. These data suggested that all levels of phosphate along with SB injection early postmortem were effective at retarding pH decline when compared with their respective controls. Additionally, pH differences generally increased with increasing concentration of phosphate at all time points with the SB treatment resulting in the greatest difference in pH. This buffering effect may in turn prevent the pH induced protein denaturation normally observed in PSE muscle early postmortem. Therefore, these results suggested that pre-rigor injection of phosphate, as well as SB, prevented low muscle pH conditions early postmortem that resulted in PSE pork.

Since all solutions were heated to 38 °C prior to injection, no temperature differences were expected between treatment-control pairs or among treatments. Although not statistically significant, control hams tended to have a higher temperature than treated hams. Significant differences in temperatures, however, were observed between 0.3% P and 0.4% P treated and control hams. This phenomenon is not fully understood.

CIE L*data showed that early postmortem injection of P or SB solutions was effective at preventing development of pale lean color. The decreased lightness of the P and SB treatments are commercially important because color is often indicative of pork quality and often is considered by consumers when purchasing fresh pork (Brewer and McKeith 1999). Our results are in agreement with previous studies. Pre-rigor injection of phosphate-based solutions has been shown to darken color of both beef and turkey muscle (Carpenter and others 1961; Young and Lyon 1994). The level and form of phosphate is important, however, as Kamstra and Saffle (1959) showed that hams injected with a 23.3% hexametaphosphate solution at 15 min postmortem resulted in an undesirable dark color characteristic of dark, firm, dry (DFD) pork.

The greater difference in L*value between control and treated hams in the SM muscle was most likely not a muscle-phosphate interaction effect. The SM was more adversely affected by electrical stimulation than the other muscles as evidenced by higher L*value in the controls. The inherently more glycolytic nature of the SM muscle probably makes it more susceptible to developing the PSE through a rapid pH decline when induced by electrical stimulation. Thus, the greater increase in L*with phosphate injection into the SM was most likely the result of inherent muscle differences.

Much research has shown that addition of polyphosphates to meat products post-rigor increases water retention during processing. Sheard and others (1999) showed that addition of 0.3% and 0.5% polyphosphate to post-rigor pork loins improved water holding capacity. Additionally, polyphosphates, or their blends, have been incorporated into further processed products such as sausages and restructured meat products to enhance water-holding capacity (Knipe and others 1985; Anjaneyulu and others 1989; Bernthal and others 1991). The poultry industries, as well as the red meat industry, have also taken advantage of the increased moisture retention through use of phosphates (Mahon 1962; Farr and May 1970; Young and others 1987). The current results indicate that pre-rigor phosphate and SB treatments also may be utilized to enhance the water-holding capacity of the final product. Although a titration effect was immediately apparent from our data, a higher concentration of phosphate numerically yielded a greater decrease

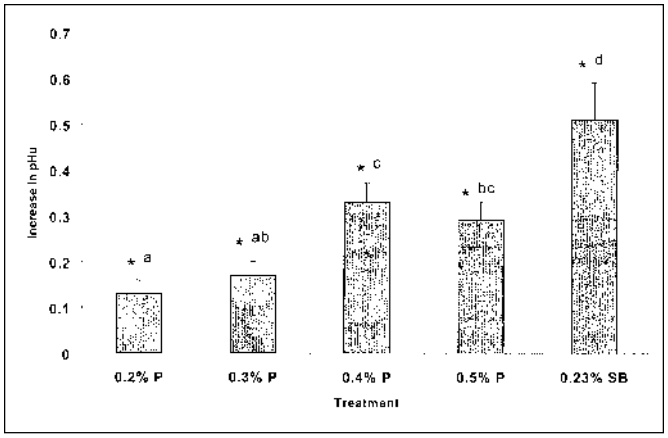

Figure 3—Mean (+/- SE) ultimate pH (pHu) values for sodium bicarbonate (SB) and phosphate (P) injected hams. *Indicates differences ($P < 0.006$) between treatment and paired control (N=135/treatment). [a]Indicates difference (0.0001) among treatments.

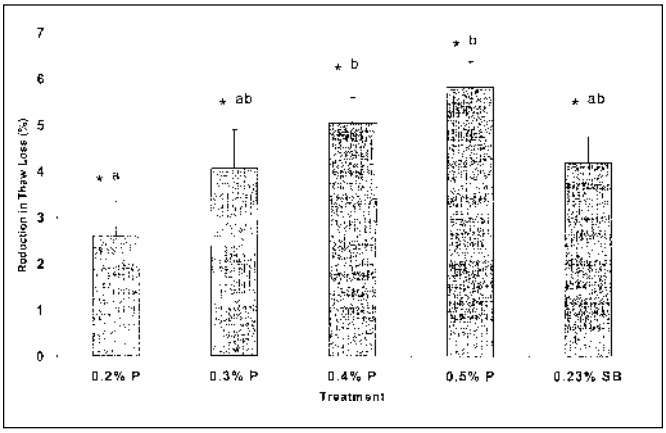

Figure 4—Mean (+/- SE) thaw loss values for sodium bicarbonate (SB) and phosphate (P) injected hams. *Indicates differences ($P < 0.0001$) between treatment and paired control (N=135/treatment). [a]Indicates difference ($P < 0.01$) among treatments.

in drip loss. The greater treatment-control pair difference in drip loss in the SM when compared with the BF and QF was again likely due to inherent muscle differences and their ability to respond to stimulation. In general, phosphates and SB effectively reduce drip loss when used in the pre-rigor state and have the potential to reduce economic loss within the pork industry.

Several mechanisms contribute to the effectiveness of pre-rigor phosphate injection enhancing water-holding capacity. The moisture binding improvements with the addition of phosphates can be attributed to increases in pH and ionic strength, the binding of phosphates to meat proteins, and the dissociation of actomyosin into actin and myosin (Hamm 1971). Ionic strength is related to the number of ions in solution, phosphates increase the number of ions, which react with the protein and increase hydration. The phosphate-protein interaction involves some disintegration of alkali earth metal linkages between proteins and allows water to migrate into the muscle structure. In meat, it is a well-known phenomenon that increased pH will increase water-holding capacity. The ability of phosphates to increase pHu is not surprising since phosphates have been shown to have excellent buffering capacities (Ellinger 1972). These data, combined with the early postmortem pH measurements, indicated that phosphates inhibited the extent as well as the rate of pH decline. The increase in pHu, as mentioned earlier, may explain in part, the increase in WHC in the phosphate and SB treatments.

All phosphate treatments and SB were effective at reducing thaw loss when compared with their respective controls. Thaw loss was generally reduced with increasing phosphate concentration. The ability of phosphates to decrease thaw loss can also be attributed to increases in pH and ionic strength, the binding of phosphates to meat proteins, and the dissociation of actomyosin into actin and myosin. Because the SB treatment resulted in the highest pHu and the phosphate treatment resulted in less thaw loss than the SB treatment, this implied that phosphates and sodium bicarbonates might work by slightly different mechanisms to increase water-holding capacity. Furthermore, the increasing of pHu must not explain all of the increase in water holding capacity. The difference in thaw loss ranged from 2.61 to 5.81%. This decrease in the amount of moisture lost after freezing is of economic interest to the pork industry, especially in applications where freezing will be used. Even the lower range of change in thaw loss could result in increased profits to industry.

All phosphate doses and SB injections decreased cooking loss compared with controls. Additionally, the 0.5% P pre-rigor injections reduced cooking loss more than the SB. These results support past research showing the benefits of phosphate in meat products on cooking yields. Work by Sheard and others (1999) demonstrated that increasing sodium tripolyphosphate from 0 to 0.5% in pork loins reduces cooking loss by 3%. Lee and others (1998) showed that inclusion of 0.5% sodium pyrophosphate or tripolyphosphate in restructured beef rolls, along with 1% NaCl, had higher cook yields and moisture levels compared to controls. Young and Lyon (1997) have shown that inclusion of 0.4% sodium tripolyphosphate with 1.5% NaCl increases marinade absorption and decreases cooking loss in chicken breast. Lamkey and others (1986) reported restructured beef steaks made with 0.5% phosphate reduced cooking losses compared to restructured steaks made without phosphate. Thus, our results indicated that injecting phosphates pre-rigor might be equally effective at reducing cooking loss as observed in the post-rigor injection.

The influence of phosphate and SB injection on tenderness was determined by Warner-Bratzler shear force measurement. Tenderness is a major component of the palatability characteristics of meat. Phosphates and SB were effective at reducing shear force, indicating an increase in tenderness. No titration effect was observed with increasing concentrations of phosphate. Many researchers have shown similar effects of phosphate addition on tenderness of meats. Smith and others (1984) noted lower initial shear values and increased tenderness sensory ratings of both pork loins and beef inside rounds injected to a final concentration of 0.475 % sodium tripolyphosphate. Similarly, Sheard and others (1999) found pork loins injected with 0.3% and 0.5% sodium tripolyphosphate were rated by a sensory panel as more tender and juicy compared with controls.

The tenderness effect may be attributed to the fact that polyphosphates promote the weakening of the myosin heads

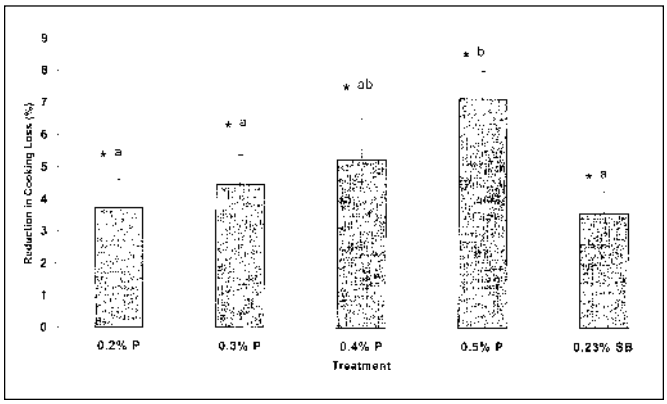

Figure 5—Mean (+/- SE) cooking loss values for sodium bicarbonate (SB) and phosphate (P) injected hams. *Indicates differences ($P < 0.0001$) between treatment and paired control (N=135/treatment). [a]Indicates difference ($P < 0.01$) among treatments.

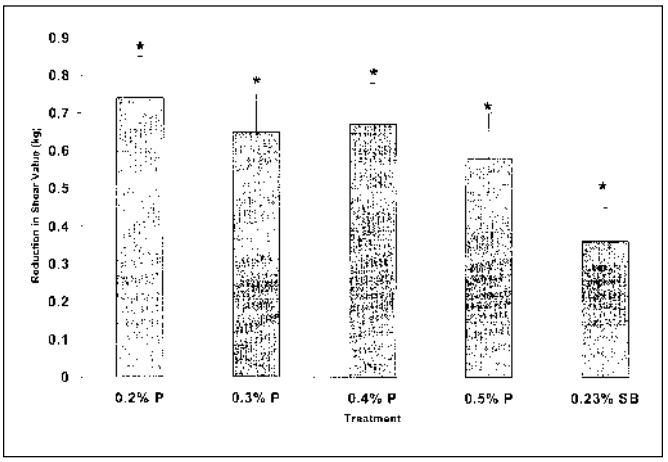

Figure 6—Mean (+/- SE) shear values for sodium bicarbonate (SB) and phosphate (P) injected hams. *Indicates differences ($P < 0.001$) between treatment and paired control (N=135/treatment).

to actin, and thus promote the dissociation of actomyosin (Yasui and others 1964). This dissociation in turn allows more water to be retained or taken up by phosphate-treated meat. Thus, the increased tenderness may be attributed directly to the higher water content and weakened muscle structure.

One of the greatest challenges with this research was attempting to obtain an even distribution of solution throughout the ham. This challenge was never overcome with the methodologies used in this research. One way that could possibly help alleviate the distribution concern may be through tumbling of the product after injection. Tumbling is common for further processed products within the meat industry to help with distribution of solution. Another approach may be through using higher injection rates. This research only had injection levels of 10% above the green weight of the ham. Using higher injection levels (that is, 15 to 20 %) to include the same levels of final phosphate concentrations may help resolve the uneven distribution that was observed. It may also be the case that the problem we observed with distribution may be due to the equipment (multi-stitch injector) that was used to inject the hams. The injector used was a small version that would normally be used in industry. Industrial sized injectors are calibrated to deliver equal amounts of solution throughout meat systems with many more needles. No attempts were made to determine the optimal pressure to inject the treatment solutions. In an industry setting, these parameters are better defined for certain applications. Any of the aforementioned factors affecting the distribution of solution should be further investigated before actual practice in industry can be implemented.

Another concern for industry may be that only hams with a rapid pH decline were injected to buffer the postmortem pH decline. Although it would be possible to sort PSE-like meat via early postmortem pH measurements, it may be expensive and impractical for industry. The best way, in an industrial setting for injecting early postmortem, is probably by injecting every carcass that passes through the processing plant. The question arises as to what would happen if a normal, or muscle with a less rapid pH decline, was injected with a phosphate solution. Would the normal pH decline meat result in DFD (dark, firm, and dry) because of too high a pH after it was injected with a phosphate solution? This is another question that should be addressed prior to industry application.

Conclusions

IMPLEMENTING PRE-RIGOR INJECTION OF PHOSPHATE MAY PREvent certain pork quality problems. These data indicated that sodium phosphates at levels of 0.2, 0.3, 0.4, and 0.5 %, as well as sodium bicarbonate (0.3 M), when injected at 18 min postmortem were effective in inhibiting the rate and extent of postmortem pH decline and appears to improve the quality of pork.

References

Anjaneyulu ASR, Shama N, Kondaiah N. 1989. Evaluation of salt, polyphosphates and their blends at different levels on physiochemical properties of buffalo meat patties. Meat Sci., 25: 293-306.

Bendall JR, Swatland HJ. 1988. A review of the relationships of pH with physical aspects of pork quality. Meat Sci., 24: 85-96.

Bernthal PH, Booren AM, Gray JI. 1991. Effect of reduced sodium chloride concentration and tetrasodium pyrophosphate on pH, water-holding capacity and extractable protein of prerigor and postrigor ground beef. Meat Sci., 29: 69-82.

Borchert LL, Briskey EJ. 1964. Prevention of pale, soft, exudative porcine muscle through partial freezing in liquid nitrogen post-mortem. J. Food Sci., 29: 203-209.

Bowker BC, Wynveen EJ, Grant AL, Gerrard DE. 1999. Effects of electrical stimulation on early postmortem pH and temperature declines in pigs from different genetic lines and halothane genotypes. Meat Sci., 53: 125-133.

Brewer MS, McKeith FK. 1999. Consumer-rated quality characteristics as related to purchase intent of fresh pork. J. Food Sci., 64(1): 171-174.

Briskey EJ, Wismer-Pedersen J. 1961. Biochemistry of pork muscle structure. I. Rate of anaerobic glycolysis and temperature changes versus the apparent structure of muscle tissue. J. Food Sci., 26: 297-305.

Carpenter JA, Saffle RL, Kamstra LD. 1961. Tenderization of beef by pre-rigor infusion of a chelating agent. Food Technol., 15(4): 197-198.

Carr TR, Kauffman RG, Meeker DL, Meisinger DJ. 1997. Factors reducing pork value. Pork Industry Handbook, PIH-135. Purdue University Cooperative Extension Service, West Lafayette, Ind. pp1-4.

Code of Federal Regulations, Title 9. Paragraph 318.7(4). U. S. Government Printing Office.

Ellinger RH. 1972. Phosphates in Food Processing. In: "Handbook of Food Additives" (Furia, T. E. ed.) CRC Press, Cleveland, OH, 617-780.

Farr AJ, May KN. 1970. The effect of polyphosphates and sodium chloride on cooking yields and oxidative stability of chicken. Poultry Sci., 49: 268-275.

Hamm R. 1971. Interactions between phosphates and meat proteins. In Symposium: Phosphates in Food Processing, Deman JM, Melnychyn P. (Ed.), p. 65-82. The AVI Publishing Co., Westport, Conn.

Kamstra LD, Saffle RL. 1959. The effects of a pre-rigor infusion of sodium hexametaphosphate on tenderness and certain chemical characteristics of meat. Food Technol., 13(11): 652-655.

Kauffman RG, van Laack RLJM, Russell RL, Pospiech E, Cornelius CA, Suckow CE, Greaser ML. 1998. Can pale, soft, exudative pork be prevented by postmortem sodium bicarbonate injection? J. Anim. Sci., 76: 3010-3015.

Knipe CL, Olson DG, Rust RE. 1985. Effects of selected inorganic phosphates, phosphate levels and reduced sodium chloride levels on protein solubility, stability and pH of meat emulsions. J. Food Sci., 50(4): 1010-1013.

Lamkey JW, Mandigo RW, Calkins CR. 1986. Effect of salt and phosphate on the texture and color stability of restructured beef steaks. J. Food Sci., 51(4): 873-875.

Lee BJ, Hendricks DG, Conforth DP. 1998. Effect of sodium phytate, sodium pyrophosphate and sodium tripolyphosphate on physico-chemical characteristics of restructured beef. Meat Sci., 5: 273-283.

Long VP, Tarrant PV. 1990. The effect of pre-slaughter showering and post-slaughter rapid chilling on meat quality in intact pork sides. Meat Sci., 27: 181-195.

Mahon J H. 1962. Phosphates improve poultry. Food Eng., 34: 108-113.

Offer G. 1991. Modelling of the formation of pale, soft, exudative meat: effects of chilling regime and rate and extent of glycolysis. Meat Sci., 30: 157-184.

Rasmussen A, Stouffer JR. 1996. New method for determination of drip loss in pork muscles. Poster Proceedings. 42nd International Congress of Meat Science and Technology, Norway 286-287.

Sayre RN, Briskey EJ, Hoekstra WG. 1963. Effect of excitement, fasting and sucrose feeding on porcine phosphorylase and postmortem glycolysis. J. Food Sci., 28(4): 472-477.

Sheard PR, Nute GR, Richardson RI, Perry A, Taylor AA. 1999. Injection of water and polyphosphate into pork to improve juiciness and tenderness after cooking. Meat Sci., 51: 371-376.

Smith LA, Simmons SL, McKeith FK, Bechtel PJ, Brady PL. 1984. Effects of sodium tripolyphosphate on physical and sensory properties of beef and pork roasts. J. Food Sci., 49(6): 1636-1637.

Statistical Analysis System Institute Inc. 1985. SAS Users Guide to the Statistical Analysis System. NC State Univ., Raleigh, NC.

van Laack RLJM, Kauffman RG, Lee S, Pospeich E, Greaser, ML. 1996. The effect of pre-rigor application of sodium bicarbonate on the quality of pork. 42nd International Congress of Meat Science and Technology, Lillehammer, Norway, pp 386-387.

van Laack RLJM, Kauffman RG, Pospeich E, Greaser ML, Lee S, Solomon MB. 1998. Sodium bicarbonate perfusion affects quality of porcine M. semimembranosus. J. Muscle Foods, 9: 185-191.

Yasui T, Fukazawa T, Takahishi K, Hashimoto Y. 1964. Effect of inorganic polyphosphates with myosin B. J. Agric. Food Chem., 12(5): 392-398.

Young LL, Lyon CE. 1994. Effects of rigor state and addition of polyphosphates on the color of cooked turkey meat. Poul. Sci., 73: 1149-1142.

Young LL, Lyon CE. 1997. Effect of postchill aging and sodium tripolyphosphate on moisture binding properties, color, and Warner-Bratzler shear values on chicken breast meat. Poul. Sci., 76: 1587-1590.

Young LL, Lyon CE, Searcy GK, Wilson RL. 1987. Influence of sodium tripolyphosphate and sodium chloride on moisture-retention and textural characteristics of chicken breast meat patties. J. Food Sci., 52(3): 571-574.

MS 20000201

Purdue University Agricultural Research Programs Journal Paper No. 16, 215.

Authors Bowker, Grant, and Gerrard are with Purdue Univ., 202A Smith Hall, West Lafayette, IN 47907. Author Henson is with FMC Corp., Princeton, NJ. Author Wynveen is with Viskase, Chicago, Illinois. Address inquiries to author Gerrard (E-mail: dgerrard@purdue.edu).