EFFECTS OF PRE-RIGOR INJECTION OF SODIUM CITRATE OR ACETATE, OR POST-RIGOR INJECTION OF PHOSPHATE PLUS SALT, ON POST-MORTEM GLYCOLYSIS, PH DECLINE, AND PORK QUALITY ATTRIBUTES

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Summary

Forty pork carcass sides were assigned to one of four treatments: pre-rigor citrate (CIT) or acetate (ACE) injection, post-rigor phosphate plus salt (PHOS) injection, and non-injected control (CON). Loins in 20 sides were injected 50 min post-mortem with 4% solutions of CIT or ACE to approximately 110% of projected loin weights, and 10 PHOS-treated loins were injected at 24 h post-mortem to 106.6% with a 4.4% PHOS plus 2.2% salt solution. Although CIT increased pH ($P<0.05$), neither CIT nor ACE altered ($P>0.05$) glycolytic metabolite concentrations. The pH increase in CIT-injected muscle was most likely due to its buffering ability rather than glycolytic inhibition. Citrate improved tenderness without the detrimental effects on color or flavor found with PHOS plus salt, but neither CIT nor ACE altered glycolytic metabolites or improved firmness, wetness, or fresh visual color over CON. Poor flavor attributes of the ACE treatment will discourage its use as an ingredient for pork enhancement solutions.

(Key Words: Pork, Pre-rigor Injection, Citrate, Acetate, Phosphate.)

Introduction

Improving pork quality traits, such as tenderness, juiciness, and flavor, is a common goal in the pork industry. Great strides have been made to improve handling conditions and to alter genetics to remove stress susceptibility, but pork quality defects have been estimated to cost the industry an average of $2.13 per carcass. It is now common practice to 'enhance' pork with solutions of phosphate, salt, and various other ingredients. Although these solutions have been shown to improve tenderness and juiciness, they concomitantly induce some negative consequences in flavor and consumer acceptability.

Pork quality is highly dependant on the relationship of pH and temperature early post-mortem. Anaerobic glycolysis is responsible for pH decline in post-mortem muscle. The lack of oxygen and absence of a circulatory system from exsanguination, leads to myocellular accumulation of lactate and hydrogen ions. If glycolysis occurs at an accelerated rate, pH declines too rapidly and muscle proteins denature due to the combination of low pH and high temperature.

Citrate is recognized for its glycolysis-inhibiting properties; it inhibits the glycolytic enzyme, phosphofructokinase (PFK). This enzyme regulates the transfer of a phosphate from adenosine triphosphate (ATP) to fructose-6 phosphate (F6P), producing adenosine diphosphate (ADP) and fructose-1,6 bisphosphate (F16BP). It has been identified as a key

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regulatory enzyme of glycolysis in post-mortem muscle.

In previous research, injecting pork loins 1 h post-mortem with a solution of citrate, phosphate, and salt increased ultimate pH values and improved color, cook loss, and shear force, compared with phosphate and salt-injected controls. Sodium citrate has been used as a glycolysis inhibitor in beef muscle to improve tenderness. Sodium citrate and sodium acetate have been used to improve tenderness in beef without detrimental impact on flavor attributes.

The objective of our study was to determine the effects of pre-rigor injection of pork carcasses with sodium citrate or acetate, or post-rigor injection of phosphate plus salt, on post-mortem glycolysis, pH decline, and pork quality attributes, including display life and attributes scored by a sensory panel.

Procedures

Pigs and Treatments. Two replicates of 10 pigs were fed finishing diets containing ractopamine for at least 14 d before harvest. Pigs were weighed and assigned to pairs of similar weights. The four sides from each pair of pigs were assigned to one of four treatments: pre-rigor citrate (CIT) injection, pre-rigor acetate (ACE) injection, post-rigor phosphate plus salt injection (PHOS), and non-injected control (CON).

Harvest. Twenty hours before harvest, pigs were fasted and transported to the Kansas State University Meat Laboratory. Pairs of pigs were harvested in random order. Pigs were stunned with both an electric stunning wand and a captive bolt stunner. After stunning, pigs were exsanguinated and harvested according to normal procedures. After the carcasses were split and washed, each side was weighed.

Pre-rigor Injection. At approximately 50 min post-mortem, loins in the sides assigned to CIT and ACE treatments were injected with a 4% solution of CIT or ACE in distilled water. A hand-held injector fitted with five 10-cm injection needles was used to inject the solutions. Before injection, the skin was sliced perpendicular to the length of the loin at approximately 3-cm intervals to allow the injection needles to penetrate the skin and into the *longissimus* muscle. The loins were injected from a point beginning opposite the last lumbar vertebrae to a point immediately posterior to the scapula. The solutions were injected at room temperature; injection-solution temperature was recorded for each side to ensure uniformity. Sides were weighed again, and pump percentage was calculated. It was assumed that the loin was 20% of the total side weight, and that only the loin absorbed the solution. The estimated injection percentage of the loins injected pre-rigor was 10%.

To monitor temperature decline, a temperature logger was placed in the *longissimus* muscle of each side. A slice was made at the sirloin-loin juncture, and the temperature probe was inserted into the muscle at least 2.75 inches, at a 45-degree angle to the skin surface. After injection, a muscle sample was removed from the anterior portion of the injected *longissimus* from both sides of the carcasses. The muscle samples were cubed, quick-frozen in liquid nitrogen, packaged, temporarily stored on dry ice, and stored at –80^{o}C for pre-rigor pH and glycolytic metabolite analysis. Additional muscle samples were removed from the *longissimus* muscle of each side at 3, 6, 12, and 24 h post-mortem and frozen in liquid nitrogen as previously described. At least 1.5 inch of muscle was maintained between muscle sample locations, to minimize the effects of chilling rate on the cut surfaces.

Pre-rigor pH Analysis. Frozen muscle samples were pulverized into a powder and

stored at -80°C until analysis for pre-rigor pH and glycolytic metabolites. Duplicate 5-g samples of powdered muscle were mixed with 50 ml of a solution of iodoacetate in 150 mM potassium chloride. The mixture was covered with Parafilm and allowed to acclimate to room temperature for no less than 4 h. After acclimation, the solution was remixed, and each duplicate was read twice by using two pH probes with a portable meter.

Glycolytic Metabolites. Samples from 50 min, 3 h, and 12 h were analyzed for glucose-6 phosphate (G6P), fructose-6 phosphate (F6P), fructose-1,6 bisphosphate (F16BP), a combination of glyceraldehyde-3 phosphate and dihydroxyacetone phosphate (GAPDAP), and lactate.

Fabrication and Post-rigor Injection. At 24 h post-mortem, loins were removed from the sides; the anterior section, where the muscle samples were removed, was discarded. Loins assigned to CIT, ACE, and CON treatments were vacuum packaged and stored at 1°C. Loins assigned to post-rigor PHOS treatment were injected with a solution containing 4.4% sodium tripolyphosphate and 2.2% sodium chloride by using the hand-stitch injector used for the CIT and ACE treatments. After two rounds of PHOS injection, the loins had absorbed 6.6% of their pre-injected weight. After injection, the loins assigned to PHOS were vacuum packaged and stored overnight at 1°C. The loins were re-weighed after vacuum storage and found to retain 104.6% of their pre-injected weight.

Chop Removal, Initial Pork Color, Firmness, and Wetness. At 2 d post-mortem, loin sections were de-boned, and three 2.54-cm chops were removed from the posterior section of the *longissimus*. One chop, for sensory-panel analysis, was vacuum packaged and stored at 1°C for 8 d before freezing at –20°C. An additional chop was vacuum packaged and stored at 1°C overnight for pH and expressible moisture-analysis. The third chop was allowed to bloom for no less than 30 min and was evaluated by a three-member, trained visual panel for color, firmness, and wetness. Color was evaluated according to the official NPPC color standard cards (1 = lightest and 6 = darkest). Firmness and wetness were evaluated separately by using three-point scales (1 = softest or wettest and 3 = firmest or driest).

Display Color. Chops for visual evaluation were packaged in white foam trays with absorbent pads, over-wrapped with PVC film, and placed in an open-top display case under continuous fluorescent lighting. A trained visual panel of no fewer than six persons evaluated color each day over 7 d of display. Panelists scored each chop for color on a six-point scale (1 = extremely bright pink, 2 = bright pink, 3 = dull pink, 4 = slightly dark pink or tan, 4.5 = borderline panelist unacceptable, 5 = moderately dark pink or tan, 6 = dark pink or tan) and scored for discoloration on a seven-point scale (1 = no discoloration (0%), 2 = slight discoloration (1 to 19%), 3 = small discoloration (20 to 39%), 4 = modest discoloration (40 to 59%), 5 = moderate discoloration (60 to 79%), 6 = extensive discoloration (80 to 99%), 7 = total discoloration (100%)). The scores for each d were averaged for analysis.

Display Loss. After display, packages were weighed. Chops were removed, dabbed with a paper towel, allowed to dry for 5 min, and weighed again to calculate display loss, calculated as follows: [(pre-display weight – post-display weight)/pre-display weight] × 100.

Instrumental Color. Each day of display, a HunterLab Miniscan XE Plus spectrophotometer was used to obtain L*, a*, and b* values on the over-wrapped chops. Each chop was measured twice with a 3.2-cm aperture, a

10^o observer, and illuminant D_{65}. Readings were averaged for analysis.

Expressible Moisture. At 3 d post-mortem, chops assigned to expressible-moisture evaluation were removed from their vacuum bags. A scapel and tweezers were used to remove duplicate samples (2 to 3 g) parallel to the muscle fiber direction, from the interior of the chop. The rest of the chop was vacuum packaged and stored at 1^oC until pH analysis. Samples were weighed and placed in a 50-ml centrifuge tube fitted with one piece of Whatman No. 3 filter paper folded around one piece of Whatman No. 50 filter paper. The tubes were capped and centrifuged at 2100 rpm for 10 min. After centrifugation, samples were weighed again, and expressible moisture was calculated.

Ultimate pH Analysis. Duplicate samples (10 g each) were minced with a scalpel. Samples were placed in a filtered stomacher bag with 100 ml of distilled water and stomached for 2 min. After stomaching, pH was measured.

Evaluations by Trained Sensory Panel. Chops for analysis by a trained sensory panel were stored frozen for 3 months and thawed overnight at 4^oC. Chops were cooked to 70^oC, and temperature was monitored. After cooking, the outer connective tissue was removed, and the chops were cut into cubes and held in pre-heated double broilers. No fewer than six trained panelists were seated in an environmentally controlled room. Two cubes from each chop were served to panelists in a statistically randomized order, and a score was determined by using an 8-point scale to the nearest 0.5. Scores were determined for myofibrillar tenderness (1 = extremely tough, 8 = extremely tender), juiciness (1 = extremely dry, 8 = extremely juicy), pork flavor intensity (1 = extremely intense pork flavor, 8 = extremely bland), connective tissue amount (1 = abundant, 8 = none), overall tenderness (1 = extremely tough, 8 = extremely tender), and off-flavor intensity (1 = abundant, 8 = none).

Statistical Analysis. Muscle temperature data were analyzed as an incomplete block with repeated measures, with individual pig as the block. Pre-rigor pH and glycolytic metabolite data were analyzed in a split-plot design, with injection treatment as the whole plot and time post-mortem as the subplot. Pig was used as the block in the whole plot. Visual color, firmness, wetness, expressible moisture, and ultimate pH were analyzed in an incomplete block, with pig as the block. Visual- and instrumental-display data were analyzed in an incomplete-block design, with the repeated measure of time and pig as the block. Data from the sensory panel were analyzed in an incomplete-block design, blocking on pig and panelist. Injection treatment and time post-mortem were treated as fixed effects; pig and panelist were treated as random effects. Data were analyzed by using PROC MIXED in the Statistical Analysis System; means were separated by using the PDIFF test when $P<0.05$. For repeated-measures analysis, the Repeated Measures command was used with the autoregressive option.

Results and Discussion

Temperature. At 1 h post-mortem, *longissimus* muscles from carcasses not injected were warmer ($P<0.05$) than those from CIT- and ACE-injected carcasses, and those from ACE-injected carcasses were warmer ($P<0.05$) than those from CIT-injected carcasses (Figure 1). Nevertheless, muscle temperatures among treatments were similar ($P>0.05$) for measurements taken in 1-h increments afterwards. It is probable that the temperature of the injection solution lowered the temperature of the muscle in the first few minutes after injection, but did not affect chill rate after 1 h.

Pre-rigor pH. There was no time × treatment interaction ($P>0.05$) for pre-rigor pH (Table 1). *Longissimus* muscles from CIT-injected carcasses had the highest ($P<0.05$) pre-rigor pH values, whereas those from ACE-injected carcasses did not differ ($P>0.05$) from CON and PHOS-injected carcasses. The pH was highest ($P<0.05$) at 50 min post-mortem, and values at 3, 6, 12, and 24 h were similar ($P>0.05$), indicating that the majority of pH decline occurred before 3 h.

Glycolytic Metabolites. A time × injection treatment interaction ($P<0.05$) was found for G6P concentration (Figure 2). All four treatments resulted in similar ($P>0.05$) G6P concentrations at 50 min post-mortem. Values for G6P in CON muscles increased ($P<0.05$) with post-mortem time, and were higher ($P<0.05$) than for CIT- and ACE-injected muscles at 3 and 12 h post-mortem. In muscles designated for post-rigor PHOS injection, 12-h concentrations of G6P were higher ($P<0.05$) than those at 50 min, and 3-h concentrations were intermediate. Concentrations of G6P from *longissimus* muscles designated for PHOS injection were higher ($P<0.05$) than those from CIT-injected muscles at 3 h, but were similar to those from CIT- and ACE-injected muscles at 12 h. Concentrations of G6P from ACE- and CIT-injected *longissimus* muscles were similar ($P>0.05$) at 50 min and 3 h. The 12-h G6P concentrations were higher than 50-min and 3-h concentrations in ACE-injected muscles, but only higher than the 3-h samples in CIT-injected carcasses. No interaction existed for F6P values ($P>0.05$; Figure 3). The CON and PHOS-injected muscles had higher concentrations ($P<0.05$) of F6P than those from ACE- and CIT-injected muscles did. Concentrations of F6P were similar ($P>0.05$) at 50 min and 3 h, but were higher ($P<0.05$) at 12 h.

Glucose-6 phosphate is the precursor to F6P, which is a substrate for PFK. Successful inhibition of PFK by CIT and ACE treatments should have resulted in elevated concentrations of G6P and F6P. Nevertheless, G6P and F6P concentrations were highest ($P<0.05$) for CON and PHOS-injected treatments, indicating that CIT and ACE injection activated PFK activity, rather than inhibited it. Citrate increases the enzyme's affinity for ATP at the substrate site and activates the reaction. Reactions of rigor take place due to a drop in ATP concentration; pre-rigor CIT injection, in combination with low ATP concentrations associated with rigor, may have actually activated PFK. Although previous researchers have not observed this phenomenon in post-mortem beef muscle, pork is inherently more glycolytic than beef and goes into the rigor state at an earlier time post-mortem. It is possible that the approximately 10% addition of water diluted G6P and F6P concentrations in the ACE- and CIT-injected *longissimus* muscles, but this dilution effect was not evidenced in other metabolites.

A time × treatment interaction ($P<0.05$) was found for F16BP values (Figure 4). At 50 min post-mortem, concentrations of F16BP in samples from CIT-injected muscles were lower ($P<0.05$) than those from CON. Concentrations of F16BP from CIT-injected muscles were higher than those from ACE-injected muscles at 3 h, and those from CON and PHOS were intermediate. Levels were similar for all treatments at 3 and 12 h. For CON, PHOS-injected, and ACE-injected muscles, the 50-min concentrations were higher ($P<0.05$) than at 3 and 12 h. For CIT-injected muscles, 50-min and 3-h F16BP concentrations were similar ($P>0.05$) and greater than 12-h ($P<0.05$) concentrations, but concentrations were similar to those from CON and PHOS-injected muscles at 3 and 12 h. There was a time × treatment interaction ($P<0.05$) for GAPDAP concentrations (Figure 5). *Longissimus* muscles designated for PHOS injection had larger ($P<0.05$) GAPDAP values than those from ACE-injected muscles did at

50 min; all other treatments were similar. All treatments were similar at 3 and 12 h post-mortem. The 50-min concentrations were highest ($P<0.05$), and the 3- and 12-h concentrations were similar ($P>0.05$) for all treatments.

The product of PFK is F16BP; inhibition of PFK should have resulted in decreased concentrations of F16BP for CIT- and ACE-injected muscles. Maintenance of high concentrations of F16BP at 3 h for CIT-injected muscles could indicate that F16BP was being replenished by PFK as it was used, and that the PFK was activated rather than inhibited. The F16BP concentrations from CON, PHOS-injected, and ACE-injected muscles were not being replenished. Aldolase, the enzyme that cleaves F16BP to form GAP and DAP, operates continuously in the presence of substrate, F16BP. Therefore, GAPDAP concentrations indicate PFK activity. Our data indicate that GAPDAP concentrations were not being replenished by PFK for any treatment.

There was no interaction ($P>0.05$) for lactate concentrations (Figure 6). Muscles that were injected with CIT had lower ($P<0.05$) lactate concentrations than those designated for 24-h PHOS injection did, but CON and ACE-injected muscles were not different ($P > 0.05$) in lactate concentration than those from CIT- and PHOS-injected muscles. Lactate concentrations increased ($P<0.05$) as post-mortem time increased; and this was expected because lactate accumulates with time.

Glycolytic metabolite data indicate that CIT and ACE were ineffective as glycolytic inhibitors when injected into pork muscle, even though CIT-injected muscles had higher pre-rigor pH. The CIT solution likely increased muscle pH due to its buffering capacity and multiple negative charges on the citrate ion. Others have found that pre-rigor injection of beef muscles with CIT inhibited glycolysis, as evidenced by increased muscle pH and glycogen levels. Glycogen levels were not measured in our study. In other research, PFK was thought to be inactivated within 20 min post-mortem and not affect pork quality attributes. Nevertheless, others have stated that PFK is the main rate-limiting enzyme in post-mortem muscle glycolysis. Our research indicated that PFK was still active in the muscle after 50 min post-mortem when the CIT and ACE solutions were introduced into the muscle system, because the glycolytic metabolites were still changing after 50 min post-mortem. Concentrations of ATP may have been at a non-saturated state at an earlier time post-mortem, and PFK may have been activated by CIT injection, as discussed earlier. In past research, CIT has been found to be inhibitory in pork, but that injection solution included phosphate and salt, which would have drastically affected muscle pH. Enzyme activities are altered at higher pH. Furthermore, the increase in ionic strength due to the phosphate and salt may have affected the PFK activity.

Pork Quality Attributes. Mean values for visual color, firmness, and wetness, as well as expressible moisture, ultimate pH, and display loss, are presented in Table 2. According to visual panelists, chops from ACE- and CIT-injected carcasses were less firm ($P<0.05$) and wetter ($P<0.05$) than those from CON and PHOS-injected carcasses. These inferiorities were not surprising because the CIT- and ACE-injection treatments added approximately 10% water to the *longissimus* muscle. Chops from PHOS-injected carcasses also had added water, but the percentage was lower than for CIT- and ACE-injected carcasses, and PHOS injection greatly increased ($P<0.05$) muscle pH. Chops from PHOS-injected carcasses had the highest ($P<0.05$) ultimate pH values, and chops from CIT-injected carcasses had higher ($P<0.05$) ultimate pH values than those from CON or ACE-injected carcasses. Chops from CIT- and ACE-injected carcasses

had greater (P<0.05) display losses than those from PHOS and CON treatments had. Chops from PHOS-injected carcasses had the least (P<0.05) display loss. Visual color and expressible moisture were not affected by injection treatment.

Display Evaluations. Visual color scores increased (P<0.05) throughout display for all four treatments, indicating a deterioration of color during display (Figure 7). Chops from PHOS-injected carcasses had the highest (darkest; P<0.05) visual scores each day of display, compared with those of other treatments. Chops from PHOS-injected carcasses were considered unacceptable (color scores greater than 4.5) by the panelists after 5 d of display; no other treatment reached that mark. Chops from ACE- and CIT-injected carcasses were similar (P>0.05) to those from CON carcasses each day of display. Although discoloration scores for chops from PHOS-injected carcasses were similar (P>0.05) to those from CON carcasses for the first 2 d of display, they were higher (P<0.05) than scores from other treatments throughout the rest of the display period (Figure 8). Chops from ACE-injected carcasses were similar (P>0.05) to those from CON carcasses in discoloration scores throughout display. For the first 6 d of display, chops from CIT-injected carcasses were similar (P>0.05) to those from CON carcasses, but on the final day of display, the discoloration scores were higher (P<0.05) for chops from CIT-injected carcasses than for chops from CON carcasses.

Chops from PHOS-injected loins were darkest (smallest L* values; P<0.05) throughout display. Although chops from ACE-injected carcasses were similar (P>0.05) to those from CON carcasses for the first 2 d of display, they were lighter (P<0.05) than those from CON for the last 5 d of display (Figure 9). Chops from CIT-injected carcasses were similar (P>0.05) to those from CON carcasses in L* value throughout the display period. Chops from CIT-injected carcasses did not change (P>0.05) throughout display, whereas L* values for chops from PHOS-injected and CON carcasses peaked (P<0.05) after 1 d of display.

Chops from PHOS-injected carcasses were less red (smaller a* value; P<0.05) than those from CON and ACE-injected carcasses each day of display (Figure 10). Chops from CIT-injected carcasses were similar (P>0.05) to those from PHOS-injected carcasses on d 0 and the final 2 d of display. Chops from CON carcasses were similar to those from ACE-injected carcasses on the first 2 d of display, and similar to chops from CIT-injected carcasses after 1 d, but they had the largest a* values (P<0.05) the final 5 d of display. Chops from ACE-injected carcasses were redder (P<0.05) than those from CIT-injected carcasses on d 0 and 2, but they were similar (P>0.05) throughout the rest of display. Previous research found that pork chops from CIT-injected loins had larger a* values than phosphate-injected controls did, but that CIT treatment also included phosphate.

Chops from PHOS-injected carcasses had the smallest b* values (least yellow; P<0.05) throughout display (Figure 11); chops from CIT- and ACE-injected carcasses were similar (P>0.05) to those from CON carcasses throughout display. Chops from PHOS-injected carcasses had the smallest b* values on d 0, but values for b* did not notably change (P>0.05) over time for any of the other treatments. Previous research in beef found that CIT-injected samples were less yellow than controls, whereas ACE-injected samples were similar to controls.

Sensory Attributes. Values for attributes evaluated by the trained sensory panel are displayed in Table 3. Control chops were toughest (P<0.05), chops from PHOS-injected car-

casses were most tender ($P<0.05$), and the treatments injected pre-rigor were intermediate in both myofibrillar and overall tenderness. Control chops also had the lowest ($P<0.05$) connective tissue scores, indicating a higher percentage of detectable connective tissue. The increase in tenderness of chops from PHOS-injected carcasses may have been partly due to the swelling of myofibrils caused by phosphate and salt and to the dilution of the proteins by the injection solutions. In other research, chops from CIT-injected loins had lower shear force values than CON.

Chops from PHOS-injected carcasses were also juiciest ($P<0.05$), whereas chops from CIT- and ACE-injected carcasses were similar ($P>0.05$) to those from CON carcasses. The increase in ultimate pH, resulting in improved water holding capacity, by the PHOS injection likely was responsible for the improved juiciness of that treatment.

Chops from CON and CIT-injected carcasses had higher ($P<0.05$) pork flavor intensity scores and less incidence ($P<0.05$) of off-flavors than those from PHOS- and ACE-injected carcasses. It is likely that the off-flavors associated with the PHOS- and ACE-injected treatments masked the pork flavor of the chops. The most common off-flavor descriptor for chops from PHOS-injected carcasses was salty. Other off-flavor descriptors of soapy, metallic, rancid, and acidic, were also used to describe the chops from PHOS-injected carcasses. Chops from ACE-injected carcasses were most commonly described as sweet or sugary, as well as acidic, lemony, or vinegary. Other, infrequent off-flavor descriptors for chops from ACE-injected carcasses included chemical, soapy, salty, metallic, cleaner fluid, and Tabasco. Although chops from CIT-injected and CON carcasses had less incidence ($P<0.05$) of off-flavors than ACE- and PHOS-injected carcasses had, some descriptors were provided. Chops from CIT-injected carcasses were infrequently described as acidic, metallic, salty, bitter, and rancid, whereas those from CON carcasses were described as acidic, bitter, salty, and metallic.

Glycolytic-metabolite data indicated that the increase in pH in CIT-injected muscle was not due to an inhibition of glycolysis post-mortem. The pH increase in the muscle was likely due to the relatively high pH of the citrate solution. The very glycolytic conditions of pork muscle and low ATP levels during rigor may have overwhelmed citrate's ability to inhibit glycolysis. The data reinforced the evidence for rate-limiting effects of PFK in post-mortem muscle.

Although pre-rigor CIT injection increased pH and improved tenderness, compared with CON, visual firmness and wetness were decreased with CIT injection. Chops from CIT-injected carcasses were similar to those from CON carcasses in pork-flavor intensity, and there were no excessive off-flavors. Perhaps using CIT in conjunction with a phosphate and salt solution would allow for improved muscle water-holding capacity, and the water-soluble CIT in the injection-solution would be more accessible to PFK.

Chops from ACE-injected carcasses were superior to those from CON carcasses in tenderness, but glycolytic-metabolite and pH data indicated that ACE did not inhibit post-mortem glycolysis. Furthermore, the decreased pork-flavor intensity and objectionable off-flavors of ACE injection likely will discourage use of this compound at this concentration in injection solutions for fresh meat.

Table 1. Mean Values for Pre-rigor pH of *Longissimus* Muscle From Carcasses Injected 50 min Post-mortem with Sodium Citrate or Sodium Acetate, Non-Injected Control Carcasses, and Carcasses Designated for 24 h Injection with Phosphate + Salt

	Pre-rigor Injection		Non-injected	Injected at 24 h	
Time	Acetate	Citrate	Control	Phosphate + Salt	Mean[c]
50 min	5.87	5.96	6.00	5.90	5.93[a]
3 h	5.45	5.58	5.49	5.49	5.51[b]
6 h	5.52	5.56	5.49	5.47	5.51[b]
12 h	5.49	5.52	5.46	5.44	5.48[b]
24 h	5.50	5.55	5.47	5.48	5.50[b]
Mean	5.57[b]	5.63[a]	5.58[b]	5.56[b]	

[ab]Means for times and treatments lacking common superscript letters differ ($P<0.05$).
[c]Standard error for all means = 0.02.

Table 2. Visual Evaluations, Expressible Moisture, Ultimate pH, and Display Loss Measurements of *Longissimus* Chops from Pork Carcasses Injected 50 min Post Mortem with Sodium Acetate or Sodium Citrate, Non-injected Controls, or 24 h Injection with Phosphate + Salt

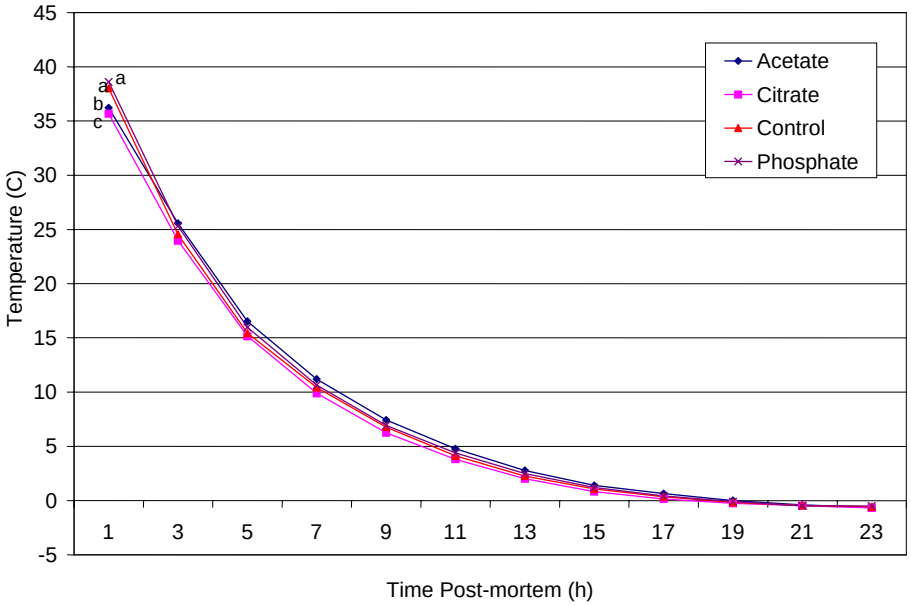
	Pre-rigor Injection		Non-injected	Injected at 24 h	
Item	Acetate	Citrate	Control	Phosphate + Salt	S.E.[c]
Color[a]	3.26	3.16	4.48	4.33	0.53
Firmness[b]	1.95[y]	2.14[y]	2.36[z]	2.49[z]	0.15
Wetness[b]	1.93[y]	1.96[y]	2.46[z]	2.41[z]	0.18
Expressible moisture	18.87	20.01	20.14	18.56	1.35
Ultimate pH	5.51[x]	5.63[y]	5.48[x]	5.99[z]	0.03
Display loss	9.36[z]	9.71[z]	7.45[y]	4.73[x]	0.58

[a]Color was evaluated on a 6-point scale according to official color standards from the National Pork Producers Council (1 = lightest and 6 = darkest).
[b]Firmness and wetness were evaluated separately on 3-point scales (1 = softest and wettest and 3 = firmest and driest).
[c]Standard error.
[xyz]Means, within a row, lacking common superscript letters differ ($P<0.05$).

Table 3. Mean Values and Standard Errors for Trained Sensory Panel Traits for *Longissimus* Chops from Carcasses Injected with Sodium Citrate or Sodium Acetate 50 min Postmortem, Non-injected Controls, and Injection with Phosphate + Salt at 24 h

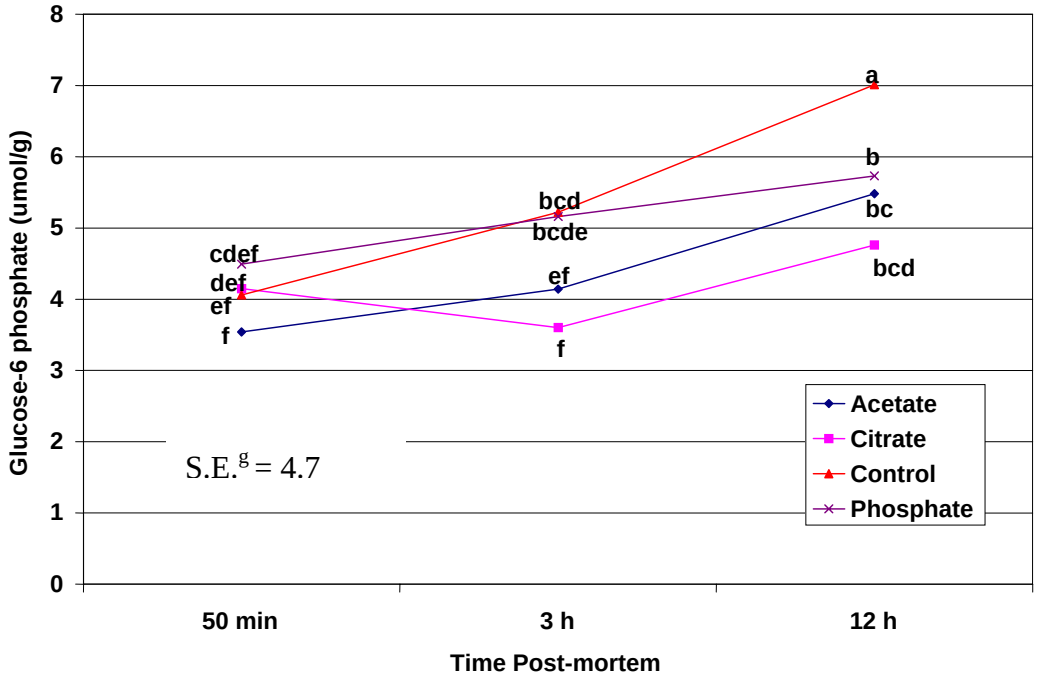
	Pre-rigor Injection		Non-injected	Injected at 24 h	
Item	Acetate	Citrate	Control	Phosphate + Salt	S.E.[f]
Myofibrillar tenderness[a]	5.78[y]	5.83[y]	4.81[z]	6.34[x]	0.19
Juiciness[b]	5.12[z]	4.99[z]	4.83[z]	6.17[y]	0.15
Pork flavor intensity[c]	4.56[z]	5.22[y]	5.19[y]	4.83[z]	0.22
Off flavor[d]	5.42[z]	7.52[y]	7.09[y]	5.30[z]	0.24
Connective tissue[e]	7.34[y]	7.38[y]	6.94[z]	7.42[y]	0.14
Overall tenderness	6.02[y]	6.13[y]	5.10[z]	6.61[x]	0.18

[a]Myofibrillar tenderness and overall tenderness were evaluated on an 8-point scale (1 = extremely tough and 8 = extremely tender).
[b]Juiciness was evaluated on an 8-point scale (1 = extremely dry and 8 = extremely juicy).
[c]Pork flavor intensity was evaluated on an 8-point scale (1 = extremely bland and 8 = extremely intense pork flavor).
[d]Off flavor was evaluated on an 8-point scale (1 = abundant and 8 = none).
[e]Connective tissue amount was evaluated on an 8-point scale (1 = abundant and 8 = none).
[f]Standard error.
[xyz]Means, within a row, lacking common superscript letters differ ($P<0.05$).



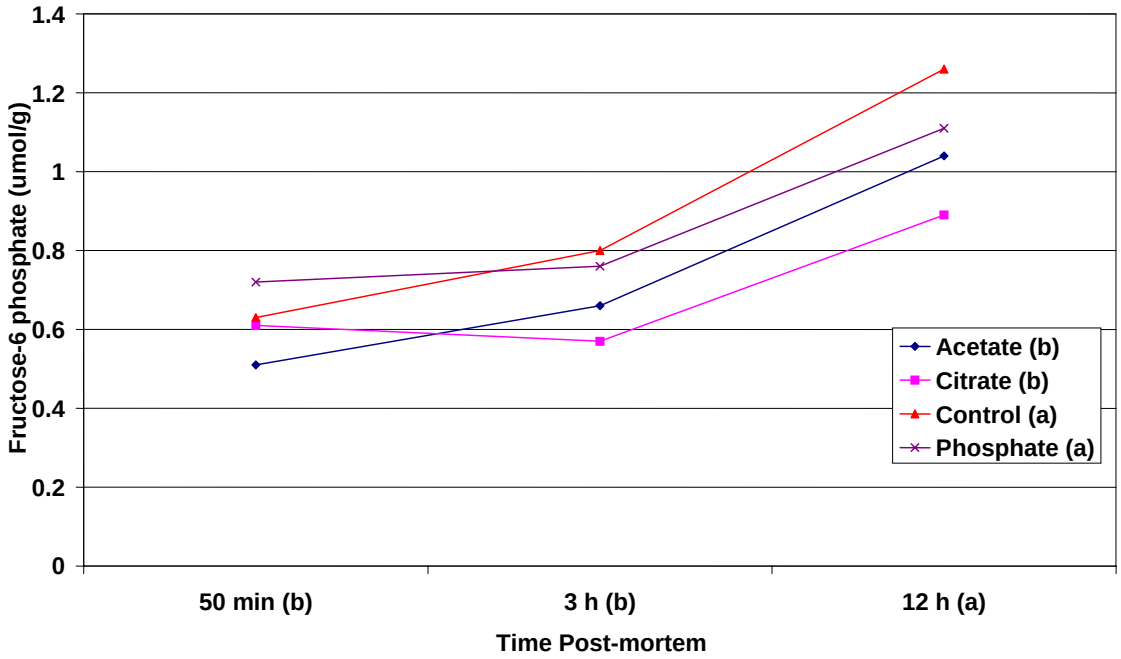
[abc] Data points, for the first temperature reading, lacking common superscript letters differ ($P<0.05$).

Figure 1. Mean *Longissimus* muscle Temperatures of Carcasses Injected at 50 min Post-mortem with Acetate or Citrate, Non-injected Controls, and Carcasses Designated for Injection with Phosphate + Salt at 24 h.



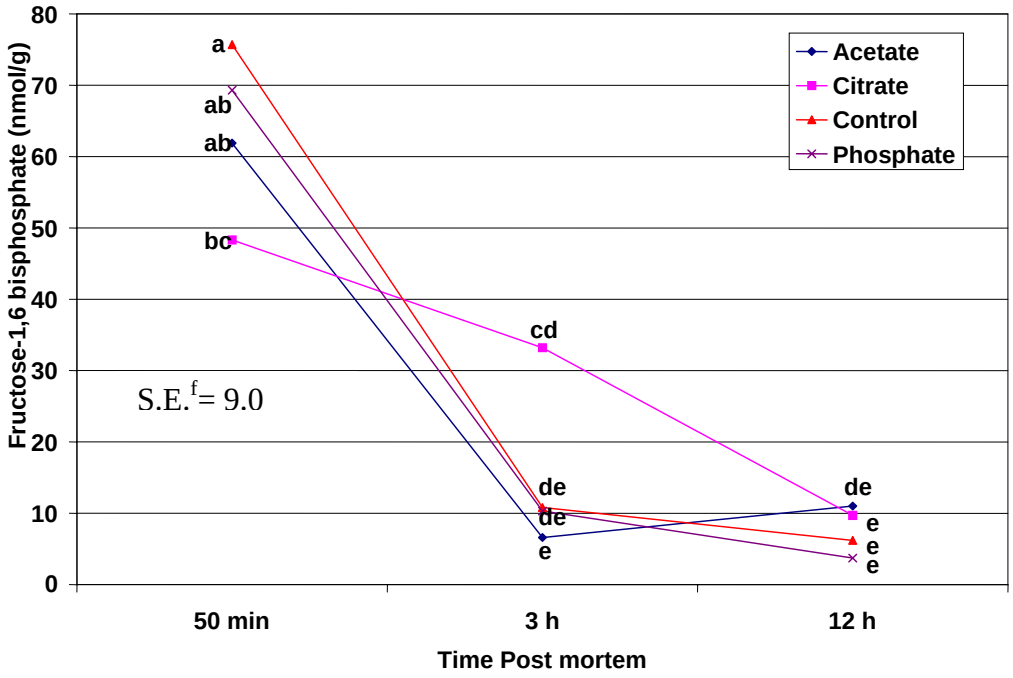
[abcdef]Means lacking common superscript letters differ ($P<0.05$).
[g]Largest interaction mean standard error.

Figure 2. Mean Concentrations of Glucose-6 Phosphate in *Longissimus* Muscle at 50 min and 3 and 12 h Post-mortem from Carcasses Injected at 50 min Post-mortem with Acetate or Citrate, Non-injected Controls, and Carcasses Designated for Injection with Phosphate + Salt at 24 h.



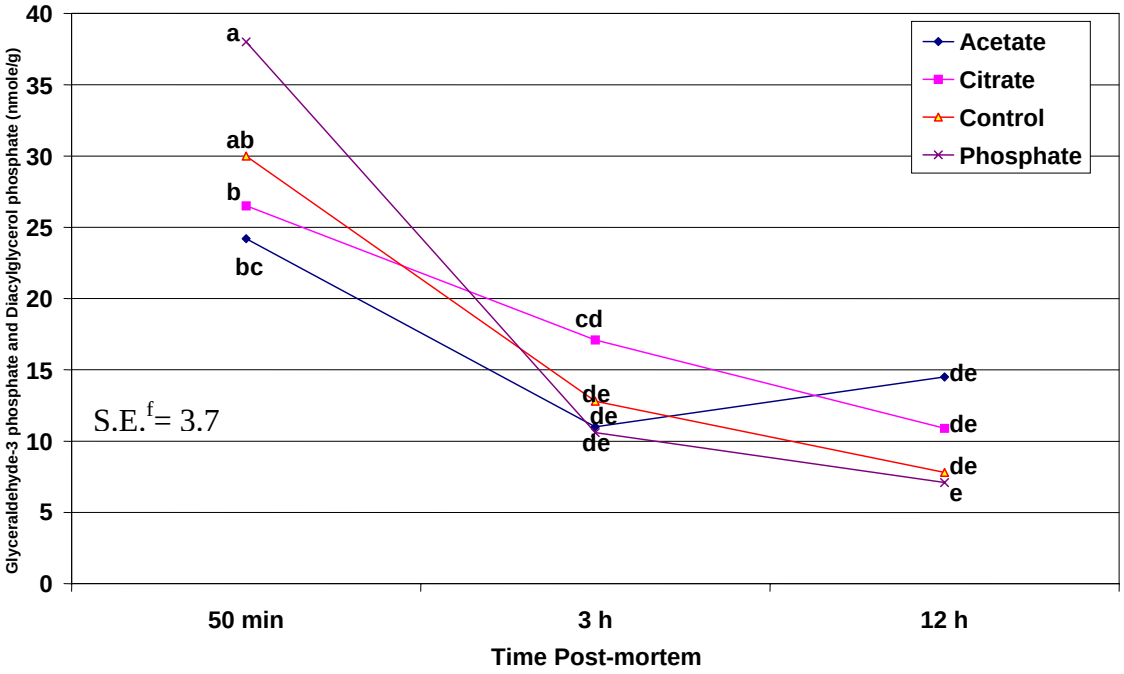
[ab]Main effect means lacking common superscript letters (in parenthesis) differ ($P<0.05$),
Standard error for ante mortem treatment main effects = 0.06,
Standard error for time main effects = 0.05

Figure 3. Mean Concentrations of Fructose-6 Phosphate in *Longissimus* Muscle at 50 min and 3 and 12 h Post-mortem from Carcasses Injected at 50 min Postmortem with Acetate or Citrate, Non-injected Controls, and Carcasses Designated for Injection with Phosphate + Salt at 24 h.



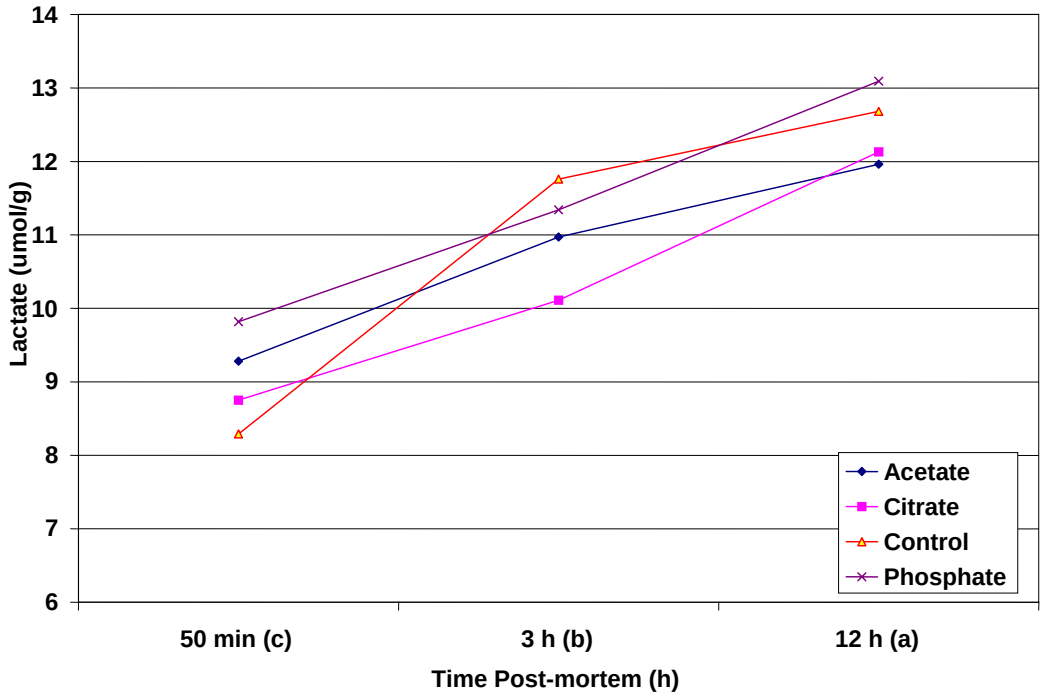
[abcde]Means lacking common superscript letters differ ($P < 0.05$).
[f]Largest standard error for interaction means.

Figure 4. Mean Concentrations of Fructose-1,6 Bisphosphate in *Longissimus* Muscle at 50 min and 3 and 12 h Post-mortem from Carcasses Injected at 50 min Post-mortem with Acetate or Citrate, Non-injected Controls, and Carcasses Designated for Injection with Phosphate + Salt at 24 h.



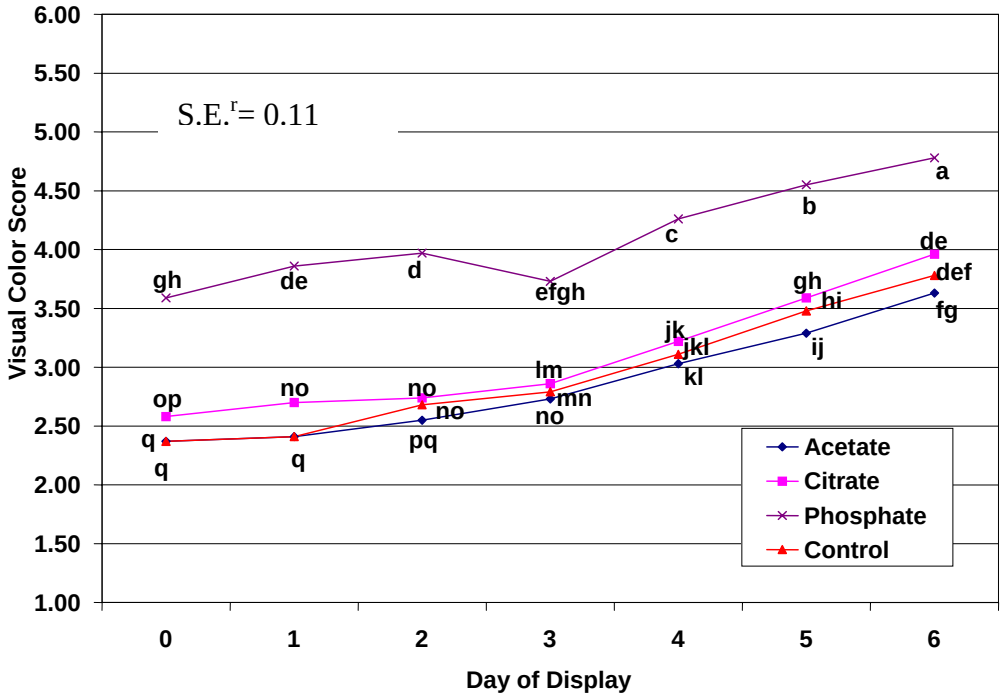
[abcde]Means lacking common superscript letters differ ($P < 0.05$).
[f]Largest standard error for interaction means.

Figure 5. Mean Concentrations for a Combination of Glyceraldehyde-3 Phosphate and Dihydroxyacetone Phosphate in *Longissimus* Muscle at 50 min and 3 and 12 h Post-mortem from Carcasses Injected at 50 min Post-mortem with Acetate or Citrate, Non-injected Controls, and Carcasses Designated for Injection with Phosphate + Salt at 24 h.



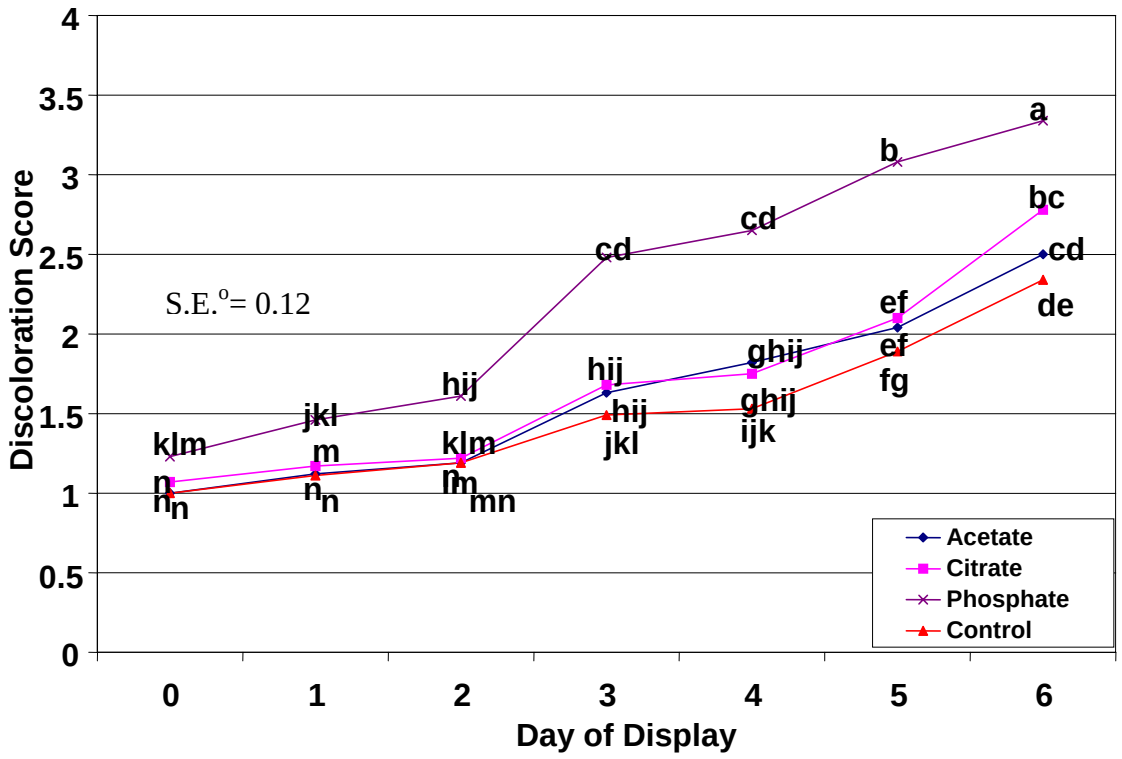
[abc]Main effect means lacking common superscript letters (in parenthesis) differ ($P<0.05$),
Standard error for ante-mortem treatment main effect = 0.30,
Standard error for time main effect = 0.26.

Figure 6. Mean Concentrations of Lactate in *Longissimus* Muscle at 50 min and 3 and 12 h Post-mortem from Carcasses Injected at 50 min Post-mortem with Acetate or Citrate, Non-injected Controls, and Carcasses Designated for Injection with Phosphate + Salt at 24 h.



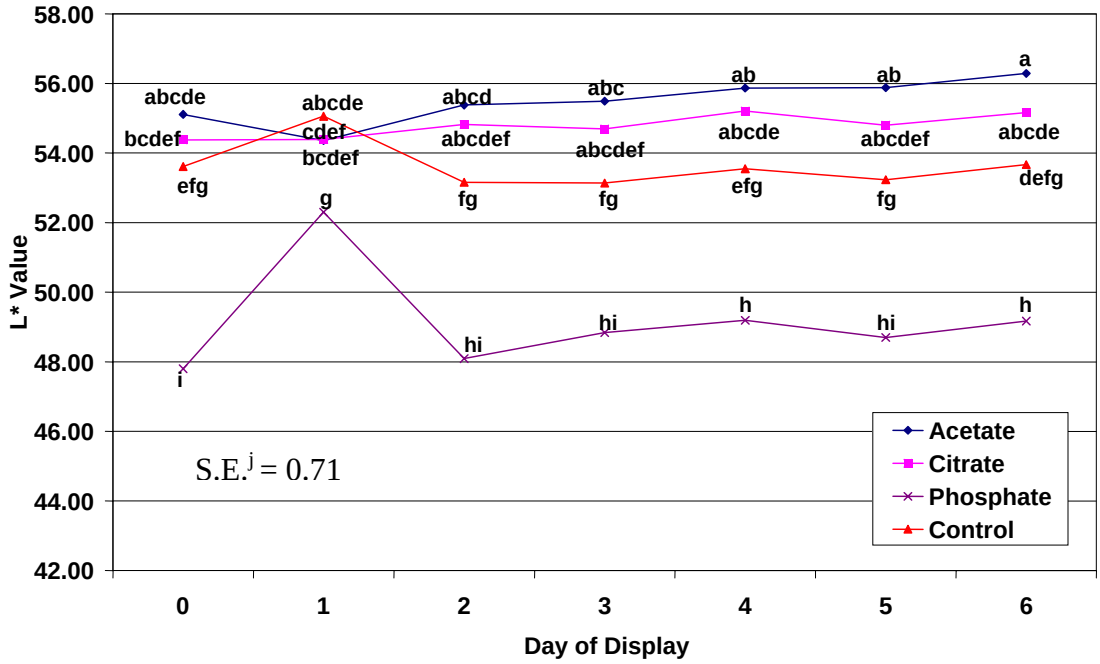
[a-q]Means lacking common superscript letters differ ($P<0.05$).
[r]Standard error of the interaction means.

Figure 7. Visual Color Scores for *Longissimus* Chops from Acetate or Citrate Injection at 50 min Post-mortem, Phosphate plus Salt Injection at 24 h, and Non-injected Controls over 7 d of Display.



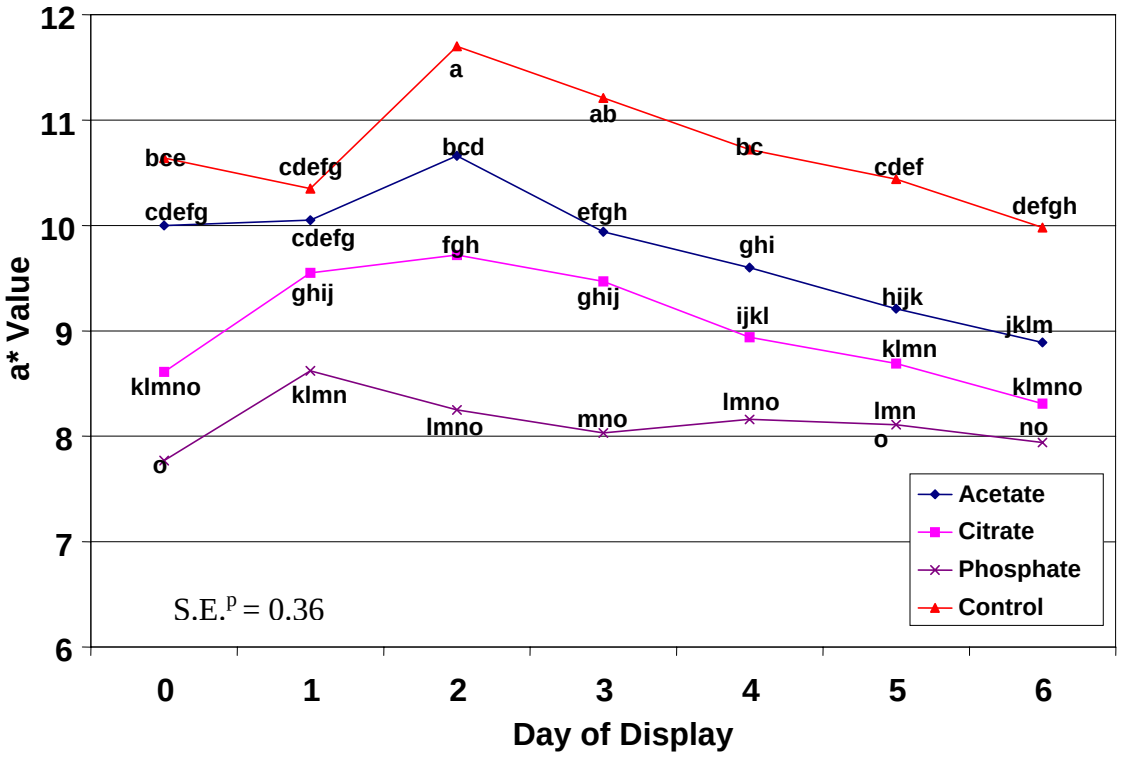
[a-n]Means lacking a common superscript letter differ ($P<0.05$).
[o]Standard error of the interaction means.

Figure 8. Discoloration Scores for *Longissimus* Chops from Acetate or Citrate Injection at 50 min Post-mortem, Phosphate plus Salt Injection at 24 h, and Non-injected Controls over 7 d of Display.



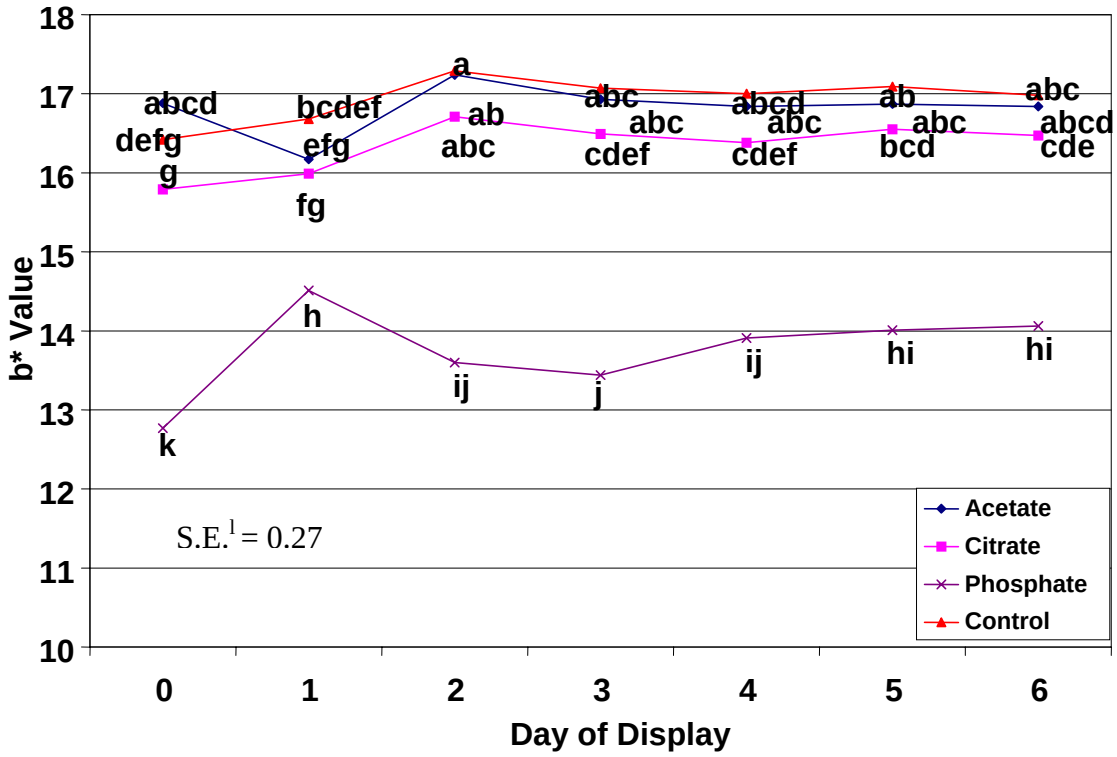
[a-i]Means lacking common a superscript letter differ ($P<0.05$).
[j]Standard error of the interaction means.

Figure 9. Values for L* for Chops from Acetate or Citrate Injection at 50 min Post-mortem, Phosphate plus Salt Injection at 24 h, and Non-injected Controls over 7 d of Display.



[a-o]Means lacking common a superscript letter differ ($P<0.05$).
[p]Standard error of the interactions means.

Figure 10. Values for a* for *Longissimus* Chops from Acetate or Citrate Injection at 50 min Post-mortem, Phosphate plus Salt Injection at 24 h, and Non-injected Controls over 7 d of Display.



[a-k]Means lacking common a superscript letter differ ($P<0.05$).
[l]Standard error of the interaction means.

Figure 11. Values for b* for *Longissimus* Chops from Acetate or Citrate Injection at 50 min Post-mortem, Phosphate plus Salt Injection at 24 h, and Non-injected Controls over 7 d of Display