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Shelf life characteristics of enhanced modified atmosphere packaged pork

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Abstract

The objective of these studies was to identify a chemical indicator for predicting performance of enhanced pork during storage, then select raw materials with the potential for color and shelf life instability and enhance them with antimicrobial solutions in an attempt to overcome their initial deficits. The purpose of Study 1 was to evaluate the use of pH, glycolytic potential, and glucose levels in the drip to assess shelf life characteristics of modified atmosphere packaged (MAP), enhanced pork loin chops during display. Chops from higher pH carcasses had higher color scores and aerobic plate counts, and less discoloration. Study 2 evaluated shelf life characteristics of chops derived from high pH (>5.75) raw materials enhanced with solutions containing salt and phosphate, and/or lactate and/or acetate. Overall, pH was the best indicator of color and microbiological stability. Raw materials with high ultimate pH were least stable. MAP chops derived from high pH raw materials and enhanced with a sodium acetate-containing solutions had better color and microbiological shelf life than those enhanced with other solutions.

Keywords: pH; Glycolytic potential; Color; Pork; Shelf life

1. Introduction

Muscle color, at the point of purchase, is an indicator of freshness and anticipated palatability for the consumer (Brewer, 2002; Brewer, Jensen, Prestat, Zhu, & McKeith, 2002; Jeremiah, 1982). Today's meat industry has a limited understanding of the factors creating variation in the shelf life of modified atmosphere packaged (MAP) products. Product color is a known obstacle for shelf life extension (Ernst, 1980).

Modified atmosphere packaging uses a combination of specific gases (O_2, CO_2, N_2), which can enhance color and shelf life of retail meat products (Jeremiah, 2001). Most aerobic bacteria are inhibited by CO_2 concentrations of 10% or higher, while obligate anaerobic bacteria are inhibited by the presence of even small amounts of oxygen (Ray, 2001). Gill (1991) stressed that while ~20% CO_2 does retard the growth of aerobic spoilage bacteria, temperature control is still critical. High O_2 (80%), low CO_2 (20%) is a common mix used in today's case ready products. The high oxygen concentration allows for formation of oxymyoglobin creating the more desirable pink/red color of fresh pork (Gill, 1991), while CO_2 suppresses of spoilage microorganisms (Gill & Molin, 1991). Maintaining color has become as important as improving microbial shelf life to the retailer.

Modified atmosphere packaged loin chops in retail display have a retail display life of 14 d. However, there is a significant amount of shelf life variation among individual packages. A variety of approaches to shelf life extension including enhancement with antimicrobial, organic acid solutions have been evaluated in an effort to create a more desirable, longer lasting product (Jensen et al., 2002).

Enhancement, injection of a brine solution, has been successful in increasing tenderness and juiciness in both beef and pork. Currently, a brine solution containing

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salt, phosphate, and other flavorings has been the choice for pork enhancement. Phosphate increases both pH and water holding capacity (Jones, Carr, & McKeith, 1987). Unfortunately, the pH increase creates a more desirable environment for microbial growth (Jeremiah & Gibson, 2001). The anti-microbial effects of lactic and acetic acid salts in meat products are well documented (De Wit & Rombouts, 1990; Jensen et al., 2002). These salts have been shown to be antimicrobial in neutral culture media (De Wit & Rombouts, 1990; Ita & Hutkins, 1991), in pork (Jensen et al., 2002) and in beef (Robbins et al., 2002). The USDA has approved the use of sodium and/or potassium lactate in fresh meat products up to 4.8%, and sodium acetate up to 0.25% (9 CRF 424.21).

While altering the current enhancement solution formulation, and/or modifying the atmosphere of the package may increase pork shelf life, preselection of raw materials for potential color and microbiological stability may provide an additional opportunity to increase finished product quality. Only after understanding the role that raw materials play in shelf life can we move on to modification of enhancement solutions and atmospheres to optimize the finished product.

The purposes of these studies were (1) to evaluate the use of pH, glycolytic potential (GP), and glucose levels in the drip for assessing specific shelf life characteristics including aerobic plate count (APC), color, and discoloration of enhanced, MAP pork loin chops, and (2) to evaluate the effects of potassium lactate and/or sodium acetate on enhanced chops derived from raw materials of higher postmortem pH (>5.75) in an attempt to decrease microbial growth while maintaining color.

2. Materials and methods

2.1. Study 1

2.1.1. Study 1 – sample collection and display

Boneless center-cut pork loins ($n = 60$), from pigs of known similar genetics, were selected from the boning line in a commercial plant (Smithfield Packing, Smithfield, VA) based on ultimate pH. The pH was determined in the center of the *longissimus* with a pH star probe (SFK Technologies Inc., Cedar Rapids, IA.) calibrated against pH 4.0 and 7.0 buffers. Two chops (2.5 cm) were removed from the center of the *longissimus* for drip loss, and determination of glucose concentration, and GP. Loins were then pumped to a target of 110% over initial weight with an enhancement solution to produce a final concentration of 0.25% salt (Morton, Chesapeake, VA), 0.5% phosphate (Astaris, St. Louis, MO), 0.05% pork stock (Proliant, Westminster, MD) and 3.0% potassium lactate (Trumark Inc., Linden NJ). Loins were sliced (1.25 cm) into chops and packaged, 4 chops/loin/package, 5 packages/loin. Packages approved for MAP use were sealed containing 80% oxygen and 20% carbon dioxide then transported to the Meat Science Laboratory at the University of Illinois for further data collection. Packages were held in a master pack cardboard box at 4 °C with no exposure to light until 48 h before scheduled evaluation day. Packages were placed in a coffin-style retail case and held at 4 °C with exposure to fluorescent light (GE warm white, 3013 lux) for 48 h prior to evaluation. One package from each loin was evaluated for discoloration, color, and APC on each evaluation day (6, 12, 15, and 18).

2.1.2. Study 1 – drip loss

Chops for drip loss determination were taken from the loin section directly posterior to the end of the *spinalis dorsi*. Chops were weighed, suspended on a fishhook line and allowed to drip in a Whirlpack bag for 24 h at 4 °C. Samples were reweighed and percent drip was calculated as

$$\text{Drip loss } (\%) = \left([\text{initial wt} - \text{final wt}]/\text{initial wt}\right) \times 100\%.$$

2.1.3. Study 1 – glucose content determination

Glucose content was determined with a Glucometer Dex2 Blood Glucose Meter (Bayer Corporation, Elkhart, IN) according to manufacturers instructions on drip collected for drip loss determination. Results are reported as mg glucose/dl of drip.

2.1.4. Study 1 – glycolytic potential

Postmortem glycolytic potential was determined as described by Miller, Ellis, Sutton, McKeith, and Wilson (2000) on a 3-g sample from the *longissimus* obtained from the chop used for drip loss. Cold 3 N perchloric acid was added at five times the sample weight and homogenized. Duplicate aliquots (200 μl) were pipeted into 1.5 ml microcentrifuge tubes. Amyloglucosidase (1 ml of 1 g protein/ml, 0.2 M acetate buffer, pH 4.8; A-1602 Sigma Chemical Co., St. Louis, MO) was immediately added followed by 20 μl of 5.4 N KOH and vortexed. Samples were then incubated for 2 h at 37 °C and shaken every 20 min. Samples were cooled (10 min) in an ice bath, then cold 3 N perchloric acid (100 μl) was added. Samples were vortexed, allowed to settle for 10 min at 2 °C, then centrifuged (7000*g*, 5 min) and stored at 2 °C.

One milliliter ATP/NADP/glucose-6-phosphate (G8289 Sigma Aldrich, St. Louis, MO) solution was pipeted into 1.5 ml microcentrifuge tubes. Sample (50 μl) and hexokinase (50 μl, Type C-130, Sigma Chemical Co., St. Louis, MO) was added, and solution was vortexed. A blank was prepared using 1 ml APT/NADP/glucose-6-phosphate solution and 5 μl hexokinase. Absorbance was determined spectrophotometrically (Beckman DU 640 spectrophotometer, Fullerton, CA) against the blank at 340 nm.

Lactate solution was prepared containing 0.01 g NAD, 2 ml glycine buffer (826-3 Sigma Diagnostics, St. Louis, MO), 4 ml deionized water, and 0.1 ml lactate dehydrogenase (No 826-6 Sigma Chemical Co., St. Louis, MO). In 15 ml tubes, 2.9 ml of lactate solution and 100 μl of sample were vortexed. A blank was prepared from 100 μl 3 N perchloric and 2.9 ml lactate solution. Samples and blanks were incubated for 15 min at 37 °C and absorbance was determined at 340 nm. GP was calculated based on equations of Monin and Sellier (1985)

$$\text{Glycolytic potential} = 2[\text{glycogen} + \text{glucose} + \text{glucose-6-phosphate}] + [\text{lactate}].$$

2.1.5. Study 1 – color and discoloration

A six-member sensory panel with experience in pork product color evaluation was trained in the use of a 15 cm scale with numerical anchors every 3 cm. The NPPC color scale (1991) points 1–6 were used for visual color anchor points. Standards developed by Ohene-Adjai, Ellis, McKeith, and Brewer (2003) were used to evaluate percent discoloration (1 = 0% discoloration, 6 = 80–100% discolored). Chop color was evaluated in the packages against a white background under fluorescent light (GE warm white, 3013 lux) on days 6, 12, 15, and 18.

2.1.6. Study 1 – aerobic plate count

Using a sterile template, a 5 × 5 cm area of one chop/package/loin/evaluation day was swabbed with a sterile cotton swab (Fisher Scientific, Pittsburgh, PA). The swab was placed into a 25 ml test tube containing 10 ml of sterile 0.1% Peptone water (Bacto Peptone, Difco Laboratories, Detroit, MI) and vortexed. Standard dilutions (1 ml/9 ml) were spread plated (0.1 ml) on sterile, prepoured nutrient agar plates (Bacto Nutrient Agar, Becton–Dickinson Microbiology Systems, Sparks, MD) then incubated at 25 °C for 48 h. Plates with 25–250 colonies were counted. APC are reported as log[CFU/cm^2].

2.1.7. Study 1 – statistical analysis

All data were analyzed using the mixed model procedure (SAS, 2000). Data were subjected to two-way analysis of variance for main effects (time and group within pH, GP and glucose content) and interactions. Effects were considered significant at $P < 0.05$. Because no significant interactions existed, only main effects were separated using probability of difference.

2.2. Study 2

Paired, boneless center-cut pork loins ($n = 15$), from pigs of known similar genetics, were preselected from carcasses with ultimate pH > 5.75, determined as previously described. Loins were deboned and blade sections removed leaving only the intact *longissimus*. Loins were then cut across the *longissimus* to create four identical center-cut loin sections which were randomly assigned to one of four enhancement treatments: sp: salt + phosphate; spl: salt + phosphate + potassium lactate; spa: salt + phosphate + sodium acetate; spla: salt + phosphate + potassium lactate + sodium acetate. Loins were pumped to a target of 110% to final concentrations of 0.25% salt (Morton, Chesapeake, VA), 0.5% phosphate (Astaris, St. Louis, MO), and/or 0% or 4.0% potassium lactate (Trumark Inc., Linden NJ), and/or 0% or 0.25% sodium acetate (Trumark Inc., Linden NJ) then sliced into 1.25 cm chops. Four MAP packages of three chop/package were created from each loin. One set of packages was evaluated on the day of manufacture (day 0) for initial APC only. Three packages/loin/treatment group were transported to the University of Illinois for further data collection and displayed as previously described. One package/loin/treatment group was evaluated for visual color, discoloration, and APC after 14, 21, and 28 days as previously described. Data were treated as a 4 (enhancement solutions) by 4 (display times) factorial design and analyzed using the mixed model procedure (SAS, 2000). Main effects and interactions were considered significant at $P < 0.05$. If no significant enhancement × time interactions occurred, means for main effects only are presented. Means were separated using probability of difference.

3. Results

3.1. Study 1

3.1.1. Study 1 – pH

The pH of samples in Study 1 ranged from 5.13 to 6.45 (data not shown). Loins were grouped according to pH: group one had pH < 5.45 ($n = 16$), group two had pH values between 5.46 and 5.64 ($n = 16$), group three had pH values between 5.65 and 5.80 ($n = 15$), and group four had pH values > 5.80 ($n = 13$).

The initial pH of loins had a significant ($p < 0.05$) effect on color of chops in display (Table 1). On day 6, loins in the lower pH groups (<5.8) had lower color scores than those in the higher pH group. Color scores of loins with higher initial pH (>5.65) decreased ($p < 0.05$) over the display period while those with lower initial pH did not. These findings are consistent with those of Ockerman and Cahill (1977) and Lawrie (1985) who reported that color was significantly affected by pH. Brewer, Lan, and McKeith (1998) reported that hue angle (red color) of vacuum packaged pale, soft and exudative (PSE) pork decreased more than did that of normal or DFD pork during refrigerated storage

Table 1
Color[1] of pork loin chops in various pH, glucose content and glycolytic potential groups

	Days			
	6	12	15	18
pH Group				
Group 1: <5.45	$_{x}2.61^{a}$	$_{xy}2.40^{a}$	$_{xy}2.35^{a}$	$_{y}2.23^{a}$
Group 2: 5.46–5.64	$_{x}2.75^{a}$	$_{xy}2.55^{a}$	$_{xy}2.67^{ab}$	$_{y}2.30^{ab}$
Group 3: 5.65–5.80	2.90^{ab}	2.86^{a}	2.95^{b}	2.82^{bc}
Group 4: >5.8	3.26^{b}	3.45^{b}	3.56^{c}	3.17^{c}
SE	0.12	0.12	0.14	0.14
Glucose content (mg/dl)				
Low: <112	3.19^{b}	3.30^{b}	3.35^{c}	3.10^{b}
Medium: 112–280	$_{y}2.77^{a}$	2.64^{a}	$_{y}2.77^{b}$	$_{x}2.47^{a}$
High: >290	$_{y}2.59^{a}$	$_{xy}2.34^{a}$	$_{xy}2.35^{a}$	$_{x}2.20^{a}$
SE	0.14	0.11	0.14	0.14
Glycolytic potential				
Low: <100	3.02^{b}	3.22^{b}	3.16^{b}	2.99^{b}
Medium: 100–140	$_{xy}2.92^{b}$	$_{xy}2.80^{b}$	$_{y}2.95^{b}$	$_{x}2.64^{b}$
High: >140	$_{y}2.63^{a}$	$_{xy}2.39^{a}$	$_{xy}2.42^{a}$	$_{x}2.27^{a}$
SE	0.11	0.12	0.15	0.14

[a,b,c]Means in a column with like superscripts do not differ ($p < 0.05$).
[x,y,z]Means in a row with like subscripts do not differ ($p < 0.05$).
[1] NPPC color scale.

indicating a pH dependency for color stability. Zhu and Brewer (2002) reported that changes in hue angle were more rapid in PVC-packaged PSE pork than in normal or DFD pork during retail display.

No significant discoloration score differences occurred among pH groups on day 6 (Fig. 1). By day 12 however, differences were apparent. Loins with pH < 5.45 were most discolored while those with high pH (>5.8) were least. By day 18, loins in lower pH groups (<5.65) were more discolored than loins in the higher pH groups (Fig. 1). This trend is consistent with most reports in the literature (Jeremiah, 2001). Sorheim, Erlandsen, Nissen, Lea, and Hoyem (1997), however, found no discoloration differences over time between non-enhanced, PSE and normal pork.

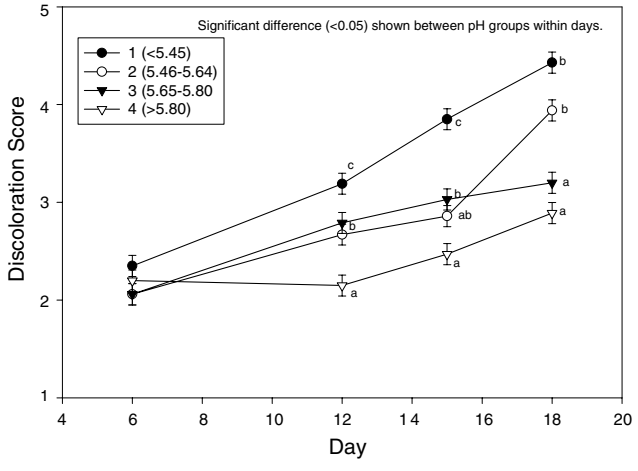

Fig. 1. Discoloration of MAP pork in various pH groups. [1]Discoloration scale: 1, no discoloration; 15, intense discoloration. [a,b,c] Means with like superscripts do not differ ($p < 0.05$).

Significant, but inconsistent, differences in APC occurred among chops in the various pH occurred on days 6 and 12. By day 12, chops with a pH > 5.8 had aerobic plate counts more than 1 log higher ($p < 0.05$) than chops with lower pH. By day 15, those from loins with pH < 5.65 had APC more than 2 log lower ($p < 0.05$) than those from loins with pH > 5.65 (Fig. 2). At this point, chops from loins with pH > 5.65 had 10^6 CFU/cm^2 which is considered spoilage level. Chops from loins with pH > 5.65 did not reach this level until day 18.

3.1.2. Study 1 – glucose content

Initial glucose content in the drip of loins in Study 1 ranged from 53 to 537 mg/dl (data not shown). Loins were segregated into three groups based on glucose content as described by Sutton (1997): High >291 ($n = 27$), medium = 112–259 ($n = 14$), and low = <111 ($n = 14$).

Loins with glucose content > 112 mg/dl had lower ($p < 0.05$) color scores than those with <112 mg/dl throughout the display period (Table 1). While loins from all groups had similar discoloration scores (<2.5) on day 6, by day 12, a clear trend emerged. Loins with high glucose content were most discolored while loins with low glucose content were least (Fig. 4). Residual glycogen decreases with increasing pH, therefore these results were not unexpected. Bidner (2003) reported a significant negative correlation ($r = -0.62$) existed between pH and residual glycogen components (glyco-

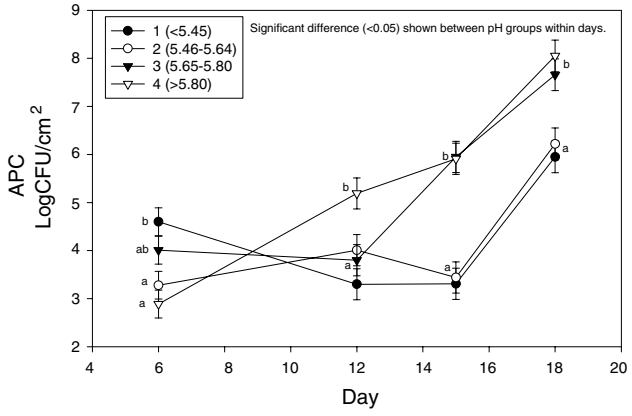

Fig. 2. Aerobic plate counts of MAP pork in various pH groups. [a,b]Means with like superscripts do not differ ($p < 0.05$).

gen + glucose + glucose-6-phoshate). Pigs that have higher glycogen levels pre-slaughter typically produce more lactic acid as a result of postmortem metabolism resulting in a lower ultimate pH. However, not all glycogen is metabolized to lactic acid and higher residual glycogen is present proportionally to the pH (Bidner, 2003). The underlying determiner of color stability may be pH which is also related to residual glycogen.

No significant differences in discoloration occurred among glucose content groups on day 6; however by day 12, differences emerged (Fig. 3). Over time, loins with more glucose became significantly more discolored than those with less (Fig. 3). As discussed earlier, glucose breakdown to lactic acid decreases pH. Lowering pH has been shown to decrease myoglobin stability (Zhu & Brewer, 2002). Muscles with higher levels of glucose typically have lower ultimate pH values supporting MacDougall's (1977) explanation of pH on color.

On day 6, samples with more glucose (>200 mg/dl) had higher APC than samples with less glucose. However, starting on day 12, microbial growth on samples with low glucose content outstripped growth of those with medium or high glucose content (Fig. 4). By day 18, samples in the high glucose content group had significantly lower APC than those in the low or medium groups. These results are consistent with the pH results previously described.

3.1.3. Study 1 – glycolytic potential

Initial GPs for samples in Study 1 ranged from 62 to 213 (data not shown). Loins were segregated into three groups based on GP: High > 141 ($n = 17$), medium = 101–140 ($n = 28$), and low < 100 ($n = 15$). Visual color, discoloration, and APC among loins in the various GP groups are shown in Table 1, and Figs. 5 and 6.

Loins with high GP had lower color scores than loins with low or medium GP (Table 1). This trend was apparent on day 6 and continued throughout the study to day 18. While color scores were lower, no discoloration differences occurred among GP groups on day 6. By day 12, loins with high GP (>140) discolored more than did loins with low or medium GP (<140). These differences continued to day 18 (Fig. 5).

Significant APC differences among GP groups were established by day 6, with higher APC occurring in high GP loins compared to low or medium GP loins. By day 12, the high GP chops had lower APC compared to the low or medium groups. These differences continued throughout the study to day 18 (Fig. 6). Lower APC may be related to lower ultimate pH rather than to elevated GP, per se. An increase in lactic acid concentration increases the GP value, as well as lowering the pH, thus the negative relationship between pH and GP.

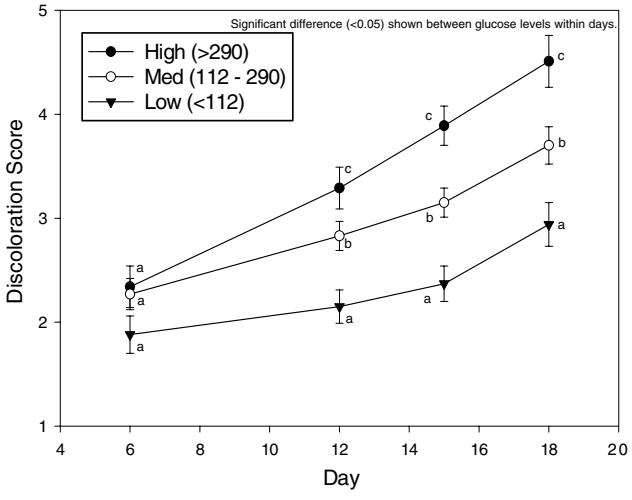

Fig. 3. Discoloration of modified atmosphere packaged pork containing various glucose levels. [1]Discoloration scale: 1, no discoloration; 15, intense discoloration. [a,b,c]Means with like superscripts do not differ ($p < 0.05$).

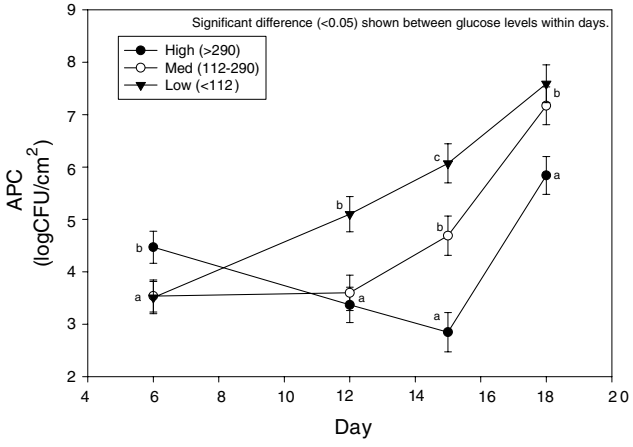

Fig. 4. Aerobic plate counts of modified atmosphere packaged pork containing various glucose levels. [a,b,c]Means with like superscripts do not differ ($p < 0.05$).

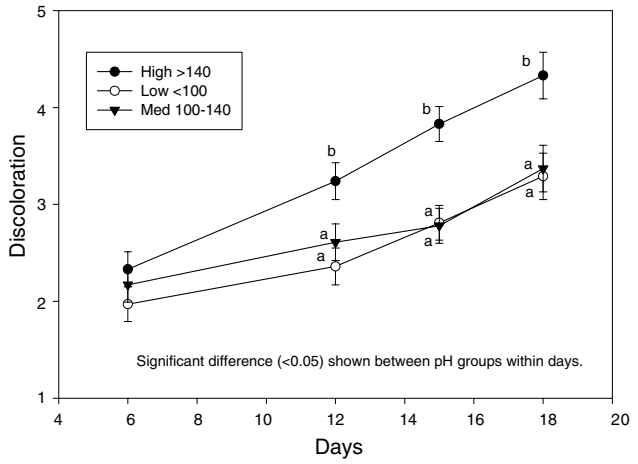

Fig. 5. Discoloration of modified atmosphere packaged pork in various glycolytic potential groups. [1]Discoloration: 1, no discoloration; 15, extreme discoloration. [a,b]Means with like superscripts do not differ ($p < 0.05$).

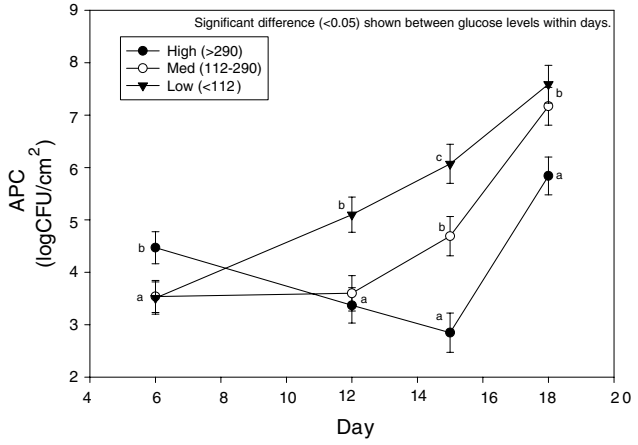

Fig. 6. Aerobic plate count of modified atmosphere packaged pork in various glycolytic potential groups. [a,b,c] Means with like superscripts do not differ ($p < 0.05$).

This explanation supports past research suggesting that pH affects microbial growth (Jeremiah, 1982, 2001; Ray, 2001). This was borne out in the present research in that samples with high GP and low pH had lower APC through out the study than did those with low GP and high pH (Figs. 2 and 6).

3.2. Study 2

3.2.1. Study 2 – color and discoloration

In Study 2, no significant differences occurred in color scores among enhancement groups over the display period (Table 2). No discoloration differences occurred among treatment groups through day 6. By day 21, all groups were significantly discolored, however, spl-enhanced chops experienced more discoloration than

Table 2
Enhancement solution effects on discoloration and color of modified atmosphere packaged pork loin chops

	Days		
	14	21	28
Discoloration[1]			
Sp	$_{x}1.60$	$_{y}2.54^{a}$	$_{z}3.59^{b}$
Spl	$_{x}1.51$	$_{y}2.91^{b}$	$_{z}3.73^{b}$
Spa	$_{x}1.48$	$_{y}2.60^{ab}$	$_{y}2.94^{a}$
Spla	$_{x}1.39$	$_{y}2.36^{a}$	$_{z}3.45^{b}$
SE	0.13	0.18	0.22
Color[2]			
Sp	3.19	3.16	3.36
Spl	3.36	3.21	3.43
Spa	3.33	3.32	3.26
Spla	3.38	3.34	3.34
SE	0.10	0.14	0.16

[a,b,c]Means in a column with like superscripts do not differ ($p < 0.05$).
[w,x,y,z,]Means in a row with like subscripts do not differ ($p < 0.05$).
[1] Discoloration scale: 1, no discoloration; 15, extreme discoloration.
[2] NPPC color scale

either sp- or spla-enhanced chops. All groups continued to discolor through day 28. With respect to prevention of discoloration in MAP chops derived from loins with high initial pH, the use of a brine solution containing acetate and phosphate appeared to be most efficacious. High pH raw materials generally have good initial color but rapidly lose it due to microbial growth, so the prevention of discoloration may be due to the negative effect of the acetate on microbial growth.

3.2.2. Study 2 – aerobic plate count

Aerobic plate counts (APC) are shown in Fig. 7. Initially (day 0), sp- and spl-enhanced chops tended to have higher APCs than other treatments. However, all samples had $<10^2$ CFU/cm^2. microbial growth on these samples decreased between days 0 and 7, an effect that

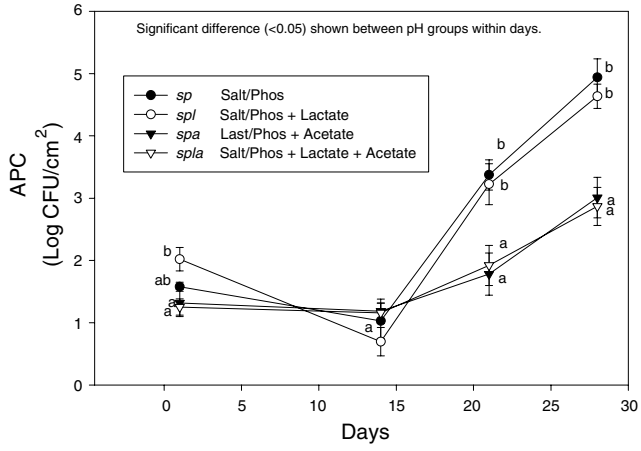

Fig. 7. Aerobic plate counts of pork loin chops enhanced with different solutions. [a,b]Means with like superscripts do not differ ($p < 0.05$).

did not occur in the acetate-containing treatments. By day 14, APCs of all enhancement groups were similar. By day 21, sp- and sl-enhanced chops had significantly higher APCs than chops enhanced with solutions containing acetate (spa and spla). This trend continued through day 28. These results agree with other reports in the literature on the effects of organic acid salts on microbial growth (De Wit & Rombouts, 1990; Jensen et al., 2002).

Ita and Hutkins (1991) found that, although other acids decreased pH more than acetic acid, acetic acid had the greatest effect on microbial growth. This was considered to be due to the effects of the undissociated form of the acid in the cell, not because of the environmental effect of pH. Adams and Hull (1988) found that the closer the medium pH is to the pK_a of the acid, the greater the lag phase of microbial growth. The salts of these organic acids appear to inhibit microbial growth without changing enhancement solution pH. This lack of effect on solution pH is advantageous in terms of reducing purge and cook losses which ultimately reduces production costs.

Acetic acid has been shown to reduce microbial counts on steaks when sprayed on loins prior to fabrication Bala, Stringer, and Nauman (1977). Anderson, Cerveny, and Milkowski (1989) reported that beef plates sprayed with 3% acetic acid took 16 days longer than controls to reach 10^8 CFU/cm^2. Jensen et al. (2002) reported a synergistic effect between lactate and diacetate which resulted in lower APC than either solution alone, when used for pork enhancement. In this study, addition of lactate to an acetate-containing solution did not appear to depress microbial growth any more than using acetate alone.

4. Conclusions

While enhanced MAP chops from loins with higher ultimate pH values (>5.65) had greater color stability, they were more susceptible to microbial growth over time than loins with lower ultimate pH. The lower ultimate pH (<5.65) group experienced reduced microbial growth but discolored more rapidly over time. The lower glucose content groups experienced greater microbial growth than the high glucose content group. Selection of raw materials based on higher pH and lower GP may reduce the incidence of discoloration in MAP pork loins chops during retail display, creating a product which is more appealing to the consumer. Unfortunately, increased microbial growth was observed in products produced from such raw materials.

Because results of Study 1 indicated increased microbial growth in enhanced fresh MAP pork with pH > 5.75 and discoloration in pork with pH < 5.75, use of various enhancement solutions containing organic acid salts to increase shelf life in this susceptible group was assessed. Solutions containing salt (0.25%), phosphate (0.5%) and sodium acetate (0.25%) reduced microbial growth and sustained color of high pH (>5.75) product when held in storage in a 20% CO_2/80% O_2 modified atmosphere package.

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