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Evaluation of Meat Quality on High pH Strip Loins Injected with Buffered Acetic Acid

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Abstract: This experiment evaluated the effects of injection of buffered vinegar [e(Lm)inate V, Hawkins Inc., Minneapolis, MN] at pH 5.0 on quality attributes of high pH beef strip loins. Strip loins (n = 16) were sectioned and treatments assigned to evenly represent each section, and on d 6 after harvest and fabrication treatments were injected into each section using a multi needle injector. One control and three treatments were used: 0 (T0), 0.4 (T0.4), 1.2 (T1.2), and 1.6% (T1.6) of the green weight of steaks was injected, and quality characteristics of strip loins were evaluated. Sections were then vacuumed packaged for an additional 3 d to simulate transport to retail outlets, then fabricated into steaks and overwrapped for an addition 3 d for simulation of retail storage. High pH control (T0) final pH (FpH) values were the highest, with a pH of 5.87. While there were similarities between treatments, overall as percentage of injection increased, FpH decreased. There was no difference among location ($P > 0.05$) when evaluating FpH. There were no difference in cook loss or TBARS for location or treatment. Drip loss was greatest for T1.2 injection and in the most caudal section. Warner-Bratzler shear force (WBSF) was different due to the location of the section ($P \leq 0.05$), with section Y (the third section) having the greatest value. Off flavor intensity increased ($P \leq 0.05$) as percentage of injection increased. Final L*, a*, and b* values were different ($P \leq 0.05$) for treatment levels in the loins with the control having the lowest L* and b* values. While this product was sufficient at altering final raw color and pH, it may not be feasible for industry use, due to minimal impacts on drip loss, cook loss, oxidation, and sensory characteristics with an increase in off flavor. Nonetheless, investigation of application with an antioxidant and/or functional ingredient could prove beneficial for industry use.

Keywords: acetic acid, beef, high pH, quality
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Introduction

Beef lean appearance (i.e., color, shape, presentation) is a driving factor in beef retail acceptance, which influences both consumers and purveyors purchasing decisions (Carpenter et al., 2001). As it relates to the beef industry, dark, firm, and dry (DFD) lean otherwise known as "dark cutting" meat is characterized by an apparent dark purplish-red color, as a result of a pH greater than 5.7 due to a depletion of muscle glycogen prior to harvest resulting in minimal conversion to lactic acid. Past literature has shown that dark cutting beef has little to no acceptance among consumers and food service chefs when purchasing retail cuts from the rib or loin, compared to a normal beef carcass that exhibits a bright cherry-red colored lean with a pH ranging from 5.4 to 5.6 (Lawrie and Ledward, 2006; Aalhus et al., 2009).

In the most recent National Beef Quality Audit, 1.9% of cattle exhibited dark cutting characteristics (Boykin et al., 2017). With a loss of over $36 per cwt according to current discounts (USDA-AMS, 2017), the estimated loss to the industry is $5.90/head per yr.

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Research on dark cutting beef has primarily focused on pre-harvest management to reduce incidence of dark cutting beef. Literature suggests that a combination of improved implant strategies, followed by the use of good handling practices, well designed handling facilities, and proper hauling practices would reduce the incidence of dark cutting beef (Smith et al., 1995; Scanga et al., 1998). Regardless of these pre-harvest management improvements, dark cutting beef continues to be an issue, and processors are investigating possible post-harvest methods to combat the detrimental effects of dark cutters.

In an effort to improve lean color some researchers have researched the use of organic acids; they have primarily utilized lactic acid (Apple et al., 2005; Sawyer et al., 2008; Sawyer et al., 2009; Apple et al., 2011). As stated in the literature, further research is warranted to investigate the impact of acidic marination on palatability attributes of fresh and cooked color stability of dark cutting beef (Sawyer et al., 2008; Sawyer et al., 2009). Thus, there is a critical need for innovative research that focuses on adding value in terms of lean color appeal and shelf-life to the rib and loin of dark cutting carcasses. Moreover, using previously under-utilized Generally Recognized as Safe compounds could prove beneficial to beef processors.

Acetic acid, referred to as vinegar, is a potential alternative that may be used to combat the negative impacts of dark cutters. Acetic acid is an organic acid that is commonly used in meat production, primarily due to its low pH and antimicrobial activity. It is characterized by a pungent odor and taste. Acetic acid has the ability to lower pH, cause disruption within the cell membrane (Jay, 1992). We believe that acetic acid would produce beneficial color change and stability when applied to high pH beef. Acetic acid is generally recognized as safe to use and has been notably recognized for its effectiveness against *E. coli* O157:H7 and *Salmonella* typhimurium.

Limited research has been performed on the meat quality aspects of dark cutting beef (Apple et al., 2011). Previous studies have recommended the sensory aspects of dark cutting beef be further examined, stating that there is no real palatability issue with dark cutting beef which is why it is used in the foodservice industry (Savell, 2013). The objective of this study was to determine the differences on pH, raw and cooked color, cook loss, drip loss, rancidity, and sensory characteristics in high pH (lower end of DFD pH threshold) beef strip loins treated with acetic acid at different injection levels. Because studies on other muscles indicate that is a location effect on different muscles of the carcass (Bratcher et al., 2005; Denoyelle and Lebihan 2004; Reuter et al., 2002), location effects are also included as a variable of interest.

Materials and Methods

Institutional review board

All studies involving the use of human subjects were approved by the Institutional Review Board at Auburn University (17–044 EX 1703).

Strip loin procurement and experimental design

Strip loins (n = 16) were provided by a commercial meat processor. The processor was asked to send strip loins they would have classified as dark cutters. The strip loins chosen were classified as 'no roll' due to the dark color, but were 'A maturity' with a 'Slight' amount of marbling. Strip loins were vacuum-packaged and shipped overnight in a Styrofoam cooler with ice packs to the Auburn University Meats Lab. Upon arrival, the strip loins remained in the package and placed in a holding cooler at 4 ± 2°C. Subprimals remained in storage for 5 d until further use. On d 5 after fabrication (6 d after harvest), all high pH loins were randomly assigned a number 1 through 16 and each loin was sectioned into 4 equal pieces. The loin sections were assigned a letter W, X, Y, or Z from cranial to caudal end. The injection treatments were assigned as a control with no injection (T0), a low (T0.4), a medium (T1.2), or a high (T1.6) concentration of buffered acetic acid at a pH of 5.0 based on preliminary experiments of our research, where injection levels of greater than 2% would yield poor sensory and color evaluation scores. In consequence, these values were determined after calculating mean percentage pickup due to injection by adjustment of the settings on the equipment to obtain the different pick-up percentages indicated above. The injection treatment (T0, T0.4, T1.2, or T1.6) was rotated clockwise for strip loins one through four and nine through twelve. The injection treatment was rotated counter-clockwise for strip loins five through eight and thirteen through sixteen. This was done to remove any muscle location effects on the tested parameters and allow for statistical testing of location effect.

Treatment application

All strip loin sections assigned to an injection treatment and then were injected with 4°C buffered vinegar [e(Lm)inate V, Hawkins Inc., Minneapolis, MN] at pH 5.0. Strip loin sections were weighed and placed fat side down on the injector belt. After injection, strip loins were allowed to equilibrate for 10 min and were then weighed to determine the final percentage pick-up. Initially, all

T0 sections were passed through the injector without using injection solution. Injections were performed with a multi-needle injector (model PI 9–52 Pickle Injector; Gunther Maschinenbau GmbH, Dieburg, Germany). Once the sections were injected and weighed, each section was vacuum-packaged in 18 × 20 in, 3 mm thick, oxygen impermeable oxygen transmission rate = 0 cc × 100 $cm^2 \times 24^{h-1}$) bags (Prime Source, Kansas City, MO) and stored at 4 ± 2°C for 3 d to simulate transportation of strip loins to retail outlets. Upon completion of the 3 d storage period, all strip loin sections were cut into 3 individual steaks (2.54 cm thickness) for further laboratory analysis. Steaks were placed on 1S Styrofoam trays (Copaco, Inc., Columbus, GA) and overwrapped with oxygen-permeable polyvinyl chloride film (O^2 transmission = 23,250 mL/m^2 per 24 h. 72 gauge) using a floor model stretch film over wrapper (Heat Seal, LLC, Cleveland, OH). After storage, steaks were allocated randomly for 1) sensory analysis, 2) WBSF and cook loss, and 3) TBARS and drip loss. Steaks were placed in a holding cooler at 4 ± 2°C for an additional 3 d in continuous fluorescent lighting (~1,900 l× using high-output bulbs with a color temperature of 3,500°K and color rendering index of 73) to simulate retail packaging. Steaks determined for sensory analysis, WBSF and cook loss were then vacuum packaged and frozen (–20°C) until needed for further analysis. Steaks for TBARS and drip loss were taken to the laboratory at Upchurch Hall at Auburn University and a subsample was taken from each steak for determination of drip loss. The remainder of the sample was used for TBARS evaluation.

Color evaluation and pH evaluation

Initial color and pH readings were obtained at the anterior cut surface of each strip loin section before injection (20 min after exposure of the cut surface). Following injection of respected treatments, T0, T0.4, T1.2, or T1.6 at 4°C with buffered acetic acid at pH 5.0 and storage as described above, each sample package was opened and steaks were allowed to bloom for 20 min to stabilize color and final color and pH measurement were obtained. All measurements were recorded in duplicate to obtain an accurate representation, and the values were averaged. Prior to use, the colorimeter (Hunter Miniscan XE Plus, Reston, VA) and pH meter (Oakton Vernon Hills, IL) was calibrated according to manufacturer recommendations. The colorimeter used illuminant D_{65} with a 10° observance angle, and a 2.5 cm aperture. Color measurements were conducted in accordance with American Meat Science Association (AMSA) guidelines (American Meat Science Association, 2012).

Drip loss

A 40 to 50-g sample was obtained from each steak and trimmed of any fat and connective tissue. Samples were weighed, then suspended by a fish hook (Model 31 number:121– 2/0, Eagle Claw) in a 800 mL plastic screw cap container (Nalgene) and stored for 48 h at a temperature of 4°C. Following the 48 h time period samples were removed from hooks, and blotted to remove excess surface fluid. Samples were then weighed to the nearest 0.1g. Percent drip loss was calculated by the following NPPC recommended equation (NPPC, 2000).

Percent Drip Loss = (Loss in Weight/Initial Weight) × 100

Cook loss and WBSF

Steaks used to evaluate cook loss and WBSF were removed from frozen storage and thawed at 4 ± 2°C for 48 h. Steaks were cooked on clam-shell grills (Calphalon Removable Plate Grill, Caphalon, Perrysburg, OH), that were preheated to ~177°C, and cooked to an internal temperature of 71°C. Temperatures were monitored with copper constantan thermocouple wires inserted into the geometric center of the steak and attached to a hand-held Omega data logger HH309A temperature recorder (Omega Engineering, Stamford, CT). Cook loss values were determined by weighing steaks prior to cooking. After cooking, steaks were allowed to cool and were then reweighed to determine percent cook loss. Also after steaks cooled, external color readings were obtained by utilizing a Hunter Miniscan XE Plus. The colorimeter used illuminant D_{65}, with a 10° observer angle, and a 2.5 cm aperture. Cooked steaks were then covered in aluminum foil, labeled, and allowed to chill at 4°C for 24 h. When preparing steaks to remove cores for WBSF, steaks were cut with a transverse cut to expose the muscle fiber orientation and also to record cooked internal color with the Hunter Miniscan XE Plus. Six cores (1.27 cm in diameter) were then removed from each steak with a brass cork borer (Model 1601A Series Brass Cork Borer, Boekel Scientific, Feasterville, PA), parallel to the muscle fiber orientation. Each core was sheared once at its center, perpendicular to the muscle fiber orientation, using a TA-XT2i Texture Analyzer shear machine (Texture Technologies Corp., Scarsdale, NY). The peak force measurements were then averaged from the 6 cores from each steak for statistical analysis. The probe was programmed to be lowered 30 mm after detection of resistance. The penetration speed was 3.3 mm/s with a post-test speed of 10 mm/s and a pre-test speed of 2.0 mm/s.

Sensory evaluation

Randomly selected frozen strip loin steaks were thawed at 4°C for 24 h and cooked as described above for WBSF. Sensory evaluation was conducted in accordance with AMSA guidelines (American Meat Science Association, 2012). The steaks were trimmed of external fat and connective tissue, and samples were cut into 1.27 cm × 1.27 cm × 2.54 cm portions using a plastic grid, placed in sample cups and labeled. Sample cups were then placed in pans and kept in a warming oven until served to a trained sensory panel, consisting of 8 to 14 members. Panelists underwent multiple training sessions prior to evaluation. After sampling beef steaks that were treated with varying concentrations of the product used in the project, the panelists discussed the magnitude of effects on sensory attributes. During evaluation, each panelist was given a sample cup containing 2 samples from each steak for evaluation of initial and sustained juiciness, initial and sustained tenderness, beef flavor intensity, and off flavor intensity on a scale of 1 to 8, where 1 = extremely dry, tough, bland, and uncharacteristic of beef, and 8 = extremely juicy, tender, intense, and characteristic of beef. Panelists evaluated samples in secluded partitioned booths with red incandescent light. They were instructed to cleanse their palate with a salt-free saltine cracker and a sip of apple juice before evaluating each sample. Panelists were asked to wait a period of 60 sec between samples for a rest period. A total of 8 sessions were needed for statistical procedures of the 80 sensory samples. Furthermore between 8 and 12 samples per session were evaluated to minimize any possible panelist fatigue.

Thiobarbituric acid reactive substances (TBARS)

Thiobarbituric acid reactive substances (TBARS) analysis was conducted using a modified procedure described by Tarladgis et al. (1960), and performed by Fernando et al. (2003). Briefly, a 5-g sample was cut from the steak free of fat and connective tissue, was blended in a Waring commercial laboratory blender with 30 mL of deionized water for 1 min, and transferred to a 250 mL distillation tube. The blender cup was washed with an additional 20 mL of deionized water and the rinsate was added to the same distillation tube. A volume of 2.5 mL of 4 N HCl was added to the mixture, stirred, and distilled at a maximum rate until 25 mL of distillate was collected in a volumetric flask. After distillation was complete, 5 mL of distillate was pipetted into a 50 mL pre-sterilized centrifuge tube in duplicate. Then, 5 mL of.02 M 2-thiobarbituric acid in 90% acetic acid was added and vortexed. The caps were tightly capped and heated in a reciprocal shaking boiling water bath (Thermo Scientific Laboratory Services Equipment) for 30 min, and allowed to cool to room temperature. The absorbance was read at 532 nm using a Beckman Coulter Du 730 Life Science UV/Vis spectrophotometer (Tarladgis et al., 1960; Fernando et al., 2003). K-value was calculated using 1,1,3,3-tetraethoxypropane as the standard and the TBARS readings were recorded by multiplying the absorbance by the K-value of 7.8 (Fernando et al., 2003).

Statistical analysis

The experimental design was a completely randomized design. The fixed effects include location, treatment and their interaction. Type-3 tests of fixed effects were performed using the MIXED Procedure of SAS (Version 9.4; SAS Inst. Inc., Cary, NC). Least squares means for protected F-tests ($P < 0.05$) were separated by using the PDIFF option (least significant differences) and were considered significant at $P < 0.05$

Results and Discussion

pH

Initial pH of the strip loins was 5.81 ± 0.11 (Table 1). There was no difference in pH for location or treatment. Previous research states that when beef pH exceeds 6.0 within 24 h after harvest meat quality can deteriorate, the eating experience is undesirable for the consumer, and economic losses begin to increase (Viljoen et al., 2002; Wulf et al., 2002; Pipek et al., 2003). The pH of the beef in this project was not as great a 6.0, but none the less, still higher than normal beef. In a study conducted by (Viljoen et al., 2002), consumers preferred ($P = 0.02$) the color of the normal (pH = 5.51 to 5.64) raw steaks compared to the raw DFD (pH = 6.15 to 6.37) steaks.

There was no difference among location ($P > 0.05$) when evaluating FpH as seen in Table 1. However, there was a variation ($P \leq 0.05$) detected within treatment. It was expected that the T) sections would have a higher FpH value compared to the other treatments (T0.4, T1.2, and T1.6). As is evident in Table 1, T0 FpH values were the highest, with a pH of 5.87 in comparison to T0.4, T1.2, and T1.6 with respective FpH values of 5.76, 5.75, and 5.70. While there were similarities between treatments, overall as percentage of injection increased, FpH decreased.

Table 1. LSMEANS of initial pH, final pH, cook loss, drip loss, TBARS, off flavor intensity values for strip loins within treatment and location of acetic acid

Treatments, %	Initial pH	Final pH	Cook loss, %	Drip loss, %	TBARS, MDAmg/kg	WBSF, kg
0	5.81 ± 0.11	5.87 ± 0.12^{a}	19.10 ± 1.20	0.91 ± 0.13^{a}	0.16 ± 0.04	3.08 ± 0.29
0.4	5.82 ± 0.11	5.76 ± 0.12^{ab}	19.59 ± 1.20	0.99 ± 0.13^{a}	0.20 ± 0.04	3.11 ± 0.29
1.2	5.81 ± 0.11	5.75 ± 0.12^{bc}	20.19 ± 1.20	0.92 ± 0.13^{a}	0.21 ± 0.04	3.01 ± 0.29
1.6	5.81 ± 0.11	5.70 ± 0.12^{bc}	20.03 ± 1.20	1.27 ± 0.13^{b}	0.25 ± 0.04	3.29 ± 0.29
Location						
W	5.83 ± 0.11	5.72 ± 0.12	19.25 ± 1.20	0.89 ± 0.13^{x}	0.22 ± 0.04	2.89 ± 0.29^{a}
X	5.81 ± 0.11	5.76 ± 0.12	19.34 ± 1.20	0.93 ± 0.13^{x}	0.19 ± 0.04	3.01 ± 0.29^{a}
Y	5.81 ± 0.11	5.77 ± 0.12	20.33 ± 1.20	1.03 ± 0.13^{xy}	0.21 ± 0.04	3.48 ± 0.29^{b}
Z	5.81 ± 0.11	5.83 ± 0.12	19.98 ± 1.20	1.24 ± 0.13^{y}	0.19 ± 0.04	3.12 ± 0.29^{a}

$^{a–c}$Means with different superscripts in treatment columns are different.

^{x,y}Means with different superscripts in location columns are different.

Cook loss

There was no difference ($P > 0.05$) for location or treatment in cook loss (Table 1). Numerically, the greatest cook loss value within treatments was observed with T1.2 injection with a 20.19% cook loss compared to the least cook loss percent at 19.10% for the T0 steaks. The greatest numerical cook loss was also observed with section Y at 20.33%. In other research on dark cutting beef, cook loss decreased as pH increased (Grayson et al., 2016). The researcher discovered that severe dark cutting beef had the lowest cook loss, whereas normal beef had the highest cook loss values ($P \leq 0.05$; Grayson et al., 2016). Other authors convey that meat with a higher pH results in improved WHC with more water to gather within the myofibril (Dransfield, 1981; Purchas, 1990), giving rise to lower cooking loss and a more tender product. While statistical significance is not seen in the current study, there are trends to support this.

Drip loss

Evaluation of drip loss was conducted on d 6 after treatment injection. As is shown in Table 1, drip loss was greater ($P < 0.05$) for T1.6 with a value of 1.27%. There was also a location effect with sections. Section Z had the greatest drip loss at 1.24%, but was not different ($P > 0.05$) than section Y at 1.03%. Section Y was not different ($P > 0.05$) than section W or X. In a Canadian study dark cutting carcasses were categorized into 2 different dark cutting classifications based on pH of the *Longissimus thoracis* (Holdstock et al., 2014). Classic dark cutters had a pH greater than 6.0 and atypical dark cutters had a pH of less than 6.0. These researchers reported that classic dark cutters resulted in lower drip loss values compared to atypical dark cutters and the control had the greatest drip loss value. The numerical increase in drip loss values in the present study are most likely related to amount of injection solution; however, section Z is represented equally among injection treatments, so it is ironic that it also has the greatest amount of cook loss.

Thiobarbituric acid reactive substances (TBARS)

Results for TBARS means are also reported in Table 1. There was no difference between location or treatment ($P > 0.05$). T0 had the lowest value of 0.1569 mg MDA/kg, and the 1.6% treatment had the greatest value of 0.2519 mg MDA/kg. Though not statistically different, as amount of acetic acid increased, so did TBARS values. Therefore, based on the results of this study, it could be beneficial to add an antioxidant in conjunction with the vinegar to help retard rancidity since TBARS values tended to increase as amount of injection level increased. Previous studies have shown that antioxidants have a large effect on shelf-life and color stability (Tapp et al., 2012), so the possible interactive effects of an additive could drastically impact the quality attributes that we evaluated.

Warner bratzler shear force (WBSF)

Results from previous studies (Jeremiah and Murray, 1984) indicate that steaks from various anatomical locations in the LD can differ in percent soluble intramuscular collagen without differing in either the concentration of intramuscular collagen or overall tenderness. Previous research reported that meat from DFD carcasses is uniquely tender, as compared to normal meat (Katsaras and Peetz, 1990). The authors suggest a possible explanation for this increased tenderness of DFD beef relates to the in-

creased fragmentation of the myofibrils during heating compared to normal beef (Katsaras and Peetz, 1990). As reported in other research, cooked *longissimus* from DFD carcasses had 46% higher shear force values compared to normal carcasses (Wulf et al., 2002). Furthermore, these authors describe that there was significant variation among tenderness among DFD carcasses compared to normal carcasses, within the *longissimus* (Wulf et al., 2002).

When examining location, there was a difference ($P \leq 0.05$) in instrumental tenderness scores. Location W, which was the most anterior, was evaluated by WBSF to be the most tender at a force value of 2.89 kg (Table 1). Tenderness tended to increase between anterior to posterior locations of the loin, with the exception of section Y, which had the greatest ($P < 0.05$) shear force value (3.48 kg). Previous research has evaluated the effect of WBSF on location within the same muscle. Some authors report that the caudal end of the *longissimus* was the most tender (Ramsbottom et al., 1945), whereas others report that the cranial end of the *longissimus* was the most tender (Martin et al., 1970). Still, others state that there is no effect within the *longissimus* as it relates to location (Jeremiah and Murray, 1984). Thus, it is evident that the cause of WBSF values can be contradicting throughout the literature.

Sensory evaluation

There were no differences ($P > 0.05$) in treatment, or location for initial juiciness, sustained juiciness, initial tenderness, sustained tenderness, and beef flavor intensity (Table 2). All values were acceptable having at least a mean value of 5 on our ballot, which corresponded to slightly juicy or slightly tender. Literature has shown that sensory panel data revealed less tender *longissimus*, *gluteus medius*, and *semimembranosus* for DFD carcasses than normal carcasses (Wulf et al., 2002).

Sensory panelists' responses for tenderness were compared to WBSF measurements and the results had a relationship based on the location of the loin. As stated before, location W, which was the most anterior location, had the lowest shear force value at 2.89 kg. Location W was also reported by the panelists to have the greatest initial tenderness score of 5.89 using our sensory ballot. Studies on other muscles indicate that is a location effect on different muscles of the carcass (Bratcher et al., 2005 Denoyelle and Lebihan, 2004 and Reuter et al., 2002).

Sensory panel juiciness and beef flavor intensity scores were not different in the present study. These results are in agreement with information in the literature (Wulf et al., 2002), that reports dark cutting carcasses had no effect ($P > 0.05$) on sensory panel juiciness and flavor intensity. On the other hand, it has been reported that severe (pH = 6.89) and moderate (pH = 6.59) dark cutters were juicier than normal (pH = 5.66) steaks as rated by a trained sensory panel (Grayson et al., 2016). In a similar study using timed dip applications, Kotula & Thelappurate (1994) reported that 1.2% acetic acid-treated samples had lower ($P < 0.05$) values juiciness values than their control, but the magnitude of the differences was small and, therefore, may not be of practical importance as it was still found to be acceptable.

The means for off flavor intensity (OFI) among treatments are reported in Table 2. The greater the num-

Table 2. LSMEANS of sensory panel trait values for strip loins within treatment and location of acetic acid[1]

Treatments, %	Initial juiciness	Sustained juiciness	Initial tenderness	Sustained tenderness	Beef flavor intensity	Off flavor intensity
0	5.39 ± 0.20	5.26 ± 0.19	5.81 ± 0.26	5.82 ± 0.24	5.84 ± 0.08	7.76 ± 0.12[a]
0.4	5.61 ± 0.20	5.49 ± 0.19	5.99 ± 0.26	5.92 ± 0.24	6.03 ± 0.08	7.71 ± 0.12[ac]
1.2	5.46 ± 0.20	5.34 ± 0.19	5.79 ± 0.26	5.65 ± 0.24	5.89 ± 0.08	7.53 ± 0.12[bc]
1.6	5.57 ± 0.20	5.42 ± 0.19	5.83 ± 0.26	5.74 ± 0.24	5.94 ± 0.08	7.47 ± 0.12[b]
Location						
W	5.41 ± 0.20	5.35 ± 0.19	5.89 ± 0.26	5.82 ± 0.24	6.06 ± 0.08	7.63 ± 0.12
X	5.58 ± 0.20	5.43 ± 0.19	5.86 ± 0.26	5.81 ± 0.24	5.88 ± 0.08	7.66 ± 0.12
Y	5.53 ± 0.20	5.40 ± 0.19	5.80 ± 0.26	5.69 ± 0.24	5.92 ± 0.08	7.52 ± 0.12
Z	5.51 ± 0.20	5.33 ± 0.19	5.86 ± 0.26	5.80 ± 0.24	5.85 ± 0.08	7.66 ± 0.12

[a–c]Means with different superscripts in the same column are different ($P \leq 0.05$).

[1]1 = extremely dry, extremely tough, extremely bland, extreme off flavor; 2 = very dry, very tough, very bland, intense off flavor; 3 = moderately dry, moderately tough, moderately bland, very much off flavor; 4 = slightly dry, slightly tough, slightly bland, moderate off flavor; 5 = slightly juicy, slightly tender, slightly intense flavor, modest off flavor; 6 = moderately juicy, moderately tender, moderately intense flavor, small off flavor; 7 = very juicy, very tender, very intense flavor, slight off flavor; 8 = extremely juicy, extremely tender, extremely intense flavor, no off flavor.

ber, the less off flavor detected. There was a difference ($P \leq 0.05$) among treatments, as T0.4 had an OFI score of 7.71, T1.2 had an OFI of 7.53, T0 had the greatest OFI score of 7.76, and T1.6 had the lowest OFI score of 7.47. It would have been expected that with increasing concentration of injection, that the off flavor would increase, which would also correlation with the trend of increasing TBARS values as injection percentage increased. This was the result from a trained sensory panel, as percentage of acetic acid injection increased, so did the amount of detectable off flavor. Panelists were also asked to describe the flavor detected, and most common descriptors were 'vinegar', 'bitter', or 'sour'.

Color

In this study, all initial color measurements were taken in the same (anterior) location within strip loin sections. Initial color scores are reported in Table 3. The initial color readings were done prior to any treatments, so there was would be minimal difference in initial L*, a*, and b* values when comparing treatments. There were no differences in location or treatment for any of the initial color values. In addition, we did not observe any differences ($P > 0.05$) among locations.

Final colorimetric values were taken on d 6 after injection and read from the same anterior location. There was also no difference ($P > 0.05$) for L*, a*, or b* values comparing location. Nevertheless, a difference ($P \leq 0.05$) was identified when comparing treatments (Table 3). The greatest final L* value among treatments was 42.55 for T1.6. T0.4 had a final L* value of 38.60, T1.2 had a final L* value of 40.13, and T0 had the least final L* value of 36.14. The results are in agreement with the hypothesis that final L* would increase as treatment percentage increased. Final a* (Fa) values were also different ($P \leq 0.05$) within treatments. The greatest final a* value was 15.22 for T0.4, T1.2 resulted in a final a* value of 12.27, T0 had a final a* value of 14.99, and T1.6% had a final a* value of 12.07. For b*, there was also a difference ($P \leq 0.05$). T0.4 had the greatest final b* value of 14.49, T1.2 had a value of 13.77, T0 had the least value of 13.13, and T1.6 had a value of 14.42.

Cooked external colorimetric values were recorded on d 6 after injection (data not in tabular form). There was no difference ($P > 0.05$) in cooked external color values between location, or treatment for L*, a*, and b* values. Cooked internal values were also recorded on d 6 after injection, and did not differ ($P > 0.05$) for location, or treatment. Some researchers suggest that when cooked dark cutting beef is exposed to oxygen, the internal color may become oxygenated, therefore, developing a bright red color that imitates fresh normal beef (Gašperlin et al., 2000). Previous research suggests that DFD meat has a persistent pink cooked color which results in a greater a* value (Sawyer et al., 2008; Sawyer et al., 2009). Research has also reported that there was no difference when consumers rated cooked DFD and normal steaks for color (Gašperlin et al., 2000). The DFD steaks were scored by the consumers to be 6.0 and the normal steaks were scored at 5.9. The scale utilized by this research was where 1 = totally unacceptable to 9 = very acceptable (Gašperlin et al., 2000). Because this particular study did not include the effects of normal beef to DFD, it is not clear to the extent of persistent pinking, but the internal color of the high pH strip loins did still appear pink in color even after the internal temperature of 71°C was reached.

Table 3. LSMEANS of raw colorimetric values for DFD strip loins within treatments of acetic acid

Treatments, %	Initial L*	Initial a*	Initial b*	Final L*	Final a*	Final b*
0	37.31 ± 1.11	15.07 ± 0.63	13.13 ± 0.59	36.14 ± 1.04^{a}	14.99 ± 0.56^{a}	13.13 ± 0.46^{bc}
0.4	37.19 ± 1.11	15.30 ± 0.63	13.22 ± 0.59	38.60 ± 1.04^{b}	15.22 ± 0.56^{a}	14.49 ± 0.46^{a}
1.2	36.93 ± 1.11	15.24 ± 0.63	13.12 ± 0.59	40.13 ± 1.04^{b}	12.27 ± 0.56^{b}	13.77 ± 0.46^{ab}
1.6	37.19 ± 1.11	15.33 ± 0.63	13.02 ± 0.59	42.55 ± 1.04^{c}	12.07 ± 0.56^{b}	14.42 ± 0.46^{a}
Location						
W	37.14 ± 1.12	15.42 ± 0.63	13.35 ± 0.59	40.36 ± 1.04	13.21 ± 0.56	14.27 ± 0.46
X	37.47 ± 1.12	15.04 ± 0.63	13.08 ± 0.59	38.54 ± 1.04	13.76 ± 0.56	14.14 ± 0.46
Y	37.09 ± 1.12	15.02 ± 0.63	12.94 ± 0.59	40.18 ± 1.04	13.79 ± 0.56	14.09 ± 0.46
Z	36.90 ± 1.12	15.45 ± 0.63	13.11 ± 0.59	38.34 ± 1.04	13.80 ± 0.56	13.31 ± 0.46

$^{a–c}$Means with different superscripts in the same column are different ($P \leq 0.05$).

Conclusions

After evaluation of the results, use of buffered acetic acid alone at a concentration of 1.2% or 1.6% was sufficient at altering the final raw color and pH to a level that closely represents what would be expected from a normal strip loin. This product did not have a large effect on cook loss, WBSF, TBARS, and cooked internal color. Therefore, this product used alone would most likely not be a viable option in industry with alteration in pH and color being the only advantages. However, results do suggest that it might be valuable to investigate the use of this product in conjunction with an antioxidant and/or functional ingredient used for binding water. The synergistic effects could improve raw and cooked color and increase water holding capacity in the raw product while reducing cook loss. Furthermore, due to the effects that acetic acid has on microbial survival, it may be beneficial to use this product as an antimicrobial carcass intervention in combination with citric or lactic acid in future studies.

There are some aspects of shelf life that warrant further research regarding the effects of this product used in the processing of high pH beef. With claims that buffered acetic acid can extend shelf life and reduce *Listeria* in formulated sausages, further investigation in the area would be beneficial to the industry. Due to the importance of color appearance and stability among consumers, it may be warranted to investigate the effects of this product at an array of different concentrations to observe the cooked internal color of high pH beef as well as the addition of a phosphate to help facilitate internal color in the cooked product and do this in comparison with normal beef.

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