EFFECT OF TWO ANTIMICROBIALS IN THE ENHANCEMENT SOLUTION ON THE QUALITY AND SENSORY CHARACTERISTICS OF MULTI-NEEDLE INJECTED BEEF TOP SIRLOINS

A. PONRAJAN[1,2], M. A. HARRISON[2], T. D. PRINGLE[1], J. R. SEGERS[1], B. K. LOWE[1], R. O. McKEITH[1], A. M. STELZLENI[1]

[1]Department of Animal and Dairy Science, University of Georgia, Athens
[2]Department of Food Science and Technology, University of Georgia, Athens

ABSTRACT

Thirty market cow top sirloins were used to evaluate the effect of two antimicrobials, IONAL® LC and MOstatin™ V (World Technology Ingredients Inc., Jefferson, GA), on color, lipid oxidation, Warner-Bratzler shear force (WBS), and sensory attributes when incorporated with a common brine enhancement solution for multi-needle injection. Top sirloins were enhanced to target 110% of green weight with 0.5% sodium chloride and 0.4% sodium tripolyphosphate (CNT), CNT plus 1% IONAL® LC (IN) or CNT plus 2% MOstatin™ V (MO) in the final product, vacuum packed and stored at 0±2°C for 10 d. After 10 d storage, muscles were fabricated into steaks for further analysis. In the case of muscle and shelf-life characteristics, there was no significant difference between CNT and IN or MO, except overall appearance of CNT steaks was lower than IN or MO after 7 d of simulated retail storage ($P<0.05$). IONAL® LC significantly retarded ($P<0.05$) lipid oxidation over 14 d of simulated retail storage. Percent thaw loss was lower ($P<0.05$) for IN on d 1, 7 and 14 , while IN and MO exhibited less cook loss on d 7 and d 21, respectively, compared to CNT ($P<0.05$). Sensory initial and sustained tenderness indicate that MO steaks were more tender ($P<0.05$) than CNT and IN. Beef flavor intensity was not affected by treatment. However, CNT was juicier ($P<0.05$) than IN and MO. A slight sensory off-flavor was detected in the samples treated with MO ($P<0.05$). This study suggests that IN and MO can be used in beef enhancement without affecting meat quality.

INTRODUCTION

Consumer acceptability studies for beef palatability have reported that tenderness is the most important characteristic that impacts consumer perception (Morgan et al., 1991; Brooks et al., 2000). With the centralization of meat processing facilities, improved methods of tenderization are replacing the traditional aging process. Blade tenderization and needle injection of enhancement solution are common methods practiced by the industry to improve the value of lower quality meat cuts (Davis et al., 1975; Glover et al., 1977; Boyd et al., 1978; Wicklund et al., 2005). However, the United States Department of Agriculture (USDA) – Food Safety Inspection Service (FSIS) has linked three outbreaks of *Escherichia coli* O157:H7 between August 2000 and August 2004 to mechanically tenderized products (Food Safety Inspection Service, 2003, 2004, 2005; Laine et al., 2005). To prevent further outbreaks of *E. coli* O157:H7 through mechanically tenderized products, it was mandated in 2005 that facilities producing these products had to reassess their HACCP plans (Food Safety Inspection Service, 2005). Furthermore, it has been reported that translocation of *E. coli* O157:H7 may occur (Sporing, 1999; Luchansky et al., 2008). Researchers have evaluated surface decontamination techniques of carcasses and individual cuts before mechanical tenderization (Heller et al., 2007; Echeverry et al., 2009). Inclusion of antimicrobials, such as sodium lactate or sodium lactate and diacetate blends in the enhancement solution for needle injection, along with salt and phosphate, have been found to be effective against *E. coli* K12 (Wicklund et al., 2006; Paulson et al., 2007;

Wicklund et al., 2007). Therefore, the objective of this research was to study the effects of IONAL® LC and MOstatin™ V (World Technology Ingredients Inc., Jefferson, GA), when incorporated in the enhancement solution on the quality and sensory characteristics of multi-needle injected beef top sirloins.

MATERIALS AND METHODS

Meat procurement and multi-needle injection

Sixty IMPS 184B beef top sirloins from market cows were obtained from FPL Food LLC (August, GA) and transported (0±2°C) to the University of Georgia Meat Science and Technology Center (Athens, GA). Prior to injection, top sirloins (n=20) were randomly assigned to one of three enhancement treatments including: 0.5% sodium chloride and 0.4% sodium tripolyphosphate in the final product (CNT), CNT plus 1% IONAL® LC (IN), or CNT plus 2% MOstatin™ V (World Technology Ingredients Inc.). The active ingredients in IONAL® LC are buffered sodium citrate and sodium diacetate, while the active ingredient in MOstatin™ V is vinegar. A multi-needle injector (Injectamatic™ PI 21 Automatic Pickle Injector, Koch Equipment LLC, Kansas City, MO) with 21 needles (4 mm diameter) working at a speed of 41strokes per minute and approximate pump pressure of 130 kPa was calibrated to deliver 110% injection of green weight. All enhancement brines were manufactured the day prior to injection and thoroughly mixed into solution for a minimum of 4 h. Immediately prior to use, the brines were remixed to ensure homogenous solution. During injection, data were collected including weight (Panther Model, Mettler-Toledo Inc., Worthington, OH) and pH (pH 11 series pH/mV/°C meter, Oakton Instruments, Vernon Hills, IL with pH probe EW-05998-20 GG9, Cole-Parmer Instrument Company, Vernon Hills, IL) for each muscle before and after injection. After injection, the muscles were vacuum packaged (B-620 series; 30-50 cc O_2/m^2/24 h/101325 Pa/23°C; Cryovac, Duncan, SC) using a Type 800 (Henkelman BV, Hertogenbosch, the Netherlands) vacuum packager and stored in cold storage (0±2°C) for 10 d to simulate transportation and storage time (Voges et al., 2007). All equipment was thoroughly cleaned between each treatment to prevent mixing of the brine solutions.

Sample preparation

After 10 d of storage the weight and pH of each muscle were measured. Ten muscles out of 20 from each treatment were fabricated into four 2.54-cm thick steaks. The steaks were weighed and randomly placed on absorbent pads (Dri-Loc® AC-40, Cryovac Sealed Air Corporation, Duncan, SC) in polystyrene trays (Cryovac® thermoformed polystyrene processor trays, Cryovac Sealed Air Corporation, Duncan, SC) which were then wrapped with a oxygen permeable polyvinylchloride overwrap (O_2 transmission=23,250 mL/m^2/24 h, 72 gauge; Pro Pack Group, Oakland, NJ). The steaks were displayed (4±2°C) with 24 h luminescence (960 lux) to simulate retail display over 21 d. Shelf-life color was measured on steaks over 14 d for objective Hunter Lab (Minolta Corporation, Osaka, Japan), subjective color for overall appearance (8 = extremely desirable and 1= extremely undesirable), color (8 = light cherry red and 1 = extremely dark red/purple/brown), and discoloration (8 = no discoloration and 1 = 100% discolored) by a trained 8 member panel (AMSA, 1991). On d 1, 7, 14 and 21 designated steaks were removed from packaging and weighed to calculate purge loss. Samples were then vacuum packaged and stored (-30±2°C) for lipid oxidation analysis.

The remaining 10 top sirloins from each treatment were fabricated into five 2.54-cm thick steaks. Four steaks were vacuum packaged and randomly assigned to 1, 7, 14 or 21 d of storage (2±2°C)

to simulate the time samples could remain in a food service cold chain (Voges et al., 2007). At the end of the respective aging periods, all samples were frozen (-29±2°C) and stored for further Warner-Bratzler shear force determination. The 5th steak was immediately vacuum packaged and frozen (-30±2°C) for sensory analysis.

Lipid oxidation

On d 1, 7, 14 and 21 of retail display, a 100-g sample was collected from each steak, trimmed of all subcutaneous fat and intermuscular connective tissue, vacuum packaged (A300/16, Multivac Inc., Kansas City, MO), and stored (-30±2°C) for further analysis. Thiobarbituric acid reactive substance analysis (TBARS) for measuring lipid oxidation was adopted from Ahn et al. (1998). Briefly, a 5-g meat sample thawed from the frozen sample was placed in a 50-ml centrifuge tube and homogenized (Tissumizer® Mark II, Tekmar® Company, Cinncinati, OH) with 15 ml of deionized distilled water for 30s. One milliliter of meat homogenate was transferred to disposable glass test tubes (13 x 100 mm). Fifty microliters of butylated hydroxyanisole (7.2%) and 2 ml thiobarbituric acid/trichloroacetic acid (TBA/TCA) solutions were added to the homogenate. The solution was vortexed and incubated in a boiling water bath for 15 min to develop color. After color development the sample was cooled for 10 min in cold water. The test tubes were then centrifuged at 4000 rpm (CR 312, Jouan Inc, Winchester, VA) for 15 min and the supernatant was separated for spectrophotometric analysis. The absorbance of the supernatant was measured at 531 nm (MQX200, µQuant, Bio-Tek Instruments Inc, Winooski, VT) and fitted against a standard curve. The 5-g samples were duplicated within each steak sample from each treatment and day. The lipid oxidation value was expressed in mg of malonaldehyde (MDA) per kg of meat.

Warner-Bratzler shear force analysis (WBS)

The frozen steaks for WBS analysis were thawed for 48 h at 4±2°C before cooking. The steaks were cooked by broiling (AMSA, 1995), on Faberware® Open-hearth broilers (Model 455ND, Bronx, NY) preheated for 20 min. The steaks were cooked until they reached an internal temperature of 71°C and turned once when their internal temperature reached 35°C. The internal temperature of the steaks was monitored by a Digi-Sense® 12-channel scanning thermocouple thermometer (Model 9200-00, Cole-Parmer, Vernon Hills, IL) with copper-constantan thermocouples inserted to the geometric center of the steaks. The weights of the steaks were recorded when frozen, after thawing and immediately after cooking to calculate thaw loss (%) and cook loss (%). The cooked steaks were allowed to cool to room temperature (21±2°C) for a minimum of 4 h before six 1.27-cm cores from the *gluteus medius* muscle of each steak were removed parallel to the longitudinal orientation of the muscle fibers using a hand-held coring device. The cores were sheared once perpendicular to the muscle fibers on a Universal Testing Machine (Dual Column Model 3365, Instron Worldwide Headquarters, Norwood, MA) with a 51 kgf load cell and a Warner Bratzler shear attachment set at a crosshead speed of 25 cm/min. The peak force (kgf) required to shear the sample was recorded for all the six cores.

Sensory analysis

Frozen steaks for sensory analysis were cooked similar to those used for shear analysis. After the steaks were cooked to an internal temperature of 71°C, they were served in heated yogurt makers (YM80, Euro Cuisine, Inc. Los Angeles, CA) to maintain temperature, to a 8 member trained sensory panel (AMSA, 1995). Each panelist received 2 sample cubes (1.27-cm^3) from the *gluteus medius* muscle to evaluate initial tenderness (8 = extremely tender and 1 = extremely tough),

sustained tenderness (8 = extremely tender and 1 = extremely tough), beef flavor intensity (8 = extremely intense and 1 = extremely bland), overall juiciness (8 = extremely juicy and 1 = extremely dry) and off-flavor (6 = extreme off-flavor and 1 = none detected). The sensory panelists evaluated 6 steaks in a session, with 2 sessions per d over a week's time. Samples were randomly assigned so that at each session each panelist received two samples from each treatment. The sensory panel room was equipped with a negative pressure ventilation system and red lighting.

Statistical analysis

The data for treatment effects on muscle characteristics including pickup, purge, pH and objective color were analyzed as a completely randomized design with the muscles as the experimental and observational unit. Muscles were nested within replication and muscle within each treatment was considered a random variable. For analysis of shelf-life purge, objective color, subjective color and TBARS during simulated retail display, data were analyzed as a completely randomized split-plot. Muscle was considered the whole plot and steak was considered the subplot. The analysis of WBS and sensory attributes were also conducted using a split-plot design. Muscle was considered the whole plot and steak was considered the subplot while the core for WBS or the cube for sensory analysis was considered the observational unit. All data for the completely randomized and split plot designs were analyzed using The Mixed procedures of Statistical Analysis System V.9.1 (2002, SAS Inst. Inc., Cary, NC). Means were separated using the PDIFF option in LSMEANS with Tukey adjustment. Chi-square Frequency procedures of SAS were used to test the frequency distribution of off-flavor descriptors for the treatment effects. Differences among means were considered significant at $\alpha \leq 0.05$.

RESULTS AND DISCUSSION

Pickup, purge and pH

Percent brine pickup was higher in CNT than IN or MO ($P<0.05$; Table 1) but there was no difference between IN and MO ($P>0.05$). Percent purge after 10 d storage was not different between the treatments ($P>0.05$). Muscle pH increased with time for all the treatments ($P<0.05$). Immediately after injection, IN and MO had a lower pH than CNT ($P<0.05$), but there was no difference in pH between treatments after 10 d of storage ($P>0.05$). Contrary to these results, Paulson et al. (Paulson et al., 2007) observed a decrease in pH over 14 d storage when sodium lactate or sodium lactate plus diacetate were include in the brine solutions for injection.

Shelf-life characteristics

Percent purge of steaks stored in retail display increased with time ($P<0.05$) from 1 to 21 d for CNT and MO (Table 2). There was an increase in percent purge between d 14 and d 21 for IN ($P<0.05$). However, there was no difference in percent purge between treatments ($P>0.05$). Sodium lactate was found to be ineffective in binding water and resulted in higher purge loss when included in brines for injection, whereas a mixture of lactate and diacetate exhibited less purge loss (Wicklund et al., 2006). On the contrary, Jensen et al. (2003) reported lower purge loss in pork chops when sodium acetate, potassium or sodium lactate was included in the brine and hypothesized that addition of salts and organic acids might have increased water holding capacity and hence cause lower purge and increase cook yield. The results obtained in the current study indicate that the antimicrobial ingredients do not have a negative impact on purge.

Hunter L, a and b values for the initial 14 d of retail storage are graphically presented in Figure 1. There was no change in Hunter L value with the increase in storage time ($P>0.05$); however,

Hunter a and b values decreased ($P<0.05$) as time increased. Furthermore, there was no difference in Hunter L, a and b values between the three treatments ($P>0.05$). Inclusion of sodium lactate in the brine for needle injection has been reported to result in steaks with lighter color and decreased redness, whereas inclusion of a mixture of sodium lactate and diacetate has resulted in darker and less red steaks (Wicklund et al., 2006). In the current study, IN (which is a blend of buffered sodium citrate and sodium acetate) and MO (which is a blend of vinegar) did not alter color in relation to CNT.

Subjective color measured over 14 d of retail storage is graphically presented in Figure 2. There was a treatment x time interaction for overall appearance ($P<0.05$). No difference was observed among the treatments for the initial 7 d of storage ($P<0.05$), but after 7 d CNT had significantly lower overall appearance compared to IN and MO ($P<0.05$). The redness of the steaks decreased with increased storage time ($P<0.05$); however, there was no significant difference between the treatments ($P>0.05$). There was a treatment x time interaction for discoloration ($P<0.05$). There was no significant difference in discoloration between the treatments for the initial 10 d of storage ($P<0.05$). After 10 d, CNT treatment had a decrease in discoloration. This could be attributed to the microbial growth on the surface which hindered the evaluation by the subjective color panel (Ponrajan, 2010). Hence, these results indicate that the inclusion of the antimicrobials did not negatively impact the color of the steaks.

Lipid oxidation

The results of the TBARS analysis indicated that there was a treatment x time interaction ($P<0.05$; Table 3). On d 1, 7 and 14, IN had lower TBARS values compared to CNT ($P<0.05$) whereas there was no difference between CNT and MO ($P>0.05$). On d 21, CNT had lower TBARS than MO ($P<0.0001$). However, there was no difference between CNT and IN or IN and MO ($P>0.05$). There was no increase in lipid oxidation for IN until d 14 ($P<0.05$). The TBARS value for CNT increased between d 1 and 7 ($P<0.05$) but decreased between d 14 and 21 ($P<0.05$). For MO, there was an increase in TBARS values between d 7 and 14 ($P<0.05$) and no change between d 1 and 7 or d 14 and 21 ($P>0.05$). The maximum TBARS values for CNT, IN and MO throughout the storage period were 0.93, 0.74 and 1.32, respectively. A TBARS value of 2 mg malonaldehyde per kg of meat has been reported to be the threshold level for sensory acceptability of oxidized beef (Campo et al., 2006). The results of the current experiment indicate that the maximum TBARS values of all the three treatments are below this threshold level. Citric acid has been reported to prevent lipid oxidation during acidification of beef (Ke et al., 2009). Also, sodium citrate has been reported to be a better antioxidant for salmon slices compared to sodium acetate and sodium lactate (Sallam, 2007). Hence, buffered sodium citrate in IN could be attributed for its effectiveness in controlling lipid oxidation compared to CNT and MO during the initial 14 d.

Warner-Bratzler shear force

There was no change in WBS with an increase in storage time ($P<0.05$; Table 4). On d 1 IN had a lower WBS than CNT and MO ($P<0.05$) but there was no difference between CNT and MO ($P>0.05$). On all other sampling days, there was no difference in WBS between the treatments ($P>0.05$). The maximum WBS for CNT, IN and MO throughout the storage period were 2.97, 2.61 and 2.84 kgf, respectively. Based on WBS, Belew et al. (2003) classified 40 bovine muscles as "very tender" (WBS < 3.2 kg), "tender" (3.2 < WBS < 3.9 kg), "intermediate" (3.9 < WBS < 4.6 kg) and "tough" (WBS > 4.6 kg). The results of the current study indicate that all muscles, which were obtained from market cows, under the three different treatments could be considered

very tender after enhancement. While evaluating the effect of aging for 28 d on the *gluteus medius* from USDA Select and upper-two thirds USDA Choice, Gruber et al. (2006) reported a WBS of 4.58 kg and 4.14 kg, respectively, for the two quality grades. Rhee et al. (2004) reported a WBS value of 4.44 kg for the *gluteus medius* while evaluating the WBS of eleven beef muscles at 72 h followed by 14 d aging at 2^{o}C. During the evaluation of the effect of concentrate feed for 0, 42 and 84 d on WBS of various muscles from cull beef cows, Stelzleni et al. (2008) reported the WBS of the *gluteus medius* from cull cows as 6.09 kg and 4.61 kg after 0 and 84 d of concentrate feed, respectively. While benchmarking the WBS of muscles from commercial cull cows, Stelzleni et al. (2007) measured the WBS of *gluteus medius* from cull cows to be 6.20 kg. Thus, the enhancement of muscles from market cows by multi-needle injection has improved the tenderness of the muscle and the inclusion of the antimicrobials did not have an effect on tenderness.

Percent thaw loss was higher for CNT on d 14 and 21 when compared to IN and MO ($P<0.05$; Table 5), but there was no difference between IN and MO ($P>0.05$). On d 7, IN had lower percent thaw loss when compared to CNT ($P=0.0039$), but there was no difference between CNT and MO or IN and MO ($P>0.05$). The mean percent thaw losses for CNT, IN and MO throughout the storage period were 2.55%, 1.09% and 1.69%, respectively. Percent cook loss for CNT was higher than IN on d 7 ($P=0.019$) while there was no significant difference between CNT and MO or IN and MO ($P>0.05$). On d 21, MO had lower percent cook loss compared to CNT and IN ($P<0.05$), but there was no significant difference between CNT and IN ($P>0.05$). There was no difference in percent cook loss on d 1 and 14 between the treatments ($P>0.05$). The mean percent cook losses for CNT, IN and MO throughout the storage period were 20.40%, 16.97% and 16.10%, respectively. As hypothesized by Jensen et al. (2003), the lower percent thaw loss and percent cook loss observed with IN and MO compared to CNT could be attributed to the salts of organic acids present in the antimicrobials which could have increased the water holding capacity and cook yields. Hence, the results of the current experiment indicate that the inclusion of IN and MO increased cook yield.

Sensory analysis

The initial and sustained tenderness scores show that MO was less tender than CNT ($P<0.05$; Table 6) while there was no difference between CNT and IN or IN and MO ($P>0.05$). There was no difference in the beef flavor intensity of the three treatments ($P>0.05$). Overall juiciness of CNT was higher than IN and MO ($P<0.05$); however, there was no difference between IN and MO ($P>0.05$). Off-flavor scores for MO were higher than CNT and IN ($P<0.05$), and there was no difference between CNT and IN ($P>0.05$). The mean off-flavor scores for CNT, IN and MO were 1.53, 1.63 and 2.28, respectively. While studying the effect of concentrate feed on palatability characteristic of muscles from cull beef cows, Stelzleni et al. (2008) reported that the *gluteus medius* received overall tenderness, beef flavor intensity and overall juiciness scores of 4.83, 5.67 and 5.12, respectively. While benchmarking muscles from commercially identified cull cows for sensory attributes, the *gluteus medius* received overall tenderness, beef flavor intensity and off-flavor scores of 4.1, 5.6 and 5.1, respectively (Stelzleni et al., 2007). From the current experiment it could be interpreted that IN and MO had little to no effect on the sensory attributes, except for a slight development of off-flavors.

CONCLUSION

The inclusion of IONAL® LC and MOstatin™ V as antimicrobials in the enhancement solution during multi-needle injection of top sirloins does not negatively impact the quality or sensory

characteristics of steaks and roasts fabricated after 10 d of storage. The only negative impact noted in this study was a slight development of off flavor by MOstatin™ V which was below the threshold level. The inclusion of these antimicrobials may increase the safety and shelf-life of needle enhanced beef products (Ponrajan, 2010) while maintaining the important traits for consumer acceptability such as tenderness, color and flavor.

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LITERATURE CITED

Ahn, D. U., D. G. Olson, J. I. Lee, C. Jo, C. Wu, and X. Chen. 1998. Packaging and irradiation effects on lipid oxidation and volatiles in pork patties. Journal of Food Science 63: 15-19.

AMSA. 1991. Guidlines for meat color evaluation. Reciprocal Meat Conference, Savoy, IL.

AMSA. 1995. Research guidelines for cookery, sensory evaluation and instrumental tenderness measurements of fresh meat. American Meat Science Association in cooperation with National Live Stock and Meat Board, now the National Cattleman's Beef Association, Centennial, CO.

Belew, J. B., J. C. Brooks, D. R. McKenna, and J. W. Savell. 2003. Warner-bratzler shear evaluations of 40 bovine muscles. Meat Science 64: 507-512.

Boyd, K. J., H. W. Ockerman, and R. F. Plimpton. 1978. Sensory characteristics and microbiological evaluation of stored mechanically tenderized beef *semimembranosus* muscle. Journal of Food Science 43: 670-676.

Brooks, J. C., J. B. Belew, D. B. Griffin, B. L. Gwartney, D. S. Hale, W. R. Henning, D. D. Johnson, J. B. Morgan, F. C. Parrish, J. O. Reagan, and J. W. Savell. 2000. National beef tenderness survey -1998. Journal of Animal Science 78: 1852-1860.

Campo, M. M., G. R. Nute, S. I. Hughes, M. Enser, J. D. Wood, and R. I. Richardson. 2006. Flavour perception of oxidation in beef. Meat Science 72: 303-311.

Davis, K. A., D. L. Huffman, and J. C. Cordray. 1975. Effect of mechanical tenderization, aging and pressing on beef quality. Journal of Food Science 40: 1222-1224.

Echeverry, A., J. C. Brooks, M. F. Miller, J. A. Collins, G. H. Loneragan, and M. M. Brashears. 2009. Validation of intervention strategies to control *Escherichia coli* O157:H7 and *salmonella typhimurium* dt 104 in mechanically tenderized and brine-enhanced beef. Journal of Food Protection 72: 1616-1623.

Food Safety Inspection Service, U. S. D. A. 2003. Recall notification report: 028-2003. United Stated Department of Agriculture, Washington D. C. Available at: http://www.fsis.usda.gov/Frame/FrameRedirect.asp?main=http://www.fsis.usda.gov/OA/recalls/rnrfiles/rnr028-2003.htm, Accessed on: October 14, 2009.

Food Safety Inspection Service, U. S. D. A. 2004. Recall notification report: 033-2004. United Stated Department of Agriculture, Washington D. C. Available at: http://www.fsis.usda.gov/fsis_recalls/rnr_033_2004/index.asp, Accessed on: October 14, 2009.

Food Safety Inspection Service, U. S. D. A. 2005. Haccp plan reassessment for mechanically tenderized beef products. Federal Register 70: 30331-30334.

Glover, E. E., J. C. Forrest, H. R. Johnson, V. D. Bramblett, and M. D. Judge. 1977. Palatability and cooking characteristics of mechanically tenderized beef. Journal of Food Science 42: 871-874.

Gruber, S. L., J. D. Tatum, J. A. Scanga, P. L. Chapman, G. C. Smith, and K. E. Belk. 2006. Effects of postmortem aging and usda quality grade on warner-bratzler shear force values of seventeen individual beef muscles. Journal of Animal Science 84: 3387-3396.

Heller, C. E., J. A. Scanga, J. N. Sofos, K. E. Belk, W. Warren-Serna, G. R. Bellinger, R. T. Bacon, M. L. Rossman, and G. C. Smith. 2007. Decontamination of beef subprimal cuts intended for blade tenderization or moisture enhancement. Journal of Food Protection 70: 1174-1180.

Jensen, J. M., C. Prestat, K. J. Ryan, K. L. Robbins, C. L. Homco-Ryan, F. McKeith, and M. S. Brewer. 2003. Enhancement solution effects on shelf-life, color and sensory characteristics of pork chops during retail display. Journal of Food Quality 26: 271-283.

Ke, S. M., Y. Huang, E. A. Decker, and H. O. Hultin. 2009. Impact of citric acid on the tenderness, microstructure and oxidative stability of beef muscle. Meat Science 82: 113-118.

Laine, E. S., J. M. Scheftel, D. J. Boxrud, K. J. Vought, R. N. Danila, K. M. Elfering, and K. E. Smith. 2005. Outbreak of *Escherichia coli* 0157:H7 infections associated with nonintact blade-tenderized frozen steaks sold by door-to-door vendors. Journal of Food Protection 68: 1198-1202.

Luchansky, J. B., R. K. Phebus, H. Thippareddi, and J. E. Call. 2008. Translocation of surface-inoculated *Escherichia coli* O157:H7 into beef subprimals following blade tenderization. Journal of Food Protection 71: 2190-2197.

Morgan, J. B., J. W. Savell, D. S. Hale, R. K. Miller, D. B. Griffin, H. R. Cross, and S. D. Shackelford. 1991. National beef tenderness survey. Journal of Animal Science 69: 3274-3283.

Paulson, D. D., R. A. Wicklund, M. C. Rojas, and M. S. Brewer. 2007. Effects of shelf life enhancers and microbial load on *Escherichia coli* k12 survival in injected beef strip steaks. Journal of Muscle Foods 18: 194-206.

Ponrajan, A. 2010. Effect of two antimicrobials against *Escherichia coli* O157:H7 and study of their quality characteristics when used in conjunction with multi-needle injection of whole muscle non-intact beef. Master's Thesis University of Georgia, Athens, GA.

Rhee, M. S., T. L. Wheeler, S. D. Shackelford, and M. Koohmaraie. 2004. Variation in palatability and biochemical traits within and among eleven beef muscles. Journal of Animal Science 82: 534-550.

Sallam, K. I. 2007. Antimicrobial and antioxidant effects of sodium acetate, sodium lactate, and sodium citrate in refrigerated sliced salmon. Food Control 18: 566-575.

Sporing, S. B. 1999. *Escherichia coli* O157:H7 risk assessment for production and cooking of blade tenderized beef steaks. Master's Thesis Kansas State University, Manhattan, KS.

Stelzleni, A. M., D. D. Johnson, and T. A. Thrift. 2008. Effects of days on concentrate feed and postmortem aging on carcass and palatability characteristics of selected muscles from cull beef cows. The Professional Animal Scientist 24: 334-341.

Stelzleni, A. M., L. E. Patten, D. D. Johnson, C. R. Calkins, and B. L. Gwartney. 2007. Benchmarking carcass characteristics and muscles from commercially identified beef and dairy cull cow carcasses for warner-bratzler shear force and sensory attributes. Journal of Animal Science 85: 2631-2638.

Voges, K. L., C. L. Mason, J. C. Brooks, R. J. Delmore, D. B. Griffin, D. S. Hale, W. R. Henning, D. D. Johnson, C. L. Lorenzen, R. J. Maddock, R. K. Miller, J. B. Morgan, B. E. Baird, B. L. Gwartney, and J. W. Savell. 2007. National beef tenderness survey - 2006: Assessment of warner-bratzler shear and sensory panel ratings for beef from us retail and foodservice establishments. Meat Science 77: 357-364.

Wicklund, R. A., D. D. Paulson, M. C. Rojas, and M. S. Brewer. 2006. Effects of shelf-life enhancers on *E. coli* k12 survival in solutions used to enhance beef strip steaks. Journal of Food Science 71: M190-M195.

Wicklund, R. A., D. D. Paulson, M. C. Rojas, and M. S. Brewer. 2007. The effects of shelf-life enhancers on *E. coli* k12 survival in needle-injected, surface contaminated beef strip steaks enhanced using recycled solutions. Meat Science 75: 371-380.

Wicklund, S. E., C. Homco-Ryan, K. J. Ryan, F. K. McKeith, B. J. McFarlane, and M. S. Brewer. 2005. Aging and enhancement effects on quality characteristics of beef strip steaks. Journal of Food Science 70: S242-S247.

Table 1. Least squares means and SE for top sirloin percent pickup, percent purge and pH before and after injection and after 10 d of post injection storage

	Treatment		
Traits	CNT	IN	MO
Pickup (%)	11.60 ± 0.54^{a}	9.90 ± 0.35^{b}	10.24 ± 0.39^{b}
Purge (%)	1.90 ± 0.14	1.90 ± 0.10	2.20 ± 0.13
pH			
Before injection	5.30 ± 0.02^{z}	5.28 ± 0.02^{z}	5.29 ± 0.02^{z}
After injection	$5.59 \pm 0.04^{a,y}$	$5.33 \pm 0.03^{b,z}$	$5.38 \pm 0.02^{b,y}$
After 10d storage	5.68 ± 0.03^{x}	5.65 ± 0.03^{y}	5.65 ± 0.04^{x}

[ab]Means within a row with different superscripts differ (*P<0.05*).
[xyz]Means within a column with different superscripts differ (*P<0.05*).

Table 2. Least squares means and SE of percent purge for top sirloin steaks over 21 d retail display after 10 d of post injection storage

	Treatment		
Storage time[1]	CNT	IN	MO
Day 1	0.25 ± 0.25^{z}	---	0.90 ± 0.47^{z}
Day 7	1.40 ± 0.39^{y}	1.27 ± 0.43^{z}	1.10 ± 0.47^{z}
Day 14	2.38 ± 0.60^{xy}	1.78 ± 0.30^{z}	2.14 ± 0.40^{zy}
Day 21	3.09 ± 0.4^{x}	3.01 ± 0.33^{y}	3.22 ± 0.52^{y}

[yz]Means within a column and muscle with different superscripts differ (*P<0.05*).
[1]No significant difference between treatments on a given day (*P>0.05*).

Table 3. Least squares means and SE of lipid oxidation measurement using thiobarbituric acid reactive substances analysis (mg malonaldehyde per kg of meat) for top sirloin steaks over 21 d retail display after 10 d of post injection storage

	Treatment		
Storage time	CNT	IN	MO
Day 1	$0.35 \pm 0.06^{a,z}$	$0.13 \pm 0.03^{b,z}$	$0.20 \pm 0.04^{ab,z}$
Day 7	$0.79 \pm 0.13^{a,y}$	$0.14 \pm 0.01^{b,z}$	$0.26 \pm 0.04^{ab,z}$
Day 14	$0.93 \pm 0.19^{a,y}$	$0.23 \pm 0.02^{b,z}$	$1.32 \pm 0.23^{a,y}$
Day 21	$0.49 \pm 0.10^{b,z}$	$0.74 \pm 0.09^{ab,y}$	$1.26 \pm 0.12^{a,y}$

[ab]Means within a row with different superscripts differ (*P<0.05*).
[yz]Means within a column with different superscripts differ (*P<0.05*).

Table 4. Least squares means and SE of Warner-Bratzler shear force (kgf) for top sirloin steaks over 21 d storage after 10 d of post injection storage

	Treatment[1]		
Storage time	CNT	IN	MO
Day 1	2.97 ± 0.12[a]	2.53 ± 0.10[b]	2.84 ± 0.11[a]
Day 7	2.65 ± 0.12	2.42 ± 0.10	2.71 ± 0.11
Day 14	2.85 ± 0.11	2.54 ± 0.09	2.60 ± 0.10
Day 21	2.90 ± 0.11	2.61 ± 0.10	2.66 ± 0.13

[ab]Means within a row with different superscripts differ (*P<0.05*).
[1]No significant difference between the days within a treatment (*P>0.05*).

Table 5. Least squares means and SE of percent thaw loss and percent cook loss for top sirloin steaks over 21 d storage after 10 d of post injection storage

	Treatment		
Traits	CNT	IN	MO
Thaw loss (%)			
Day 1	2.01 ± 0.34	1.45 ± 0.15[y]	2.03 ± 0.22[xy]
Day 7	2.81 ± 0.25[a]	1.68 ± 0.27[ab,y]	2.43 ± 0.25[a,x]
Day 14	2.81 ± 0.48[a]	0.77 ± 0.13[b,z]	1.58 ± 0.22[b,y]
Day 21	2.56 ± 0.55[a]	0.44 ± 0.09[b,z]	0.73 ± 0.18[b,z]
Cook loss (%)			
Day 1	20.37 ± 1.29	18.33 ± 1.62[yz]	19.92 ± 2.07[y]
Day 7	19.41 ± 1.13[a]	13.33 ± 1.50[b,z]	15.13 ± 1.59[ab,z]
Day 14	19.69 ± 1.47	16.09 ± 0.99[yz]	15.01 ± 1.86[z]
Day 21	22.15 ± 1.68[a]	20.11 ± 1.62[a,y]	14.36 ± 0.99[b,z]

[ab]Means within a row with different superscripts differ (*P<0.05*).
[xyz]Means within a column with different superscripts differ (*P<0.05*).

Table 6. Least squares means and SE of sensory attributes for top sirloin steaks over 21 d storage after 10 d of post injection storage

	Treatment		
Traits	CNT	IN	MO
Initial Tenderness[1]	6.30 ± 0.24[a]	5.69 ± 0.24[ab]	5.43 ± 0.24[b]
Sustained Tenderness[1]	6.37 ± 0.23[a]	5.64 ± 0.23[ab]	5.31 ± 0.23[b]
Beef Flavor Intensity[1]	5.26 ± 0.14	5.06 ± 0.14	4.90 ± 0.14
Overall Juiciness[1]	5.43 ± 0.19[a]	4.80 ± 0.19[b]	4.74 ± 0.19[b]
Off-flavor[2]	1.53 ± 0.16[b]	1.63 ± 0.16[b]	2.28 ± 0.16[a]

[ab]Means within a row with different superscripts differ (*P<0.05*).
[1]8 = extremely tender, intense, juicy and 1 = extremely tough, bland, dry.
[2]6 = extreme off-flavor and 1 = none detected.

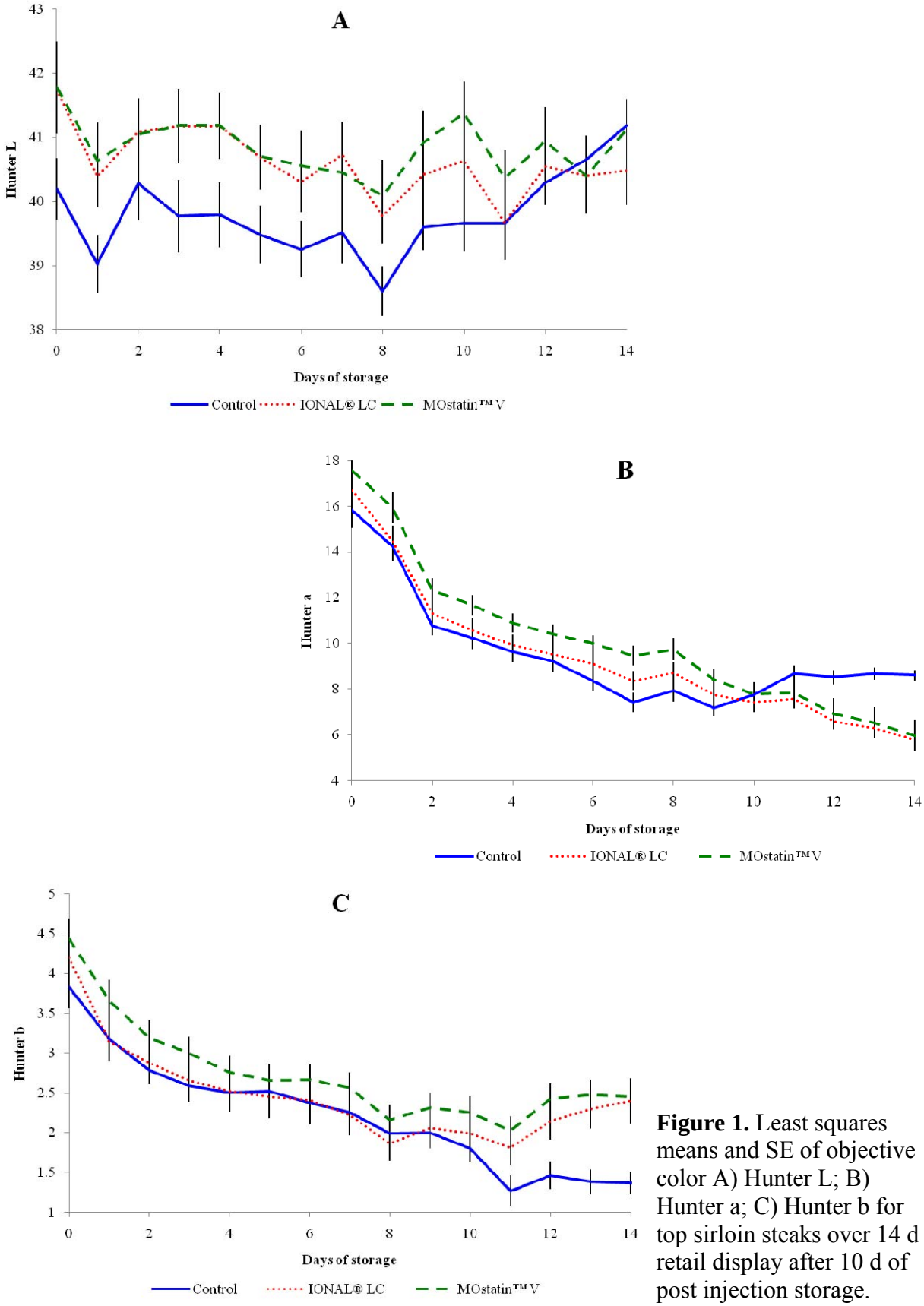

Figure 1. Least squares means and SE of objective color A) Hunter L; B) Hunter a; C) Hunter b for top sirloin steaks over 14 d retail display after 10 d of post injection storage.

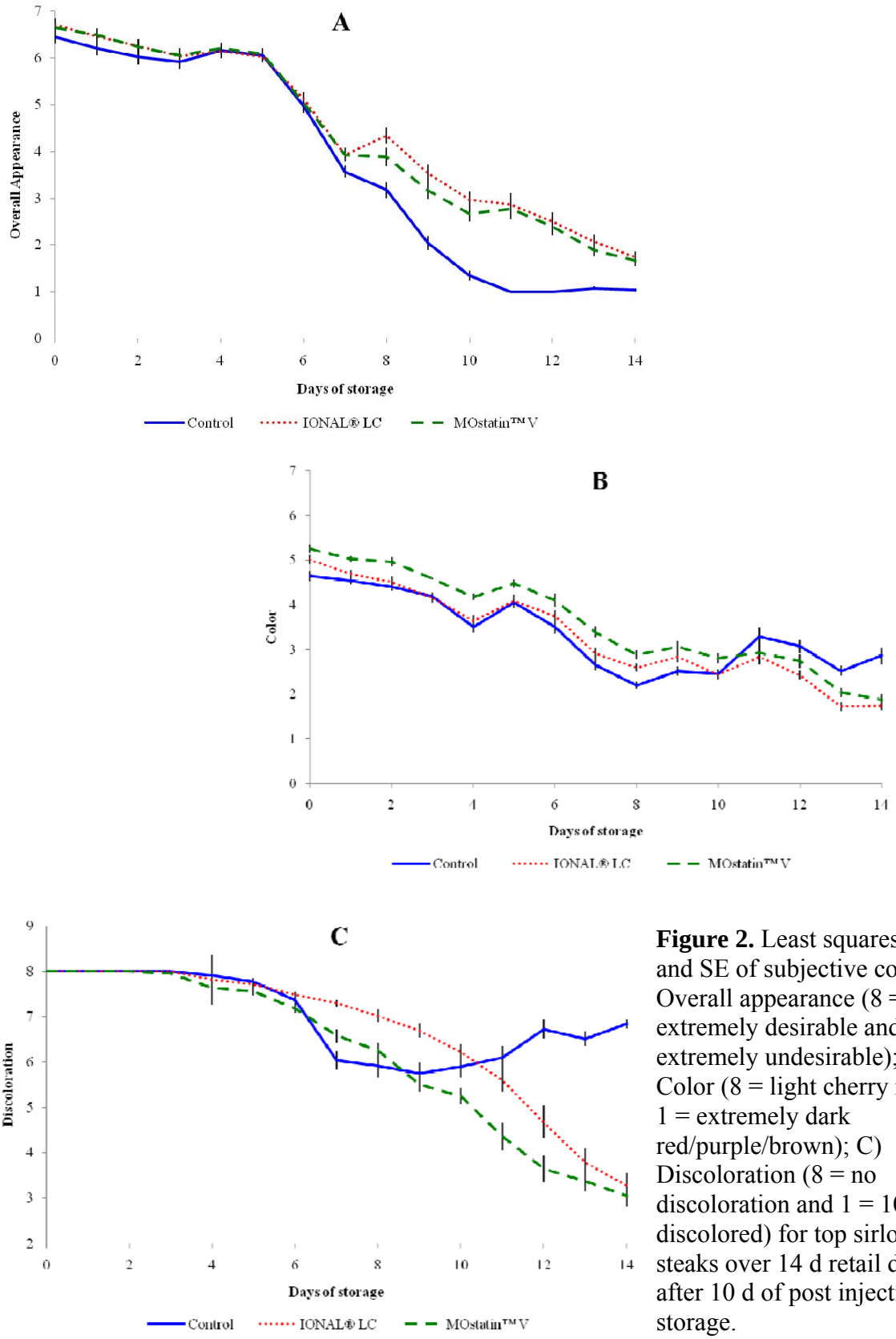

Figure 2. Least squares means and SE of subjective color A) Overall appearance (8 = extremely desirable and 1= extremely undesirable); B) Color (8 = light cherry red and 1 = extremely dark red/purple/brown); C) Discoloration (8 = no discoloration and 1 = 100% discolored) for top sirloin steaks over 14 d retail display after 10 d of post injection storage.