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Effects of Enhancement and Modified Atmosphere Packaging on Flavor and Tenderness of Dark-Cutting Beef

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Abstract: The objective of this study was to evaluate the effects of rosemary/beef flavor enhancement and modified atmosphere packaging (MAP) on retail display color and palatability of beef *longissimus lumborum* muscle. Dark-cutting beef strip loins ($n = 8$; pH > 6.0) and USDA Low Choice beef strip loins ($n = 5$) were selected from a commercial packing plant within 72 h of harvest. Dark-cutting strip loins were divided into 2 equal sections and randomly assigned to either nonenhanced or rosemary/beef flavor–enhanced treatments. Dark-cutting enhanced loins were injected to 110% of their green weight with a rosemary/beef flavor enhancement to attain 0.1% rosemary, 0.5% salt, and 0.55% beef flavor in the final product. Six 2.54-cm-thick steaks were cut from nonenhanced USDA Choice, nonenhanced dark-cutting, and enhanced dark-cutting strip loins and randomly assigned to one of 3 packaging treatments: vacuum packaging, carbon monoxide MAP (0.4% CO, 69.6% N, and 30% CO_2), and high-oxygen MAP (80% O_2 and 20% CO_2). Following 3-d retail display, instrumental color measurements were recorded, and one steak from each packaging type was evaluated by a trained sensory taste panel and another used to measure Warner-Bratzler shear force. Enhanced dark-cutting steaks packaged in high-oxygen MAP and carbon monoxide MAP had greater a^* values ($P < 0.0001$) than dark-cutting steaks in vacuum packaging. Enhanced dark-cutting steaks were lighter ($P < 0.0001$, greater L^* values) than nonenhanced dark-cutting steaks. Nonenhanced dark-cutting steaks exhibited a lower ($P = 0.03$) overall juiciness compared to enhanced dark-cutting steaks. Enhanced and nonenhanced dark-cutting steaks were more tender ($P = 0.002$) than the USDA Choice steaks. Enhanced dark-cutting steaks had higher ($P = 0.006$) sour flavor in vacuum packaging than other packaging types. The results suggest that rosemary/beef flavor enhancement has the potential to improve the surface color of dark-cutting beef while improving or maintaining palatability.

Key words: antioxidants, beef flavor, dark-cutter, enhancement, packaging
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Introduction

Beef palatability and color are the two most important quality characteristics that influence eating experience and purchasing decisions, respectively (Mancini and Hunt, 2005; Kim et al., 2018). Immediately after animal harvest, the metabolism changes from aerobic to anaerobic. Both palatability and color are influenced by the extension of postmortem muscle metabolism. For example, the glycolytic pathway decreases postmortem muscle pH to approximately 5.6, which can impact both eating experience and appearance. Dark-cutting beef is an example of an altered postmortem muscle metabolism in which the muscle pH ranges from 6.0 to 6.8. Boykin et al. (2017) reported that 1.9% of the carcasses evaluated were discounted as dark-cutters in the 2016 National Beef Quality Audit. Therefore, improving the appearance of beef without affecting palatability is important to enhancing the value of dark-cutting beef.

Many approaches, such as lowering muscle pH (Sawyer et al., 2009a; Apple et al., 2011) or modified atmosphere packaging (MAP) conditions (Gill and Penney, 1986; Rousset and Renerre, 1991; López-Campos et al., 2014; Mitacek et al., 2018; Zhang et al., 2018), have been used to improve the redness of dark-cutting beef. More specifically, the use of carbon monoxide modified atmosphere packaging (CO-MAP; 0.4% carbon monoxide; Mitacek et al., 2018; Zhang et al., 2018), nitrite packaging (Ramanathan et al., 2018), and high-oxygen modified atmosphere packaging (HiOx-MAP; 80% oxygen) can increase the bright cherry-red color of high-pH dark-cutting beef (López-Campos et al., 2014). Previous studies from our laboratory have reported that a combination of rosemary enhancement and MAP was more effective than MAP packaging alone to improve the redness and lightness of dark-cutting beef (Wills et al., 2017). For example, CO-MAP and HiOx-MAP improved redness (a^* values) by 32% and 41%, respectively, compared with dark-cutting steaks in polyvinyl chloride (PVC) aerobic packaging (Wills et al., 2017). However, limited studies have determined the effects of improved color on palatability traits.

Greater-than-normal pH can influence lactic acid levels, water-holding capacity, and proteolysis. The research determining the palatability of dark-cutting beef is not consistent (Wulf et al., 2002; Yancey et al., 2005; Grayson et al., 2016). Some researchers reported that there are no palatability differences between normal and dark-cutting carcasses, while others reported detection of flavor differences (Wulf et al., 2002; Yancey et al., 2005; Grayson et al., 2016). Therefore, characterizing the flavor profiles of enhanced dark-cutting beef will provide an additional marketing opportunity for increasing the value of beef discounted as a “dark-cutter.” Therefore, the objective of the current research was to determine the effects of rosemary/beef flavor enhancement and MAP on retail display, flavor, and tenderness of beef *longissimus lumborum* muscle.

Materials and Methods

Raw materials and processing

Five USDA Low Choice (normal-pH) and eight dark-cutting beef carcasses (pH > 6.0) were selected, identified, and marked prior to fabrication from Creekstone Farms in Arkansas City, KS, within 72 h of harvest. Care was taken to limit variation between carcasses and have similar marbling. Carcasses were fabricated, and strip loins were collected (*longissimus lumborum*; Institutional Meat Purchase Specifications 180) from one side, vacuum packaged, and transported on ice to the Robert M. Kerr Food & Agriculture Product Center at the Oklahoma State University campus in Stillwater, OK. Dark-cutting loins were divided into 2 equal sections and randomly assigned to one of the following enhancement treatments: nonenhanced or rosemary/beef flavor–enhanced treatment. In the current research, our aim was to compare the effects of color-enhancing interventions on the palatability of enhanced loins with nonenhanced loins. Various studies have shown that water enhancement can increase juiciness. Therefore, water-enhancement control treatment was not included in the present study. In order to limit variation caused by the location, each normal-pH USDA Choice loin was divided into 2 sections, and 1 section was randomly used in the study. Normal-pH USDA Choice loins were utilized to characterize the normal-pH steak color and flavor. Both normal-pH USDA Choice and dark-cutting strip loin sections were packaged in 11×22 cm^2, 3-mil-high-barrier Cryovac vacuum bags (standard barrier nylon/polyethylene, 0.6 cm^3 O_2/645.16 cm^2/24 h at 0°C) utilizing a Multivac C500 vacuum packager, and were aged at 2°C for 14 d (17 d postmortem).

Enhancement

The enhancement solution was prepared by mixing deionized water stored at 2°C with 1.1% rosemary (Herbalox oleoresin rosemary, Kalsec, Kalamazoo, MI), 5% salt, and 5.5% beef flavor (ProBase B3301 Spray-Dried Beef Flavor; Essentia Protein Solutions, Ankeny, IA) using a handheld mixer for 2 min and stored under refrigerated temperature at 2°C for 24 h. Prior to enhancement, the solution was remixed to distribute the ingredients uniformly. Each loin section was individually weighed prior to enhancement to determine the green weight and calculate the percent pump. The average injection level was 10.8%, standard error = 0.6.

After the 14-d aging period, high-pH loin sections were then individually pumped to 110% of green weight with a handheld multi-needle injection system (Leeson motor; Grafton, WI) to achieve 0.1% rosemary, 0.5% salt, and 0.55% beef flavor in the final product. Sections were vacuum tumbled utilizing a Koch LT-15 vacuum tumbler (Koch; UltraSource USA, Kansas City, MO) at 12 psi for 5 min. Plastic tags were used to track the identity of loin sections during tumbling (Laser 3 Meat Fasteners, M63-Y Yellow, Meyers & Sons, Korea). The sections were re-weighed to measure the injection level percentage (10% of green weight). The injection level was calculated as (postenhancement loin section weight ÷ loin section weight prior to enhancement) × 100.

pH

The pH of Choice, nonenhanced dark-cutting, and enhanced dark-cutting strip loin sections were determined by inserting a pH probe at 4 different locations using a Mettler Toledo SevenGo pH meter (Mettler Toledo, Colombus, OH).

Packaging and retail display

Six 2.54-cm-thick steaks were cut from the anterior end of each normal-pH USDA Choice, nonenhanced dark-cutting, and enhanced dark-cutting strip loin sections and were assigned to one of 3 packaging treatments: (1) vacuum packaging (VP), (2) CO-MAP (0.4% CO, 69.6% N, and 30% CO_2), and (3) HiOx-MAP (80% O_2 and 20% CO_2). For USDA Choice sections, 5 loins × 6 steaks = 30 ÷ 3 = 10 steaks per packaging treatment, and for dark-cutting sections, 8 loins × 6 steaks = 48 ÷ 3 = 18 steaks per packaging treatment. Steaks assigned to CO-MAP and HiOx-MAP packaging were placed in Rock-Tenn Dura-Fresh rigid trays (22.2 cm × 17.1 cm × 4.5 cm; RockTenn Company, Norcross, GA) and sealed with clear, multilayer barrier film (1 mil, < 20 cm^3 $O_2/m^2/$24 h, at 4.4°C, LID 1050 film; Cryovac Sealed Air, Duncan, SC). The CO- and HiOx-MAP packaging was accomplished utilizing a Mondini semiautomatic tray-sealing machine (Model: CV/VG-5, G.; Mondini, Cologne, Italy) and certified gas blends (Stillwater Steel, Stillwater, OK). Gas compositions within the packages (O_2, CO, and CO_2) were measured utilizing a headspace analyzer (Bridge 900131 $O_2/CO_2/CO$; Illinois Instruments, Ingleside, IL) 5 h after packaging. The headspace analysis indicated that the average gas compositions were 0.34% and 76% carbon monoxide and oxygen, respectively.

Packages were randomly placed in a coffin-style retail display case under continuous fluorescent lighting (Philips Fluorescent lamps; 12 Watts, 48 inches; Philips, China; color temperature = 3,500 K) and maintained at 2°C ± 1°C for 5 d. The light intensity within the display case ranged from 714 to 1,150 lx (Extech Instruments Corporation, Waltham, MA). To limit the impact of location within the display case, the packages were rotated daily and remained in the retail case for 3 d. Following 3-d retail display, the instrumental color was measured using a HunterLab MiniScan XE Plus spectrophotometer (2.5-cm aperture, Illuminant A, and 10° standard observed angle; HunterLab Associates, Reston, VA) to measure surface color at 2 locations on each steak. Objective measures of L^*, a^*, and b^* values were utilized to characterize the surface color. For MAP-packaged steaks, color measurements were taken through the packaging film. Care was taken to limit the accumulation of fat and/or moisture smear on the MAP film after color measurements, as described in the AMSA (2012) Meat Color Measurement Guidelines. The surface color of VP steaks was taken through the packaging material.

Proximate composition analysis

Proximate compositions of each normal-pH and nonenhanced dark-cutting steaks were determined on 14-d-aged samples ($n = 5$ for Choice and $n = 8$ for dark-cutting steaks). Two-hundred-gram ground samples from normal-pH steaks and nonenhanced dark-cutting beef were utilized to measure moisture, protein, and fat using an AOAC-approved FOSS FoodScan™ 78800 near-infrared spectrophotometer (Dedicated Analytical Solutions, Hillerod, Denmark). The proximate composition was recorded on a percentage basis.

Trained sensory panel

Trained sensory panel methods were approved by the Institutional Review Board (Protocol Number: AG1528) of Oklahoma State University. The panelists were trained to become familiar with the Beef Flavor Lexicon (Adhikari et al., 2011). A 6-member trained panel evaluated 11 samples during each session. Each panelist analyzed 63 samples (dark-cutter = 8 replications × 2 treatments × 3 packaging = 48; USDA Choice = 5 replications × 3 packaging = 15). Sensory panel training was conducted to evaluate palatability attributes of normal-pH USDA Choice, nonenhanced dark-cutting, and enhanced dark-cutting strip loins on day 3 of the display.

Following color measurements, steaks in MAP were repackaged in vacuum and frozen at −20°C until use. For sensory evaluation, steaks were thawed under refrigerated conditions at 4°C for 24 h. Steaks were cooked on an XLT Impingement Oven (model 3240-TS, BOFI Inc., Wichita, KS) set at 200°C to an internal temperature of 68°C. Steak internal temperature was monitored using a handheld probe thermometer (AccuTuff 340, Atkins, Gainesville, FL) inserted into the geometric center. Cooked steaks were cut into

1-cm^3 cubes; 2 cubes were then placed in a sample cup, assigned a random number, and placed in warmers with hot packs to maintain temperature through sensory evaluation. Sensory panelists characterized samples under red lighting and were given deionized water and unsalted saltine crackers to use as palate cleansers between samples. Panelists assigned steak attributes for each sample utilizing a 3-point scale for beef flavor, sour flavor, metallic flavor, and off-flavor (1 = not detectable, 2 = slightly, 3 = strong) and utilizing an 8-point scale for overall juiciness and overall tenderness (1 = extremely dry/tough, 8 = extremely juicy/tender).

Warner-Bratzler shear force

Following day 3 color measurements, the steaks were frozen at −20°C until use. For Warner-Bratzler shear force evaluation, steaks were thawed under refrigerated conditions at 4°C for 24 h. Steaks were cooked on an XLT Impingement Oven (model 3240-TS, BOFI Inc., Wichita, KS) set at 200°C to an internal temperature of 68°C. Cooked steaks were placed in a tray, covered with aluminum foil, and placed in refrigerated conditions (4°C) for 18 h prior to Warner-Bratzler shear force evaluation. Chilled steaks equilibrated to room temperature (approximately 30 min) before being trimmed of visible fat and heavy connective tissue to expose muscle fiber orientation. From each steak, six 1.27-cm cores were removed parallel to the muscle fibers using a handheld coring device. A Warner-Bratzler Meat Shear attachment for an Instron Universal Testing Machine (Model 5943, Intron Corporation, Norwood, MA) was used to determine maximum shear force value. The crosshead speed was 200 mm/min, and the software utilized was Bluehill 3 (Instron Corporation, Norwood, MA). A maximum load (Newton) was recorded for each core. The mean maximum shear force values were used for statistical analysis.

Statistical analyses

A completely randomized block design was utilized to determine the effects of improved color on palatability ($n = 8$ replications). Each loin served as a block. The fixed effect included enhancement, packaging, and their interactions. The loins were served as a random effect. The data were analyzed using the PROC GLM procedure of SAS (SAS Institute Inc., Cary, NC). In trained panel analysis, the panelists were identified as a random effect. Least-squares means were calculated, and where analysis of variance testing indicated significance, means were separated using the PDIFF procedure and $\alpha < 0.05$. Tendencies were indicated at $P < 0.10$.

Results

Proximate analysis

Proximate analysis of dark-cutting and normal-pH steak sections showed no differences in protein and fat percentages (Table 1). However, dark-cutting steaks had a greater ($P < 0.0001$) percent moisture compared with normal-pH steaks. As expected, the pH of dark-cutting steaks was greater than USDA Choice; however, there were no differences between enhanced dark-cutting and nonenhanced dark-cutting sections.

L^* and a^* values

There was a significant packaging × muscle treatment interaction resulted for L^* and a^* values on day 3 of retail display (Table 2). Enhanced dark-cutting steaks packaged in VP had greater ($P < 0.05$) L^* values than nonenhanced dark-cutting steaks. However, there were no differences ($P > 0.05$) in L^* values for enhanced dark-cutting steaks compared to nonenhanced dark-cutting steaks packaged in either CO-MAP or HiOx-MAP. L^* values were greatest for USDA Choice steaks compared with other muscle treatments for all 3 packaging treatments. Further, nonenhanced dark-cutting steaks had lower ($P < 0.05$) L^* than any other muscle treatment and packaging combinations.

Enhanced dark-cutting steaks had greater ($P < 0.05$) redness (a^*) values than USDA Choice and

Table 1. Proximate compositions and pH of USDA Choice and dark-cutting steaks

Muscle Treatment	Moisture, %	Fat, %	Protein, %
Normal-pH USDA Choice	66.43^b	7.78^a	22.86^a
Nonenhanced Dark-Cutter	70.02^a	7.31^a	21.48^a
Standard Error	0.43	0.84	0.58
P value	< 0.0001	0.45	0.14
	pH	**Range**	
Normal-pH USDA Choice	5.6^a	5.5–5.6	
Nonenhanced Dark-Cutter	6.4^b	6.2–6.4	
Enhanced Dark-Cutter	6.3^b	6.1–6.3	
Standard Error	0.04		
P value	< 0.001		

$n = 8$ for enhanced and nonenhanced dark-cutter; $n = 5$ for USDA Choice.

$^{a–b}$Least-squares means within a parameter lacking a common letter differ ($P < 0.05$).

Table 2. Least-squares means of packaging[1] × enhancement on CIE L^* and a^* values

	L^*				a^*			
Packaging Type	VP	CO-MAP	HiOx-MAP	SEM	VP	CO-MAP	HiOx-MAP	SEM
Muscle Treatment								
USDA Choice	38.20^{c}	41.88^{b}	44.87^{a}	0.93	16.23^{g}	25.25^{c}	30.47^{a}	0.61
Nonenhanced dark-cutter	31.92^{e}	36.39^{cd}	35.75^{cd}	0.79	17.86^{f}	22.37^{d}	25.02^{c}	0.4
Enhanced dark-cutter	35.57^{d}	36.58^{cd}	37.68^{cd}	0.79	19.62^{e}	27.15^{b}	27.59^{b}	0.4
P value		=0.04				< 0.0001		

[1] Steaks from each treatment were packaged in one of 3 packaging types: vacuum packaging (VP), carbon monoxide modified atmosphere packaging (CO-MAP; 0.4% carbon monoxide), and high-oxygen modified atmosphere packaging (HiOx-MAP; 80% oxygen).

$n = 8$ for enhanced and nonenhanced dark-cutter; $n = 5$ for USDA Choice.

[a–e] Least-squares means within a color measurement lacking a common letter differ ($P < 0.05$).

CIE, Commission Internationale de l'Éclairage (International Commission on Illumination); SEM, standard error of the mean.

nonenhanced dark-cutting steaks packaged in either VP or CO-MAP. In addition, an increase in ($P < 0.05$) a^* value was observed for enhanced dark-cutting steaks compared with nonenhanced dark-cutting steaks packaged in HiOx-MAP. For all muscle treatments, steaks packaged in either CO-MAP or HiOx-MAP had greater a^* values compared with VP steaks.

Trained sensory panel

Table 3 shows muscle treatment and packaging main effects for beef palatability attributes determined by a trained panel. For beef flavor attributes, USDA Choice steaks had a greater ($P < 0.05$) beef flavor score than enhanced dark-cutting steaks. There were no differences ($P > 0.05$) among muscle treatments for metallic flavor attributes. Enhanced dark-cutting steaks had the highest ($P < 0.05$) off-flavor score. In addition, enhanced dark-cutting steaks had greater ($P < 0.05$) overall juiciness scores than nonenhanced dark-cutting steaks. The overall tenderness scores indicated that USDA Choice steaks possessed the lowest ($P < 0.05$) tenderness values. Similar ($P > 0.05$) tenderness values were reported between nonenhanced and enhanced dark-cutting steaks. The packaging had a significant impact on the sour flavor of steaks. Steaks packaged in CO-MAP had higher ($P < 0.05$) sour flavor scores than steaks packaged in HiOx-MAP and VP.

Table 3. Enhancement main effects of trained panelists' scores[1] for beef palatability attributes

Main Effects	Beef Flavor	SEM	Metallic Flavor	SEM	Sour Flavor	SEM	Off-Flavor	SEM	Overall Juiciness	SEM	Overall Tenderness	SEM
Muscle Treatment												
USDA Choice	2.09^{a}	0.07	1.29	0.03	1.08^{b}	0.05	1.38^{b}	0.07	6.55^{ab}	0.09	6.50^{b}	0.11
Nonenhanced dark-cutter	2.06^{ab}	0.06	1.33	0.04	1.37^{a}	0.06	1.47^{b}	0.06	6.48^{b}	0.08	6.87^{a}	0.09
Enhanced dark-cutter	1.88^{b}	0.06	1.22	0.03	1.44^{a}	0.05	1.90^{a}	0.06	6.76^{a}	0.08	7.03^{a}	0.09
P value	0.05		0.12		< 0.0001		< 0.001		0.04		0.001	
Packaging Type[2]												
HiOx-MAP	2.00	0.06	1.25	0.04	1.33^{a}	0.05	1.66	0.07	6.48	0.08	6.86	0.10
CO-MAP	1.99	0.06	1.33	0.04	1.17^{b}	0.05	1.48	0.07	6.73	0.08	6.70	0.10
VP	1.99	0.06	1.25	0.04	1.39^{a}	0.05	1.60	0.07	6.57	0.08	6.85	0.10
P value	0.98		0.26		0.01		0.15		0.11		0.40	

[1] Trained panelists used the following scales: beef flavor, sour flavor, metallic flavor, and off-flavor were determined using a 3-point scale (1 = not detectable, 2= slight, 3 = strong); overall juiciness and overall tenderness were evaluated utilizing an 8-point scale (1 = extremely dry, 8 = extremely juicy; 1 = extremely tough, 8 = extremely tender).

[2] Steaks from each treatment were packaged in one of 3 packaging types: vacuum packaging (VP), carbon monoxide modified atmosphere packaging (CO-MAP; 0.4% carbon monoxide), and high-oxygen modified atmosphere packaging (HiOx-MAP; 80% oxygen).

$n = 8$ for enhanced and nonenhanced dark-cutter; $n = 5$ for USDA Choice.

[a,b] Means within a trained panel attribute lacking a common letter differ ($P < 0.05$).

SEM, standard error of the mean.

There was a packaging × muscle treatment interaction ($P < 0.05$) observed for sour flavor (Table 4). Nonenhanced dark-cutting steaks packaged in VP had a lower sour flavor ($P < 0.05$) than enhanced dark-cutting steaks in VP. Enhanced dark-cutting steaks in VP had a greater sour score ($P < 0.05$) than enhanced dark-cutting steak in VP. However, there were no differences ($P > 0.05$) among muscle treatments in CO-MAP for sour flavor scores. In HiOx-MAP, nonenhanced dark-cutting steaks had a lower ($P < 0.05$) sour flavor score than USDA Choice and enhanced dark-cutting steaks.

Warner-Bratzler shear force

There were no muscle treatment or packaging differences ($P > 0.05$) for Warner-Bratzler shear force (Table 5). Nonenhanced dark-cutting steaks tended ($P < 0.1$) to have greater shear force values compared to USDA Choice and enhanced dark-cutting steaks.

Table 4. Least-squares means of packaging[1] × enhancement on trained panelists' scores of sour flavor

	Packaging			
Muscle Treatment	VP	CO-MAP	HiOx-MAP	SEM
USDA Choice	1.40^{bc}	1.20^{cd}	1.50^{ab}	0.09
Nonenhanced Dark-Cutter	1.02^{d}	1.10^{d}	1.12^{d}	0.08
Enhanced Dark-Cutter	1.74^{a}	1.22^{cd}	1.36^{bc}	0.08
P value		0.006		

[1] Steaks from each treatment were packaged in one of 3 packaging types: vacuum packaging (VP), carbon monoxide modified atmosphere packaging (CO-MAP; 0.4% carbon monoxide), and high-oxygen modified atmosphere packaging (HiOx-MAP; 80% oxygen). Trained panelist determined sour flavor using a 3-point scale (1 = not detectable, 3 = strong).

[a–d] Least-squares means within a color measurement lacking a common letter differ ($P < 0.05$).

SEM, standard error of the mean.

Table 5. Least-squares means for Warner-Bratzler shear values

Main Effects	WBS (N)		SEM
Muscle Treatment			
USDA Choice	18.14		1.27
Nonenhanced dark-cutter	22.06		1.08
Enhanced dark-cutter	18.93		1.08
P value		0.07	
Packaging Type			
HiOx-MAP	20.10		1.27
CO-MAP	20.20		1.27
VP	18.63		1.27
P value		0.70	

$n = 8$ for enhanced and nonenhanced dark-cutter; $n = 5$ for USDA Choice.

CO-MAP, carbon monoxide modified atmosphere packaging; HiOx-MAP, high-oxygen modified atmosphere packaging; SEM, standard error of the mean; VP, vacuum packaging; WBS, Warner-Bratzler shear.

Discussion

Effects of enhancement and packaging on color

Dark-cutting beef results from antemortem stress, decreasing the glycogen content in the muscle (Lawrie, 1958). A lack of glycogen limits pH decline after slaughter and results in a pH greater-than-normal muscle pH. Hughes et al. (2017) demonstrated that a greater pH could move further from the isoelectric point of meat, leading to increased water binding and muscle swelling. In the current research, moisture content was greater in dark-cutting beef compared with normal-pH beef. Previous research also noted greater moisture content in dark-cutting steaks than normal-pH steaks (Sawyer et al., 2009a; Apple et al., 2011; English et al., 2016; Wills et al., 2017). Additionally, muscle swelling can decrease light scattering and reflectance of dark-cutting beef, resulting in a darker appearance (Hughes et al., 2017; Ramanathan et al., 2020a).

Previous research determined the effects of packaging on the color characteristics of dark-cutting beef. In aerobic conditions, normal-pH steaks have greater L^* values compared with dark-cutting steaks (English et al., 2016; Wills et al., 2017; Mitacek et al., 2018; Ramanathan et al., 2020b). The atmospheric oxygen levels are not sufficient to meet the oxygen demands of dark-cutting beef myoglobin in PVC overwrap packaging. Therefore, earlier studies noted that darkness and redness were minimally improved with PVC packaging. However, HiOx-MAP and CO-MAP improved the redness and lightness of dark-cutting steaks. More specifically, greater oxygen content in HiOx-MAP can saturate myoglobin to form oxymyoglobin and improve redness (Ramanathan and Mancini, 2018). Similarly, a greater affinity of carbon monoxide to myoglobin can result in bright red carboxymyoglobin. Wills et al. (2017) demonstrated that a combination of rosemary enhancement and MAP had a greater impact on redness and lightness than nonenhanced counterparts. These authors attributed improved reflectance properties and redness to the presence of water in the enhancement solution.

In the current research, salt and beef flavor were added to offset any flavor issues in dark-cutting steaks. The addition of salt could have had effects on the color of the enhanced dark-cutting steaks. Research has shown that salt enhancement decreases the *L** values and *a** values of normal-pH meat stored in PVC and HiOx-MAP (Robbins et al., 2002; Baublits et al., 2005, 2006a, 2006b; Knock et al., 2006; Pietrasik and Janz, 2009). Salt increases the water-holding capacity (Paterson et al., 1988) and muscle swelling (Knight and Parsons, 1988; Paterson et al., 1988). More specifically, salt can increase ionic strength (Paterson et al., 1988). Greater-than-normal pH in dark-cutting steaks and increased ionic strength promote muscle fiber to bind with more water, resulting in an increase in water-holding capacity. The muscle swelling could reduce oxygen penetration, thereby decreasing the bloom and increasing dark appearance. Therefore, the salt could have decreased the lightness of the steaks by increasing water binding. In addition, prooxidant activity of salt can increase lipid (Torres et al., 1988; Mikkelsen et al., 1991) and myoglobin oxidation (Trout, 1990; Mikkelsen et al., 1991; Baublits et al., 2005, 2006a). There were no differences in *L** values between enhanced and nonenhanced dark-cutting steaks in MAP. However, the redness of enhanced dark-cutting steaks in this study was not negatively impacted by the enhancement. Enhanced dark-cutting steaks in all 3 packaging types had greater redness than nonenhanced dark-cutting steaks.

Effects of enhancement and packaging on palatability

Research has shown that more “off-flavors” in dark-cutting steaks compared with normal-pH steaks (Wulf et al., 2002; Grayson et al., 2016). However, in this study, panelists did not notice any off-flavor in nonenhanced dark-cutting steaks compared with normal-pH steaks. In agreement, past research has noted that dark-cutting beef and normal-pH beef have similar levels of beef flavor (Grayson et al., 2016). Yancey et al. (2005) noted that dark-cutting steaks had lower beef intensity than normal-pH steaks, which is inconsistent with this study. Beef broth has been used to improve the flavor and acceptability of low-fat ground beef to be similar to high-fat ground beef (Blackmer et al., 1997); however, this improvement of beef flavor was not seen in dark-cutting steaks. Previous studies observed no differences in metallic flavor between normal-pH and dark-cutting steaks (Wulf et al., 2002; Yancey et al., 2005; Apple et al., 2011). Grayson et al. (2016) reported a slight increase in metallic flavor as pH decreased; however, the intensity remained low on the 0- to 15-point scale (“none” to “intense”). Additionally, the enhancement appears to have no detrimental effects on the metallic flavor of dark-cutting steaks. Similar to the current study, the previous research reported that normal-pH steaks had higher sour flavor than dark-cutting steaks (Yancey et al., 2005; Grayson et al., 2016), and this may be due to differences in lactic acid levels. Greater purge and enhancement ingredients may have increased sensitivity of the sour flavor attribute of enhanced dark-cutting steak in VP compared with VP USDA Choice steaks. Rosemary addition to beef products has been shown to influence the sensory attributes of meat products. Fried beef patties with rosemary had lower acceptability by a trained panel compared to patties without rosemary (Gibis and Weiss, 2012). Additionally, in lamb and beef, rosemary-enhanced products had more off-flavor than the control (Sawyer et al., 2009b; Wyatt, 2015). Therefore, the presence of salt and rosemary in the enhancement could have increased the off-flavor scores in the enhanced dark-cutting steaks compared to the nonenhanced dark-cutting steaks. In the current research, water-soluble rosemary was utilized, which has less off-flavor characteristics than oil-soluble rosemary. Furthermore, the presence of salt can enhance flavor attributes.

The pH of meat has been shown to have a curvilinear relationship with tenderness (Watanabe et al., 1996; Wulf et al., 2002; Grayson et al., 2016). Research has shown that normal-pH steaks have similar tenderness as dark-cutting steaks at a pH greater than 6.4 (Grayson et al., 2016) and 6.3 (Yu and Lee, 1986; Watanabe et al., 1996). Increased toughness of dark-cutting beef has been shown to occur at an intermediate pH range including 5.8–6.0 (Wulf et al., 2002; Holdstock et al., 2014), 5.8–6.2 (Jeremiah et al., 1991), 5.8–6.3 (Yu and Lee, 1986; Watanabe et al., 1996), and 6.1–6.4 (Grayson et al., 2016). In the present study, the pH range selected for dark-cutting loins was greater than 6.0, and lack of segregation of the dark-cutting loins by pH could have influenced the tenderness and shear force. However, Holdstock et al. (2014) observed that normal-pH steaks and dark-cutting steaks ($pH > 6.0$) had similar shear force, as seen in the present study. The mechanism of decreased tenderness at an intermediate pH range is not well understood. Watanabe et al. (1996) determined that myofibrillar fragmentation was greater in low-pH (5.4) and high-pH (6.7) meat and was lower in intermediate pH (5.8–6.3) meat, attributing this to the activity of calpain enzymes. A similar effect of pH on the degradation of myofibrillar proteins was reported by Yu and Lee (1986). In support, Koohmaraie (1992) noted that calpain activity increases at a neutral pH versus an acidic pH. Additionally, tenderness was attributed to the activity of lysosomal enzymes at a pH of 5.5 (Yu and Lee, 1986). At the intermediate pH the activity of lysosomal and calpain enzymes would not be as effective. Increased nebulin and titin degradation were reported in normal-pH (pH = 5.4) and dark-cutting lamb (pH = 6.7) compared with lamb at pH 6.0–6.3 (Watanabe and Devine, 1996), which influenced the shear force. The increased water-holding capacity of dark-cutting beef also impacts the tenderness. The water-holding capacity increases with a greater pH, resulting in more water in the myofibrils (Purchas, 1990).

In enhanced dark-cutting steaks, the enhancement did not have a significant impact on the tenderness of the dark-cutting steaks. Previous research has noted that salt increases the tenderness of normal-pH meat (Robbins et al., 2002; Baublits et al., 2006b; Pietrasik and Janz, 2009). Salt will increase the ionic strength (Paterson et al., 1988) and myofibril swelling (Knight and Parsons, 1988; Paterson et al., 1988). This results in an increase in water-holding capacity and increased extraction of myofibrillar proteins (Paterson et al., 1988).

When evaluating juiciness, dark-cutting steaks have similar moisture release and juiciness compared to normal-pH steaks at a high pH (6.7–6.8) (Apple et al., 2011) and intermediate pH (6.0) (Wulf et al., 2002), respectively. Additionally, Holdstock et al. (2014) reported that normal-pH steaks and dark-cutting steaks possessed comparable initial and sustainable juiciness. However, Grayson et al. (2016) demonstrated that juiciness increased with greater pH, which was not observed in this study. The enhancement increased the juiciness of the dark-cutting steaks in the current research. Previous research has shown that the addition of salt and increasing salt concentration will increase the juiciness in a trained panel (Baublits et al., 2006b). Additionally, Pietrasik and Janz (2009) reported that consumers noted an increase in juiciness with salt in the enhancement compared to nonenhanced meat.

Conclusions

Developing postharvest processes to improve color and palatability is important to maximize the value and marketability of dark-cutting beef. In the current research, a combination of rosemary/beef flavor enhancement and MAP improved the redness of dark-cutting steaks. The inclusion of beef flavor with salt did not improve the lightness of dark-cutting steaks in HiOx-MAP and CO-MAP. The trained panelists did not observe differences in metallic flavor between Choice and enhanced dark-cutting steaks. However, the overall tenderness of enhanced dark-cutting steaks was greater than Choice steaks. The results indicate that adopting postharvest processing such as packaging or injection enhancement technology can improve color without adversely affecting palatability traits.

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