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Consumer Liking and Descriptive Flavor Attributes of M. Longissimus Lumborum and M. Gluteus Medius Beef Steaks Held in Varied Packaging Systems[1]

Jacqueline Ponce, J. Chance Brooks, and Jerrad F. Legako*

Department of Animal & Food Sciences, Texas Tech University, Lubbock, TX 79409, USA
*Corresponding author. Email: jerrad.legako@ttu.edu (J. F. Legako)

Abstract: Sensory evaluation was conducted to investigate the impact of packaging system and muscle type on beef flavor. Beef M. Longissimus lumborum (LL) and M. Gluteus medius (GM) steaks were produced from vacuum packaged subprimals at 14 d postmortem. Steaks were placed in various packaging types and held for 7 d prior to 48 h of retail display under continuous fluorescent lighting. Packaging types included: high-oxygen modified atmosphere lidded trays (80% O_2/20% CO_2, HIOX), carbon monoxide modified atmosphere lidded trays (0.4% CO/30% CO_2/69.6%N_2, CO), rollstock (forming/non-forming films, ROLL), vacuum packaging (stored in darkness, VAC), and traditional overwrap (foam trays wrapped with polyvinyl chloride film immediately before display, OW). Steaks were evaluated after cooking by consumer panelists and a trained descriptive attribute panel. For consumer evaluation, a muscle × package type interaction ($P = 0.040$) occurred for juiciness. Overall liking, tenderness, and liking of flavor were influenced ($P \leq 0.003$) by package type. Overall liking, liking of flavor, and tenderness of HIOX was lower ($P < 0.05$) than all other package types. Additionally, package type impacted ($P \leq 0.030$) overall, flavor, and tenderness acceptability. Overall and flavor acceptability was the lowest ($P < 0.05$) for the HIOX treatment. From trained panel attribute evaluation, muscle × package type interactions were detected ($P \leq 0.021$) for brown/roasted, bloody/serumy, and juiciness. Juiciness was the least ($P < 0.05$) desirable for GM HIOX compared to all other muscle and package type combinations. Steaks from HIOX packages had the highest ($P < 0.05$) ratings for oxidized and cardboardy, and were rated lowest ($P < 0.05$) in beef flavor ID and umami compared with all other package types. The LL had greater ($P < 0.05$) beef flavor ID, fat-like, umami, sweet, and overall tenderness ratings than the GM. The GM was more ($P < 0.05$) liver-like and oxidized compared with the LL. These data indicate a high oxygen packaging environment has the potential to accentuate negative descriptive sensory attributes and lower consumer sensory scores, while diminishing palatability in both muscles.

Keywords: beef, flavor, high-oxygen packaging, modified atmosphere packaging, muscle type
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Introduction

Consumers are conditioned to purchase bright, cherry-red colored beef that is free of discoloration. An acceptable visual appearance is the most critical factor concerning retail product as consumers largely depend on color as an indication of freshness and wholesomeness when making purchasing decisions (Walsh and Kerry, 2002; Killinger et al., 2004; Mancini and Hunt, 2005). Various packaging systems are utilized to obtain desirable color at the point of sale. These systems may include oxygen deficient environments or a combination of gases that can consist of carbon monoxide or oxygen. However, acceptable color does not directly correlate to an acceptable eating experience (Walsh and Kerry, 2002).

The amount of time product will retain a desirable color is limited due to exposure to prooxidants such as lighting and oxygen that promote oxidative and enzymatic degradation of beef (Seideman and Durland, 1983; Bertelsen and Skibsted, 1987; Xiong, 1995; Jeremiah, 2001; McMillin, 2008). These deg-

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radative processes eventually cause discoloration and the oxidation of lipids contributes to off flavors and off odors in cooked beef (McMillin, 1996; Kim et al., 2010; Resconi et al., 2013).

Packers and retailers are constantly moving toward more innovative packaging solutions that provide extended shelf life, convenience, and an appealing appearance. Few studies have characterized the effects of packaging and display on beef flavor. As the industry continues to develop and implement new packaging strategies it is important to understand the fundamental impact on the product to allow for more efficient use of packaging to maximize consumer satisfaction. Therefore, this study aimed to investigate the effects of packaging system on consumer perception and flavor profiles of 2 muscles known to differ in lipid and color stability (O'Keeffe and Hood, 1982).

Materials and Methods

Product

A factorial arrangement of 2 muscles and 5 package types were utilized to determine the effects of muscle and package type on beef flavor. Paired strip loins (Institutional Meat Purchasing Specifications (IMPS); IMPS 180, NAMP, 2010) and top sirloin butts (IMPS 184; NAMP, 2010) were collected from USDA Choice, "A" maturity beef carcasses ($n = 10$) at a commercial processing facility in the Texas panhandle. Subprimals were packaged under vacuum, stored in the dark at 0 to 4°C, and aged until 14 d post mortem. After initial aging, all top sirloin butts and strip loins were fabricated and sliced to produce 10, 2.54 cm steaks ($N = 400$), respectively. At 14 d postmortem, steaks from each muscle were randomly assigned to 1 of 5 package types: high-oxygen modified atmosphere lidded trays (80% O_2/20% CO_2, HIOX), carbon monoxide modified atmosphere lidded trays (0.4% CO/30% CO_2/69.6%N_2, CO), rollstock [forming and non-forming films (T6035B and T6235B, Sealed Air, Cryovac, Charlotte, NC, ROLL)], vacuum packaging without retail display (VAC), and traditional overwrap (OW). Modified atmosphere packages (MAP) were produced using a Mondini Tray Sealer, CV/VG-S (Cologne, Italy). The trays used for MAP packages had an oxygen transmission rate (OTR) of 0.1 cc/d at 73°C at 0% relative humidity (RH), and a moisture vapor transmission rate (MVTR) of 2 g/d. The tray film used for the MAP packages had an OTR of 7 cc/m^2/d at 40°C at 0% RH, and a MVTR of 9 g/m^2/d at 38°C at 100% RH. Rollstock and VAC packages were produced using a Multivac Baseline F100 (Kansas City, MO). The forming film had an OTR of 2 cc/m^2/d at 23°C at 0% RH, and a MVTR of 7 g/m^2/d at 38°C at 100% RH. The non-forming film had an OTR of 3 cc/m^2/d at 23°C at 0% RH, and a MVTR of 9 g/m^2/d at 38°C at 100% RH. Overwrap packages were produced using a Minipack-torre, Minispenser (Dalmine, Italy). All package types were held in dark storage at 0 to 4°C for an additional 7 d prior to display, although OW packages remained under vacuum prior to being placed on foam trays and sealed with polyvinyl chloride (PVC) film at 21 d postmortem. Nonetheless, at 21 d postmortem HIOX, OW, CO, and ROLL packages were displayed in coffin-style retail cases (Hussmann, BEXD-8, Bridgeton, MO; 0 to 2°C) for 48 h under continuous fluorescent lighting. However, VAC steaks remained in dark storage. All steaks were rotated every 12 h during display to ensure all packages were exposed to similar temperatures and lighting throughout the case. Temperature fluctuations and retail case temperatures were monitored continuously with remote temperature recorders and there were no abnormal fluctuations in temperature detected. (Multitrip temperature recorders, Temprecord, Auckland, New Zealand). After 48 h of retail display, all steaks were individually vacuumpackaged and frozen (–20°C) until subsequent analyses.

Cooking method

Before cooking, steaks were tempered at 2 to 4°C for 24 h to thaw. Electric clamshell grills (Cuisinart Griddler Deluxe, model GR150, East Windsor, NJ) were used to cook all designated cooked samples. Steaks were pulled from grills once they reached a predetermined internal temperature to reach a peak temperature of 71°C, a medium degree of doneness. Cooked temperatures (Thermapen, Classic Super-Fast, Thermoworks, American Fork, UT) were collected for steaks ($N = 200$) designated for cooked analyses.

Raw and cooked homogenate

Raw and cooked steaks were frozen with liquid nitrogen and homogenized (Robot Coupe, Blixer 3 Food Processor, Robot Coupe, Jackson, Mississippi). Frozen homogenates were stored at –80°C until subsequent analyses.

Proximate analysis

Total fat percent, moisture content, ash, protein, and pH analyses were all completed in duplicate on homogenate samples ($n = 200$). Duplicate samples with a coefficient of variation (CV) greater than 5% were reanalyzed. Values with less than 5% CV were averaged prior to statistical analysis.

An AOAC 983.23 approved chloroform: methanol extraction method was used to determine fat percent, as described by Folch et al. (1957). The lipid portion was extracted from 1-g samples using 8 mL of chloroform, 8 mL of methanol, and 7.2 mL of deionized water. Upon sample separation, the top layer was aspirated, 4 mL of the bottom layer were pipetted, and placed into a borosilicate culture tube. Culture tubes were placed on a heating block under a fume hood for 10 min. Remaining organic solvent was evaporated in a drying oven (6905, Thermo Fisher Scientific, Waltham, MA) held at 101°C until a constant weight was obtained. Culture tubes were placed in a desiccator until cooled, and a final weight was measured. Total fat percent was calculated using the formula: Total Fat Percent = (g residue after drying/g of wet sample) × 2 × 100.

Percent moisture of raw and cooked samples was measured utilizing the AOAC 950.46 oven drying method. Five grams were weighed into crucibles and placed in a drying oven set at 101°C for 24 h to allow for the removal of all moisture. Following the 24 h drying period, a final weight was measured. The following formula was used to calculate percent moisture: Percent Moisture = (wet weight– dry weight)/wet weight × 100.

Percent ash content of raw and cooked was measured using samples produced immediately following the completion of moisture analysis with the AOAC 923.03 protocol. Crucibles containing dried samples were placed into a muffle furnace (F30420C, Thermo Fisher Scientific, Waltham, MA). The temperature of the muffle furnace gradually increased from 100°C to a final temperature of 550°C, at which point the samples were held for 24 h or until a white ash was formed. After 24 h, crucibles were placed in a desiccator to cool. Finally, crucibles were weighed, and percent ash was calculated using the following formula: Percent Ash = (ash weight/wet weight) × 100.

Crude protein was measured using an AOAC 992.15 approved method on raw and cooked samples, utilizing a LECO TruMacN (Leco Corporation, St. Joseph, MI). A conversion factor of 6.25 was used to calculate percent protein. The following formula was used to calculate percent protein: Percent protein = total percent nitrogen × 6.25.

Analysis of pH was completed on raw samples using the method as described in Luqué et al. (2011). Frozen homogenate (10 g) was added to 90 mL of distilled water, homogenized, and filtered prior to pH analysis using a tabletop pH electrode (model 13–620–285, Fisher Scientific; Pittsburgh, PA).

Consumer sensory evaluation

Consumer panel sessions ($n = 5$) were completed using methods similar to Corbin et al. (2015) and Legako et al. (2015) and approved by the Texas Tech University Institutional Review Board. Panels were conducted at the Texas Tech Animal and Food Sciences building, in a large room under fluorescent lighting. Each panel session consisted of 20 untrained, paid panelists ($n = 100$) recruited from Lubbock, Texas and surrounding areas. All panelists were designated an individual booth and provided a ballot consisting of an information sheet, a demographic questionnaire, followed by 10 sample evaluation sheets. Panelists were given a plastic fork, toothpick, napkin, and an expectorant cup, along with a cup of water, cup of diluted apple juice, and unsalted crackers to serve as palate cleansers between samples. Verbal instructions on how to properly use palate cleansers and maneuver sample ballots were provided at the beginning of all panels. Steaks were thawed at 2 to 4°C for 24 h prior to consumer panels. Steaks were cooked on Cuisinart Deluxe Griddlers and removed accordingly to allow steaks to rise to 71°C as previously described (71.6 ± 1.39°C). Ten samples were derived from each steak and served to 10 pre-assigned panelists immediately following plating. Each panelist was served one, 1.5 cm × 1.5 cm piece, per panel round. Ten panel rounds were conducted representing all possible muscle × packaging combinations. Panelists evaluated all samples for overall liking, liking of flavor, tenderness, and juiciness. Attributes were measured on a 100-mm continuous line scale with “Dislike Extremely, Not Tender, or Not Juicy” representing 0, and “Like Extremely, Very Tender, or Very Juicy” representing 100. Acceptability was determined by asking a yes or no question for overall acceptability, flavor acceptability tenderness acceptability, and juiciness acceptability.

Descriptive attribute sensory panels

Twelve trained descriptive attribute panelists, consisting of graduate students and staff from Texas Tech University Animal and Food Sciences, participated in evaluating samples for multiple sensory attributes utilizing the Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Meat (American Meat Science Association, 2015). Panelists were trained and tested for 4 wk to objectively evaluate intensity of beef flavor attributes similar to attributes included and described in a published beef flavor lexicon (Adhikari et al., 2011): beef flavor identity (amount of beef flavor identity in the sample), brown/roasted (round, full aromatic generally associated with

Table 1. Descriptive attributes and references

Flavor attribute	Anchor	Location on scale (0–100)
Beef Flavor ID	Beef broth (heated to 74°C, served warm)	30
	80% ground chuck (71°C).	50
	Brisket (71°C)	75
Bloody/Serumy	Choice, strip steak (60°C)	40
Brown/Roasted	80% ground chuck (71°C)	40
	Well done strip steak (77°C)	65
Cardboardy	Cardboard soaked in water	85
Fat-Like	90/10 ground beef (71°C)	30
	70/30 ground beef (71°C)	60
Liver-Like	Flat iron steak (71°C)	20
	Calf liver	90
Oxidized	Microwaved vegetable oil	25
	Cooked, stored (24 h at 4°C), and microwaved ground beef (71°C)	60
Umami	Beef broth, sodium free (Heated to 74°C, served warm)	30
Sour	0.015% Citric acid	10
	0.050% Citric acid	25
Salty	0.15% NaCl	10
	0.25% NaCl	45
Bitter	0.01% Caffeine	15
	0.02% Caffeine	25
Sweet	0.50% Sucrose	25
Overall Tenderness	Eye of round (77°C)	30
	Strip steak (71°C)	55
	Tenderloin (65°C)	90
Overall Juiciness	Strip steak (85°C)	25
	Strip steak (71°C)	50
	Strip steak (60°C)	75

beef suet that has been broiled), bloody/serumy (aromatics associated with blood on cooked meat products; closely related to metallic aromatic), fat-like (aromatics associated with cooked animal fat), liver-like (aromatics associated with cooked organ meat/liver), oxidized (stale, aromatics associated with old oil), cardboardy (aromatic associated with slightly oxidized fats and oils, reminiscent of wet cardboard packaging), umami (flat, salty, somewhat brothy; taste of glutamate, salts of amino acids, and other molecules called nucleotides), sweet (fundamental taste factor associated with sucrose), salty (fundamental taste factor of which sodium chloride is typical), bitter (fundamental taste factor associated with a caffeine solution), and sour (fundamental taste factor associated with citric acid). Additional palatability characteristic evaluation was conducted by asking "Overall Juiciness" and "Overall Tenderness" following flavor attributes for each sample. Anchors that panelists were trained to reference for each flavor attribute were made available to each panelist at all panels should they need a reminder and are shown in Table 1.

Steaks of each muscle × packaging type ($n = 100$) were randomly served over 15 panel sessions. Panel sessions were completed over a 9-d period with some days consisting of 2 panels a day. On days that 2 panels occurred, a 90 min break was given. No more than 7 samples were evaluated in a single panel.

Steaks were thawed at 2 to 4°C for 24 h prior to panels and cooked as previously described. Once a steak reached peak temperature it was immediately weighed, sliced into 1.27 × 1.27 cm pieces (1/2" sensory box, Tallgrass Solutions Inc, Manhattan, KS), and 2 to 3 pieces (dependent on size of steak and number of participating panelists on each panel) were placed in 2 oz. plastic portion cups and covered with corresponding plastic lids. Samples were placed into a warmer (Cambro Ultra Heated Holding Pan Carrier, 214UPCH400, Webstaurant Store, Lititz, PA) and held at 50 to 55°C for no longer than 30 min prior to serving. Panelists were provided a plastic fork, toothpick, napkin, and an expectorant cup, in addition to unsalted crackers and a cup of distilled water to serve as palate cleansers between samples. Panelists evaluated all samples in a private booth, under red incandescent light to mask color differences. Sensory attributes were quantified on an unstructured line scale with "0" representing absence of

Table 2. Proximate composition and pH of raw (n = 100) and cooked (n = 100) M. Longissimus lumborum (LL) and M. Gluteus medius (GM) muscles

	Raw					Cooked			
Muscle	Ash	Fat	Moisture	Protein	pH	Ash	Fat	Moisture	Protein
GM	1.17[a]	2.07[b]	72.77[a]	25.54	5.55	1.36[a]	3.11[b]	63.89[a]	33.93[a]
LL	1.08[b]	3.18[a]	71.41[b]	25.30	5.52	1.14[b]	4.20[a]	63.13[b]	33.04[b]
SEM[1]	0.01	0.17	0.21	0.23	0.02	0.03	0.19	0.33	0.35
P-value	< 0.001	< 0.001	< 0.001	0.410	0.359	< 0.001	< 0.001	0.020	0.020

[a,b]Means within a column lacking a common superscript differ ($P < 0.05$).

[1]SEM (largest) of the least squares means.

specific flavor, extreme toughness, or extreme dryness, and "100" representing extreme intensity of specific flavor attribute, extreme tenderness, or extreme juiciness. Ballots were completed on panelists' personal laptops or tablets utilizing online software (Qualtrics, Dallas, TX).

Statistical analysis

All data for raw and cooked samples were analyzed using statistical procedures in SAS (Version 9.4, SAS Inst. Inc., Cary, NC). A 2 × 5 factorial arrangement was evaluated with carcass as the experimental unit and package type and muscle type as fixed effects. For sensory panels, retail case, carcass, replicate, and panel session were included as random effects, while retail case, carcass, and replicate were random effects for proximate analysis. Least squares means were generated for all analyses utilizing generalized linear mixed models (PROC GLIMMIX) and separated with the PDIFF function, with significance determined at $\alpha = 0.05$. Pearson correlation coefficients were produced using PROC CORR, with significance established at $\alpha = 0.05$.

Results and Discussion

Proximate analysis

Proximate analysis values for raw and cooked muscles are presented in Table 2. Raw LL was greater ($P < 0.001$) in fat content, while the GM was greater ($P < 0.001$) in moisture and ash content. No differences were identified for percent protein ($P = 0.410$) and pH ($P = 0.350$). These results concur with previous findings that show an inverse relationship between fat and moisture content, in addition to the expected differences in proximate composition between the LL and GM (Keith et al., 1985; Legako et al., 2015). Tarrant and Sherington (1980) found similar pH values in GM and LL muscles. Corresponding to raw results, cooked ash ($P < 0.001$) and moisture ($P < 0.020$) content were lower, and fat ($P < 0.001$) content was greater in the LL. However, in cooked samples, GM was greater in protein content ($P < 0.020$) than the LL.

Demographic characteristics and consumption habits of consumer panelists

Demographic characteristics and protein consumption habits of participating consumer panelists are presented in Tables 3 and 4. The majority of consumer panelists were female (59.0%), over the age of 36 (54.0%), and of a Caucasian ethnic origin (79.0%). A total of 52.0% worked full time with a large majority earning a household income of $75,000 to 99,999 (35.0%). These consumer demographic characteristics are fairly similar to consumers from consumer panels from previous studies completed in Lubbock, TX, which have been described to be representative of the national demographics overall (Brooks et al., 2010; Corbin et al., 2015).

At least 90.0% of consumers reported they consume beef, chicken, and pork, followed by fish (80.0%) and lamb (21.0%). Most consumers consume beef 3 or more times a week (52.0%) and when making a purchasing decision prefer traditional beef (77.0%). Medium rare was the preferred degree of doneness (43.0%), followed by medium (25.0%) and medium well (23.0%). Furthermore, most consumers prepared beef at home 2 or 3 times a week (55.0%) and consume beef at a restaurant or fast food establishment 1 or 2 times a week (68.0%).

Consumer Sensory Evaluation

The effects of 2 muscles and 5 packaging treatments on consumer palatability evaluation are shown in Table 5. A muscle × package type interaction occurred for juiciness ($P = 0.040$). The LL ROLL and LL OW were rated juicier ($P < 0.05$) than the GM HIOX. The GM ROLL, GM OW, LL CO, and LL HIOX were equivalent ($P > 0.05$) to each other, but lower ($P < 0.05$) in juiciness than the LL OW. Finally, the LL VAC, GM VAC, and GM CO were similar ($P > 0.05$) to all samples. Previous stud-

Table 3. Demographic characteristics of participating consumer panelists (n = 100)

Characteristic	Response	Percent of consumers
Sex	Female	59.0
	Male	41.0
Age	< 20 yr	16.0
	21–25 yr	25.0
	26–35 yr	5.0
	36–45 yr	5.0
	46–55 yr	10.0
	56–65 yr	19.0
	> 66 yr	20.0
Working Status	Not employed	27.0
	Part-time	5.0
	Full-time	52.0
	Student	9.0
Household Income	< $25,000	17.0
	$25,001- 49,999	18.0
	$50,000– 74,999	17.0
	$75,000- 99,999	35.0
	> $100,000	12.0
Ethnicity	Caucasian	79.0
	African-American	1.0
	Hispanic	18.0
	American Indian	0.0
	Asian/Pacific Islander	1.0
	Other	0.0

Table 4. Meat consumption habits of participating consumer panelists (n = 100)

Consumption habit	Response	Percent of consumers
Meat Consumption	Beef	99.0
	Pork	93.0
	Lamb	21.0
	Chicken	97.0
	Fish	80.0
Beef Consumption	Daily	12.0
	5 or more times per wk	14.0
	3 or more times per wk	52.0
	Once per week	19.0
	Once every 2 wk	0.0
	< Once every 2 wk	2.0
Preferred Degree of Doneness	Rare	3.0
	Medium Rare	43.0
	Medium	25.0
	Medium Well	23.0
	Well Done	6.0
Beef Purchasing Preferences	Traditional	77.0
	Natural	7.0
	Grass-Fed	11.0
	Organic	8.0
	Aged	5.0
	Other	2.0
Beef Consumption at Home	0 times per wk	0.0
	1 times per wk	16.0
	2 times per wk	29.0
	3 times per wk	27.0
	4 times per wk	8.0
	5 times per wk	15.0
Beef Consumption at Restaurant/Fast Food Establishment	0 times per wk	3.0
	1 times per wk	34.0
	2 times per wk	34.0
	3 times per wk	12.0
	4 times per wk	7.0
	5 times per wk	4.0

ies reported high O_2 MAP had a detrimental impact on juiciness compared to vacuum packaging (Clausen et al., 2009; Lagerstedt et al., 2011). However, a study conducted by Kim et al. (2010) found packaging atmosphere had no effect on juiciness scores in LL steaks, although Grobbel et al. (2008) reported LL steaks packaged in CO MAP were juicier than high O_2 MAP, and vacuum packaged steaks were similar to both packaging atmospheres.

Package type influenced overall liking ($P < 0.001$), tenderness ($P = 0.003$), and liking of flavor ($P < 0.001$). Overall liking and tenderness scores were lower ($P < 0.05$) in HIOX than all other package types. Liking of flavor was the lowest ($P < 0.05$) for HIOX compared to all other treatments. Additionally, ROLL had greater ($P < 0.05$) flavor liking compared to OW. Flavor liking of VAC and CO were similar ($P > 0.05$) to both ROLL and OW. The difference evaluated in overall liking between HIOX and all other package types can be attributed to the amount of oxidation that occurs in high oxygen environments and the resulting detrimental effects on palatability traits. After consumers deem tenderness acceptable, the next important factor concerning consumer satisfaction is flavor (Killinger et al., 2004; Sitz et al., 2005; Goodson, 2012). Numerous studies have reported a decrease in tenderness and beef flavor, as well as an increase in unsavory oxidized flavors and aromas developed in the cooked product caused by the extent of oxidation caused by high oxygen MAP (Zakrys et al., 2008; Clausen et al., 2009; Kim et al., 2010; Lagerstedt et al., 2011; Resconi et al., 2012). While the difference in overall liking between package types can be explained by the unsatisfactory changes in tenderness and flavor, the decrease in tenderness for HIOX may be attributed to an increase in protein oxidation. The formation of myofibrillar protein cross links and the loss of proteolytic enzyme activity can support the integrity of the protein structures although aging is implemented to accomplish the opposite (Lund et al., 2007; Zakrys et al., 2008; Estévez, 2011; Lund et al., 2011). The extent of lipid oxidation contributes to the generation of secondary oxidation products that are detectable as off

Table 5. Least squares means of consumer (n = 100) ratings[1] of palatability traits of 2 muscles[2] × 5 package types[3]

Package type	Muscle	Overall liking	Liking of flavor	Tenderness	Juiciness
CO	GM	62.7	60.8	64.2	62.3[abc]
HIOX	GM	52.1	48.5	55.6	55.3[c]
ROLL	GM	64.2	64.9	63.4	58.3[bc]
OW	GM	56.2	55.1	62.6	57.9[bc]
VAC	GM	63.2	61.6	67.9	62.3[abc]
CO	LL	59.5	57.9	63.7	59.7[bc]
HIOX	LL	53.4	52.3	58.0	61.7[bc]
ROLL	LL	66.5	63.2	65.3	64.9[ab]
OW	LL	65.6	62.4	68.4	69.6[a]
VAC	LL	63.0	61.0	65.2	63.3[abc]
SEM[4]		3.1	3.3	3.3	3.0
P-value		0.160	0.240	0.440	0.040
CO		61.1[a]	59.4[ab]	63.9[a]	61.0
HIOX		52.7[b]	50.4[c]	56.8[b]	58.5
ROLL		65.4[a]	64.1[a]	64.3[a]	61.6
OW		60.9[a]	58.7[b]	65.5[a]	63.7
VAC		63.1[a]	61.3[ab]	66.5[a]	62.8
SEM		2.5	2.7	2.8	2.4
P-value		< 0.001	< 0.001	0.003	0.410
	GM	59.7	58.2	62.7	59.2
	LL	61.6	59.4	64.1	63.9
	SEM	2.1	2.3	2.5	1.7
	P-value	0.220	0.460	0.350	0.003

[a–c]Means within a column specific to muscle × package type interaction, package type, or muscle lacking a common superscript differ ($P < 0.05$).

[1]Sensory scores: 0 = Dislike extremely/Not tender/juicy; 100 = Like extremely/Very tender/juicy.

[2]Muscles included M. Gluteus medius (GM) and M. Longissimus lumborum (LL).

[3]Package types included carbon monoxide modified atmosphere lidded trays (0.4% CO/30% CO_2/69.6%N_2, CO), high-oxygen modified atmosphere lidded trays (80% O_2/20% CO_2, HIOX), traditional overwrap (OW), rollstock (forming and non-forming films, ROLL), and vacuum packaging without retail display (VAC).

[4]SEM (largest) of the least squares means.

flavors and aromas capable of masking other acceptable traits in cooked product. However, there appears to be a threshold of oxidation derived flavor development that is found to be acceptable by consumers. Zakrys et al. (2008) reported consumers preferred M. Longissimus dorsi (LD) steaks stored in 50% O_2/30% N2/20% CO_2 MAP after 3 d of display under fluorescent lighting over LD steaks stored in 0, 10, 20, and 80% O_2 MAP, while the treatment containing 0% O_2 was more acceptable at 0 d of display. This concept may explain why CO and VAC were similar to ROLL and OW, despite the development of lipid oxidation that may have occurred in ROLL and OW due to photooxidation and the presence of O_2 in air permeable packaging, respectively. Furthermore, this suggests there is a particular amount of oxidation that occurs that is not detrimental to the eating experience. Nonetheless, there were no effects ($P > 0.05$) on consumer evaluation of overall liking, liking of flavor, or tenderness as a result of muscle type.

The percentage of samples consumers considered acceptable are shown in Table 6. Package type influenced overall acceptability ($P = 0.004$), flavor acceptability ($P < 0.001$), and tenderness acceptability ($P = 0.030$), however there was no effect on juiciness acceptability ($P = 0.230$). Corresponding with treatment differences in palatability scores, overall and flavor acceptability were lower for HIOX than all other package types. Tenderness acceptability was lower ($P < 0.05$) for HIOX than CO, ROLL, and OW, although VAC was similar ($P > 0.05$) to all treatments. Similarly, these differences can be related to the varying amounts of oxidation that develop in raw products and transpire as unacceptable palatability traits once cooked. These results indicate that including O_2 at 8O% in MAP accelerates the development of undesirable, oxidized flavor and utilizing VAC, ROLL, OW, and CO package types are more effective at preserving satisfactory palatability.

Descriptive sensory panels

Three, muscle × package type interactions were determined from trained descriptive sensory analysis

Table 6. Percentage of 2 muscles[1] and package types[2] rated acceptable by consumers (n = 100) for overall, flavor, tenderness, and juiciness acceptability

Package type	Muscle	Overall acceptability	Flavor acceptability	Tenderness acceptability	Juiciness acceptability
CO		85.1^{a}	85.2^{a}	87.6^{a}	71.9
HIOX		70.5^{b}	68.5^{b}	77.7^{b}	69.6
ROLL		85.8^{a}	84.6^{a}	88.7^{a}	66.5
OW		81.7^{a}	82.1^{a}	86.2^{a}	68.3
VAC		86.8^{a}	86.9^{a}	84.4^{ab}	66.3
SEM[3]		3.3	4.1	3.2	11.8
P-value		0.004	< 0.001	0.030	0.820
	GM	80.6	81.1	84.6	66.5
	LL	84.5	83.3	85.9	70.5
	SEM	1.9	2.5	1.8	11.4
	P-value	0.120	0.370	0.570	0.230
Muscle × Package Type					
P-value		0.290	0.120	0.120	0.990

[a,b]Means within a column, specific to package type or muscle, lacking a common superscript differ (P < 0.05).

[1]Muscles included M. Gluteus medius (GM) and M. Longissimus lumborum (LL).

[2]Package types included carbon monoxide modified atmosphere lidded trays (0.4% CO/30% CO_2/69.6%N_2, CO), high-oxygen modified atmosphere lidded trays (80% O_2/20% CO_2, HIOX), traditional overwrap (OW), rollstock (forming and non-forming films, ROLL), and vacuum packaging without retail display (VAC).

[3]SEM (largest) of the least squares means.

including brown/roasted (P = 0.021), bloody/serumy (P = 0.008), as well as overall juiciness (P = 0.001) as shown in Table 7. Brown/roasted is a positive flavor attribute described as caramelization developed by dry heat cooking methods (Adhikari et al., 2011; Kerth and Miller, 2015). Both LL HIOX and GM HIOX were similar to each other (P > 0.05), however displayed greater (P < 0.05) amounts of brown/roasted compared to LL OW, GM ROLL, LL VAC, and LL CO. In one instance 2 muscles within a package type were different; LL CO was lower (P < 0.05) in brown/roasted than GM CO. Finally, GM OW and GM VAC were found to be similar (P > 0.05) in brown/roasted with all muscle and package type combinations.

For bloody/serumy, the GM VAC and GM ROLL had greater (P < 0.05) ratings than all other muscle and packaging combinations, except for LL VAC (P > 0.05). Additionally, GM HIOX was the lowest (P < 0.05) in bloody/serumy, other than in comparison to LL HIOX (P > 0.05). Also, although from the same package type GM ROLL was higher (P < 0.05) in bloody/serumy than the LL ROLL. Bloody/serumy is associated with degree of doneness and has been shown to mirror juiciness responses (Kerth and Miller, 2015). Resconi et al. (2012) reported lower blood flavor intensity in high O_2 MAP LD steaks at 4 and 8 d of display under fluorescent lighting compared to vacuum-packaged (VP) steaks. It is speculated that degradative effects caused by a high O_2 environment can decrease WHC, therefore an increase in sarcoplasmic protein lost in purge loss can have a detrimental effect on bloody/serumy and juiciness ratings (Lagerstedt et al., 2011).

Table 7. Trained descriptive sensory least squares means for flavor attributes[1] based on muscle[2] × package type[3] interaction

Package type	Muscle	Brown/roasted	Bloody/serumy	Overall juiciness
CO	GM	43.5^{ab}	22.0^{b}	46.9^{c}
HIOX	GM	45.1^{a}	15.0^{d}	41.8^{d}
OW	GM	42.2^{abc}	21.6^{b}	49.5^{abc}
ROLL	GM	39.6^{bc}	26.0^{a}	49.9^{abc}
VAC	GM	41.6^{abc}	26.2^{a}	49.2^{abc}
CO	LL	38.9^{c}	20.9^{b}	51.0^{ab}
HIOX	LL	45.2^{a}	17.0^{cd}	48.8^{bc}
ROLL	LL	43.1^{ab}	20.2^{bc}	47.9^{c}
OW	LL	40.8^{bc}	20.7^{bc}	49.9^{abc}
VAC	LL	39.3^{bc}	23.7^{ab}	52.2^{a}
SEM[4]		3.3	3.3	1.7
P-value		0.021	0.008	0.001

[a–d]Means within a column lacking a common superscript differ (P < 0.05).

[1]Trained descriptive sensory scores: 0 = Absence of specific flavor/Undesirable palatability characteristic; 100 = Extreme intensity of specific flavor attribute/Extremely desirable palatability characteristic.

[2]Muscles included M. Gluteus medius (GM) and M. Longissimus lumborum (LL).

[3]Package types included carbon monoxide modified atmosphere lidded trays (0.4% CO/30% CO_2/69.6%N_2, CO), high-oxygen modified atmosphere lidded trays (80% O_2/20% CO_2, HIOX), traditional overwrap (OW), rollstock (forming and non-forming films, ROLL), and vacuum packaging without retail display (VAC).

[4]SEM (largest) of the least squares means.

Table 8. Trained descriptive sensory LS means[1] for flavor attributes based on package type[2] and muscle[3]

Package type	Muscle	Beef flavor ID	Fat-like	Liver-like	Oxidized	Cardboardy	Umami	Sweet	Salty	Bitter	Sour	Overall Tenderness
CO		54.3[ab]	17.0	2.7	8.9[c]	0.8[b]	37.1[a]	1.6	1.0	3.1	4.3[b]	54.4[b]
HIOX		50.0[c]	16.4	2.7	21.7[a]	2.6[a]	34.1[b]	1.7	1.4	3.8	6.5[a]	48.5[b]
ROLL		53.3[b]	17.0	2.7	10.9[bc]	1.2[b]	37.4[a]	1.7	1.3	3.3	5.0[ab]	57.2[a]
OW		52.9[b]	18.0	2.1	11.7[b]	1.4[b]	37.5[a]	2.2	1.5	3.6	4.3[b]	55.2[ab]
VAC		56.3[a]	18.1	1.3	7.1[c]	0.9[b]	38.6[a]	2.1	1.3	3.0	3.8[b]	56.2[a]
SEM[4]		1.8	2.7	0.8	3.7	0.6	2.4	0.8	0.5	0.8	1.0	2.5
P-value		< 0.001	0.054	0.680	0.008	0.030	< 0.001	0.130	0.260	0.480	0.030	0.007
	GM	52.6[b]	16.5[b]	3.2[a]	13.4[a]	1.4	35.9[b]	1.7[b]	1.2	3.5	5.5[a]	52.4[b]
	LL	54.1[a]	18.1[a]	1.4[b]	10.7[b]	1.4	37.9[a]	2.1[a]	1.4	3.2	4.0[b]	56.2[a]
	SEM	1.7	2.7	0.6	3.0	0.5	2.4	0.8	0.5	0.7	0.9	2.2
	P-value	0.020	0.002	< 0.001	0.005	0.960	0.002	0.030	0.080	0.240	0.003	< 0.001

[a–c]Means within a column, specific to package type or muscle, lacking a common superscript differ ($P < 0.05$).

[1]Trained descriptive sensory scores: 0 = Absence of specific flavor/Undesirable palatability characteristic; 100 = Extreme intensity of specific flavor attribute/Extremely desirable palatability characteristic.

[2]Muscles included M. Gluteus medius (GM) and M. Longissimus lumborum (LL).

[3]Package types include carbon monoxide modified atmosphere lidded trays (0.4% CO/30% CO_2/69.6%N_2, CO), high-oxygen modified atmosphere lidded trays (80% O_2/20% CO_2, HIOX), traditional overwrap (OW), rollstock (forming and non-forming films, ROLL), and vacuum packaging without retail display (VAC).

[4]SEM (largest) of the least squares means.

Overall juiciness responses were the lowest ($P < 0.05$) for GM HIOX. Additionally, differences were found within muscle type, as the LL CO was greater ($P < 0.05$) than GM CO and LL HIOX was greater ($P < 0.05$) than GM HIOX. The interaction between variation in muscle stability and package type can be attributed to muscles more susceptible to oxidation showing an increase in undesirable palatability traits as a result of exposure to an oxidative environment (Hood, 1980; O'Keeffe and Hood, 1982; Jeremiah et al., 2003; Lagerstedt et al., 2011).

Package type impacted beef flavor ID ($P < 0.001$), oxidized ($P = 0.008$), cardboardy ($P = 0.030$), umami ($P < 0.001$), sour ($P = 0.030$), as well as overall tenderness ($P = 0.007$) without dependency on muscle as shown in Table 8. Package and muscle type had no effect ($P > 0.05$) on descriptive sensory evaluation of salty and bitter. Oxidized and cardboardy were most intense ($P < 0.05$) in HIOX packaging. The presence of "oxidized" and "rancid" off flavors were greater in LL steaks packaged in high O_2 MAP in comparison to CO MAP and VP as reported by Grobbel et al. (2008), similar to the findings of Zakrys et al. (2008) and Kim et al. (2010). The presence of negative flavor attributes such as oxidized and cardboardy are due to the known oxidative environment of high O_2 atmospheres. Extended wet aging and oxidation due to display conditions can promote the development of a negative, sour flavor attribute (Sitz et al., 2004; Dikeman et al., 2013). The HIOX package type was similar ($P > 0.05$) to ROLL for sour, however greater ($P < 0.05$) than all other packaging treatments. Likely caused by the masking potential by oxidation derived attributes, HIOX was evaluated the lowest ($P < 0.05$) for beef flavor ID and umami. However, VAC samples were rated greater ($P < 0.05$) than ROLL and OW for beef flavor ID. Similar results regarding the relationship of increased off flavor development and a decrease in positive meaty flavor intensity in various packaging systems were reported by Clausen et al. (2009), Kim et al. (2010), Lagerstedt et al. (2011), and Resconi et al. (2012). The VAC and ROLL treatments were more ($P < 0.05$) tender than HIOX and CO, while OW was similar ($P > 0.05$) to all package types. Multiple studies have reported VP and CO MAP whole muscle products were more tender than high O_2 MAP samples (Grobbel et al., 2008; Kim et al., 2010; Lagerstedt et al., 2011; Resconi et al., 2012), while Zakrys et al. (2008) found no differences in tenderness of LD steaks stored in MAP containing various amounts of O_2 ranging from 0 to 80%.

Muscle type had an impact on several flavor attributes and palatability characteristics evaluated, as shown in Table 8. The LL was greater than the GM for beef flavor ID ($P = 0.020$), fat-like ($P = 0.002$), umami ($P = 0.002$), sweet ($P = 0.030$), and overall tenderness ($P < 0.001$). However, the GM possessed greater liver-like ($P < 0.001$), sour ($P < 0.003$), and oxidized ($P = 0.005$) ratings. The difference in oxidative stability between the two muscles explain the tendency of the GM to develop more intense off-flavors than the

Table 9. Pearson correlation coefficients (*r*) of consumer sensory ratings[1] and trained descriptive sensory scores[2] from two muscles[3] and five package types[4]

	Consumer sensory ratings				Trained descriptive sensory attributes												
Sensory score	Overall liking	Liking of flavor	Tenderness	Juiciness	Beef flavor ID	Brown/ roasted	Bloody/ serumy	Fat-like	Liver-like	Oxidized	Cardboardy	Umami	Sweet	Salty	Bitter	Sour	Tenderness
Liking of Flavor	0.84 ***																
Tenderness	0.41***	0.18															
Juiciness	0.50***	0.33**	0.62***														
Beef Flavor ID	0.14	0.21*	0.19	0.04													
Brown/Roasted	0.13	0.19	-0.10	0.03	0.23*												
Bloody/Serumy	-0.11	-0.15	0.10	-0.12	0.17	-0.61***											
Fat-Like	0.06	0.08	0.009	-0.03	0.10	-0.06	0.08										
Liver-Like	-0.20*	-0.16	-0.27**	-0.20*	-0.48***	-0.27**	0.07	-0.08									
Oxidized	-0.05	-0.12	-0.20*	-0.06	-0.57***	0.04	-0.18	-0.16	0.40***								
Cardboardy	0.06	0.02	-0.05	-0.02	-0.25*	-0.13	0.01	-0.13	0.16	0.53***							
Umami	0.10	0.15	0.24*	0.11	0.70***	0.008	0.24*	0.12	-0.39***	-0.49***	-0.21*						
Sweet	-0.04	-0.07	0.04	0.04	0.04	-0.37***	0.34**	-0.12	-0.10	-0.17	0.06	0.23*					
Salty	-0.06	-0.07	-0.14	-0.02	-0.05	-0.06	0.07	0.19	-0.01	-0.02	0.18	0.08	0.29**				
Bitter	-0.12	-0.18	-0.06	0.04	-0.43***	-0.33***	0.10	-0.13	0.48***	0.22*	0.24*	-0.25**	0.23*	0.35***			
Sour	-0.02	-0.16	-0.20*	-0.09	-0.59***	-0.15	0.08	-0.01	0.44***	0.56***	0.34***	-0.42***	0.08	0.10	0.47***		
Tenderness	0.08	0.01	0.43***	0.16	0.27**	-0.35***	0.43***	0.37***	-0.14	-0.33***	-0.24*	0.38***	0.19	0.09	0.01	-0.17	
Juiciness	-0.07	-0.06	0.20*	-0.02	0.33***	-0.29**	0.53***	0.38***	-0.06	-0.25*	-0.22*	0.42***	0.20*	0.12	-0.02	-0.10	0.71***

*Correlation coefficient differs from 0 ($P < 0.05$).

**Correlation coefficient differs from 0 ($P < 0.01$).

***Correlation coefficient differs from 0 ($P < 0.001$).

[1]Sensory scores: 0 = Dislike extremely/Not tender/juicy; 100 = Like extremely/Very tender/juicy.

[2]Trained descriptive sensory scores: 0 = Absence of specific flavor/Undesirable palatability characteristic; 100 = Extreme intensity of specific flavor attribute/Extremely desirable palatability characteristic.

[3]Muscles included M. Gluteus medius (GM) and M. Longissimus lumborum (LL).

[4]Package types include carbon monoxide modified atmosphere lidded trays (0.4% CO/30% CO_2/69.6%N2, CO), high-oxygen modified atmosphere lidded trays (80% O_2/20% CO_2, HIOX), traditional overwrap (OW), rollstock (forming and non-forming films, ROLL), and vacuum packaging without retail display (VAC).

LL subsequently having an adverse effect on desirable flavor attributes such as beef flavor ID, umami, and sweet. Trained panelists were able to detect the fat content difference found between the muscles as fat-like differed, likely causing a variation in mouthfeel. A study done by Yancey et al. (2006) suggests liver-like is not associated with lipid oxidation, rather with iron content and myoglobin concentration.

Correlations

Pearson correlations of consumer sensory ratings and trained descriptive sensory scores are shown in Table 9. Overall liking was correlated ($P < 0.001$) with all other consumer evaluations including juiciness ($r = 0.50$), tenderness ($r = 0.41$), and liking of flavor ($r = 0.84$). Similarly, Legako et al. (2016) reported tenderness, juiciness, and flavor were correlated with overall liking in LL steaks of various quality grades. The consumer sensory evaluation determined package type influenced ($P < 0.05$) tenderness, liking of flavor, and overall liking. Considering these attributes are frequently correlated across different studies, there is the potential to positively or negatively impact the overall eating experience through packaging. This implication further supports the importance of selecting appropriate packaging that is suitable for the lipid and color stability of various beef products.

Overall liking as assessed by consumers was found to be negatively correlated ($P < 0.05$) with liver-like ($r = –0.20$), an undesirable descriptive attribute, while flavor liking evaluated by consumers was positively correlated ($P < 0.05$) with beef flavor ID ($r = 0.21$), a desirable flavor attribute.

As shown in Table 9, negative flavor attributes including liver-like, bitter, sour, and oxidized were correlated ($r \geq 0.22$, $P < 0.05$) with each other. Correspondingly, positive flavor attributes such as beef flavor ID and brown/roasted were negatively correlated ($P < 0.05$) with attributes generally considered detrimental to flavor such as liver- like ($r \leq –0.27$) and bitter ($r \leq –0.33$).

Tenderness, evaluated by trained panelists, was correlated ($P < 0.001$) with consumer tenderness ratings ($r = 0.43$). Likewise, trained panel tenderness was correlated ($P < 0.05$) with beef flavor ID ($r = 0.27$), bloody/serumy ($r = 0.43$), fat-like ($r = 0.37$), and umami ($r = 0.38$). Negative correlations ($P < 0.05$) were determined between trained panel tenderness ratings with oxidized ($r = –0.33$) and cardboardy ($r = –0.24$), indicating greater lipid oxidation in less tender beef. Presently, it is unclear if the positive correlation with tenderness and appealing attributes (beef flavor ID, umami, etc.) is due to a biological mechanism or a halo-effect of tenderness on flavor attributes. However, anaerobic VP systems were found to have increased protein degradation, compared with more aerobic overwrap packaging systems (Fu et al., 2017; Moczkowska et al., 2017). These cited results implicate that packaging system influences proteolysis. This increase in proteolysis was determined to increase beef tenderness in VP systems, according to Warner-Bratzler shear force values (Moczkowska et al., 2017). Therefore, it seems that anaerobic packaging may have multiple advantages, including increased proteolysis and less lipid oxidation. However, this observation must be further validated with supporting biochemical data.

Conclusion

The results of this study indicate packaging environment impacts beef flavor. Packaging systems that include elevated levels of oxygen have a detrimental effect on consumer palatability scores and have the potential to accentuate negative descriptive sensory attributes, while diminishing palatability. This adverse effect on flavor was magnified in muscles which have lower chemical stability. Furthermore, this study suggests a particular amount of oxidation, if below a certain threshold, is not detrimental to an eating experience. Further research could be beneficial to fully develop a threshold at which oxidation derived flavor attributes are no longer satisfactory.

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