Published November 2, 2017

Meat and Muscle Biology™

Sensory Evaluation of Enhanced Beef Strip Loin Steaks Cooked to 3 Degrees of Doneness

Kassandra V. McKillip, Alaena K. Wilfong, John M. Gonzalez, Terry A. Houser, John A. Unruh, Elizabeth A. E. Boyle, and Travis G. O'Quinn*

Department of Animal Sciences and Industry, Kansas State University, Manhattan, KS 66506, USA
*Corresponding author. Email: travisoquinn@ksu.edu (T. G. O'Quinn)

Abstract: The objective of this study was to evaluate the impact of marbling level in combination with enhancement on beef palatability when strip loin steaks were cooked to 3 degrees of doneness. Consumer and trained sensory panelists evaluated strip steak palatability traits of 3 USDA quality grades: Prime, Low Choice, and Low Select. Additional strip loins from each grade were enhanced to 108% with a water, salt, and alkaline phosphate solution. Steaks from each treatment were cooked to 3 degrees of doneness (DOD; Rare: 60°C, Medium: 71°C, or Very Well-Done: 82°C). Consumer panelists rated all enhanced treatments similar ($P > 0.05$) for each palatability trait. Enhanced steaks had greater ($P < 0.05$) juiciness, tenderness, flavor liking, and overall liking ratings than all non-enhanced treatments, regardless of grade. Consumer juiciness, tenderness, and overall liking scores increased ($P < 0.05$) as DOD decreased. Trained sensory panelists rated all enhanced treatments similar ($P > 0.05$) for initial and sustained juiciness, myofibrillar tenderness, and overall tenderness and greater ($P < 0.05$) than all non-enhanced treatments, other than non-enhanced Prime, for the same traits. Trained sensory panel ratings increased ($P < 0.05$) as DOD decreased for sustained juiciness, and both myofibrillar and overall tenderness. Moreover, Warner-Bratzler shear force values were similar ($P > 0.05$) among all enhanced treatments, and lower ($P < 0.05$) than non-enhanced Low Choice and Low Select treatments. Results from this study indicate marbling level has no impact on the palatability traits of enhanced strip loin steaks. Therefore, enhancement of higher valued, high marbled cuts does not provide additional palatability benefits over low marbled cuts, as enhancement does not provide an additive effect with marbling on beef eating quality.

Keywords: beef, consumer, degree of doneness, enhancement, palatability, quality grade
Meat and Muscle Biology 1:227–241 (2017) **doi:10.22175/mmb2017.06.0033**
Submitted 16 Jun. 2017 Accepted 27 Sep. 2017

Introduction

Numerous studies have demonstrated increased USDA quality grades are positively associated with improved palatability characteristics (Smith et al., 1985; O'Quinn et al., 2012; Emerson et al., 2013). Premiums are applied to higher quality graded cuts, with currently a $13.69/kg premium for USDA Prime over USDA Select for strip loins (USDA, 2017a, 2017b). Additionally, as quality grade increases, the percentage of samples rated acceptable for all palatability traits and the percentage of samples identified as "premium quality" concurrently increase (Hunt et al., 2014; Wilfong et al., 2016; Lucherk et al., 2017), providing further evidence to marbling's significant contribution to beef eating quality.

In addition to marbling level, degree of doneness (DOD) has a large impact on the overall beef eating experience (Cox et al., 1997). Increased DOD results in protein hardening, connective tissue shrinkage, and the associated increase in moisture loss through the cooking process (Cross et al., 1976; Wheeler et al., 1999; Lorenzen et al., 2005). Previous studies have reported decreased tenderness, juiciness, and overall palatability

Funded by the Beef Checkoff. Contribution no. 17–382-J of the Kansas Agricultural Experiment Station, Manhattan, KS 66506.

with increased DOD (Parrish et al., 1973; Lorenzen et al., 2005; O'Quinn et al., 2015). However, a large percentage of beef consumers prefer steaks to be cooked to at least a medium DOD (Cox et al., 1997; Reicks et al., 2011). This indicates a need for beef to maintain a high level of eating quality, even at elevated DOD.

Enhancement technology has been shown to improve beef palatability, shear force values, and cooking loss (Baublits et al., 2006; Pietrasik and Janz, 2009; Brooks et al., 2010; Lucherk et al., 2016). Much of this previous research has focused on either lower palatability (tougher) muscles or lower quality grades (USDA Select or lower). Few studies have used higher quality grades of USDA Choice or Prime for enhancement. Additionally, research on cooking enhanced steaks to different degrees of doneness is limited. Therefore, the objective of this study was to determine the effect of enhancement on consumer and trained sensory panel palatability scores of 3 quality grades when cooked to 3 degrees of doneness.

Materials and Methods

The Kansas State University (KSU) Institutional Review Board approved the procedures used in this study (IRB 7440, November 21, 2014).

Experimental treatments and sample preparation

Beef strip loins [*n* = 72; IMPS #180; North American Meat Institute (2014)] were selected to equally represent 3 USDA quality grades: Prime, Low Choice (Small^{00}– Small^{100}), and Low Select (Slight^{00}– Slight^{49}) from a commercial beef processing plant in the Midwest. Strip loins were not paired, with each strip loin selected for the study collected from a separate carcass. Product was vacuum packaged and transported under refrigeration (2°C) to the KSU Meat Laboratory for further processing.

Following 14 d of aging, half (*n* = 12) of the strip loins within each quality grade were selected for enhancement. Strip loins designated for enhancement were enhanced with a solution formulated to result in 0.35% NaCl and 0.40% sodium phosphate (Brifisol 512, ICL Food Specialties, Saint Louis, MO) at a target 8% pump in the final injected product. Solution (pH = 8.09) was injected into product using a multi-needle injector (Wolf-tec, IMAX 420 eco, Kingston, NY). Weights of strip loins were recorded before and 15 min after injection for calculation of actual percentage pump (6.91 ± 1.42%). Enhanced loins were then vacuum packaged and held at 2 to 4°C for an additional 7 d. Strip loins not designated for enhancement were aged for the full 21 d under vacuum at 2 to 4°C.

At the end of the 21 d aging period, strip loins were fabricated into 2.5-cm thick steaks. The most anterior (wedge) steak was removed and used to obtain measurements of instrumental color (L*, a*, b*), pH, and proximate analysis. Immediately following slicing, the freshly cut surface of the wedge steak was allowed to bloom for 15 min prior to color measurement using a Hunter Lab Miniscan spectrophotometer (Illuminant A, 2.54-cm aperture, 10° observer; Hunter Associates Laboratory, Reston, VA). Scans were taken at 3 locations on each steak and the readings were averaged for L*, a*, and b* values. The pH was measured once for each steak using a pH meter (model HI 99163; Hanna Instruments, Smithfield, RI). After readings were collected, wedge steaks were packaged and frozen at –20°C for proximate analysis.

Each strip loin was designated into thirds (from anterior to posterior), with each third assigned to 1 of the 3 DOD (Rare: 60°C; Medium: 71°C; or Very Well-Done: 82°C) in a balanced design. Within each section, four 2.5-cm thick steaks were cut, with one steak randomly assigned to each of: consumer panel, trained panel, objective measurements, or flavor analysis (data not reported). Steak assignment was balanced across all strip loins in each treatment. All steaks were weighed fresh, identified with a unique four digit number, and were vacuum packaged individually and frozen at –20°C.

Consumer panel evaluation

Panelists (*n* = 252) were recruited from Manhattan, KS and the surrounding communities and monetarily compensated for participation. Consumer panels were conducted at the KSU Meat Science Sensory Laboratory. Each panelist was placed in individual sensory booths and samples were served under low intensity (< 107.64 lumens) red incandescent lighting used to mask DOD variations among samples. A total of 36 panels were conducted with 7 consumers per session and lasted approximately 1 h.

Panelists were provided with a ballot, toothpick, napkin, fork, knife, water cup, expectorant cup, unsalted crackers, and apple juice which were used as palate cleansers between samples. Each ballot contained an informational sheet, a demographic questionnaire, and survey ballots for each sample to be evaluated. Prior to the start of each panel, verbal instructions were given to consumers about how to fill out the ballot sheets and the testing procedures.

Steaks were thawed (2 to 4°C) 24 h prior to evaluation. A thaw weight was recorded for determination of the percentage of thaw loss and remaining external fat and accessory muscles (*M. multifidus dorsi* and *M. gluteus medius*) were removed prior to cooking and weighing for cook loss evaluation. Steaks were cooked to the preassigned DOD [Rare (60°C), Medium (71°C), or Very Well-Done (82°C)] on a clamshell grill (Cuisinart Griddler Deluxe, East Windsor, NJ). Thermocouples (30-gauge copper and constantan; Omega Engineering, Stamford, CT) monitored temperatures with a Doric Mini-trend Data Logger (Model 205 B-1-c OFT, Doric Scientific, San Diego, CA) and peak temperatures were verified with a probe thermometer (Model 450-ATT, Omega Engineering, Stamford, CT). Following a 2 min rest period, steaks were cut into 1.3-cm by 1.3-cm by 2.54-cm cubes. Two cubes were immediately served to 7 consumers, with 6 samples served per panel representing multiple DOD and quality treatments. The study was designed as a partially balanced, incomplete block design so that every quality treatment × DOD combination was compared as close to an equal number of times as possible across all 36 panel sessions. This was done to allow for consumers to evaluate multiple degrees of doneness and quality treatments within the same panel session. Prior to evaluation, panelists were asked to rate a list of 15 beef purchasing motivators in terms of importance with anchors located at 0 mm and 100 mm. The 0 mm anchor was labeled as extremely unimportant and 100 mm was labeled as extremely important. Additionally, panelists rated each sample for the traits of juiciness, tenderness, flavor liking, and overall liking on 100-mm line scales. Anchors were located at 0 mm and 100 mm, with 0 mm labeled as extremely dry, extremely tough, and extremely dislike; and 100 mm labeled as extremely juicy, extremely tender, and like extremely. Each scale also had a midpoint at 50 mm labeled as neither dry nor juicy, neither tough nor tender, and neither dislike nor like. Finally, consumers rated each trait evaluated as either acceptable or unacceptable and also classified samples into 1 of 4 quality levels: unsatisfactory, everyday quality, better than everyday quality, or premium quality.

Trained panel evaluation

Training of panelists and taste matching tests were performed using the protocols described by the *Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat* (American Meat Science Association, 1995). Ten sensory training sessions were held in the 3 wk prior to starting the trained sensory panels. Additionally, training references and anchors were consistent with those described by Lucherk et al. (2016) and Adhikari et al. (2011).

Steaks were prepared as described previously for consumer panel evaluation. A total of 36 panel sessions were conducted by an 8-member trained panel. Steaks were cut into 1.3-cm by 1.3-cm cubes and placed into double broilers, and held on a stove top (Model AKC-35D, Amana Corporation, Newton, IA) at 43°C for no more than 15 min prior to sample evaluation. A warm-up sample was served to panelists prior to evaluation of treatment samples.

Panelists were given an electronic tablet (Model 5709 HP Steam 7; Hewlett-Packard, Palo Alto, CA), toothpick, napkin, fork, knife, water cup, expectorant cup, and unsalted crackers and sliced apples which were used as palate cleansers between samples. Panelists were served in individual sensory booths at the KSU Meat Science Sensory Laboratory. Samples were served under low intensity (< 107.64 lumens) red incandescent lighting used to mask DOD variations among samples. Samples were rated on digital ballots designed through the Qualtrics survey software (Version 2417833). Each sample was evaluated for initial juiciness, sustained juiciness, myofibrillar tenderness, amount of connective tissue, overall tenderness, beef flavor intensity, salt flavor intensity, off-flavor intensity, and panelists were asked to describe any off-flavor detected. The traits were rated on continuous line scales. The 0 anchors were labeled as extremely dry, extremely tough, none, and extremely bland; and the 100 anchors were labeled as extremely juicy, extremely tender, abundant, and extremely intense. Midpoint (50%) anchors for initial juiciness, sustained juiciness, myofibrillar tenderness, and overall tenderness were labeled as neither dry nor juicy, and neither tough nor tender. Also, there were boxes labeled "not applicable" to check for salt intensity and off flavor intensity for samples where none were detected.

Slice shear force and Pressed Juice Percentage

The protocol followed for Slice Shear Force (SSF) is described by Shackelford et al. (1999) and was performed using a shearing machine (Model GR-152, G-R Manufacturing Co., Manhattan, KS) with a crosshead speed of 500 mm/min, and a basic force gauge (BFG500N, Mecmesin Ltd., West Sussex, UK) which was attached to a SSF blade to measure peak force (kg) required to shear through the warm slice. The Pressed Juice Percentage (PJP) protocol used is described by Lucherk et al. (2017). Pressed Juice Percentage samples were weighed on 2 pieces of filter paper (VWR Filter Paper 415, 12.5 cm, VWR International, Radnor, PA) and compressed for 30 s at 78.45 N of pressure using an INSTRON Model 5569 testing machine (Instron, Canton, MA). The three sample values were averaged for a single PJP value for each steak.

Warner-Bratzler shear force

After PJP and SSF sample removal, steaks were cooled for 12 h at 2– 4°C prior to Warner-Bratzler shear force (WBSF) analysis (American Meat Science Association, 1995). Six cores (1.27-cm diameter) were removed parallel to the muscle fiber orientation and sheared using an INSTRON Model 5569 testing machine (Instron, Canton, MA) set to a crosshead speed of 250 mm/min, with a WBSF (V-notch) blade attached. The peak force (kg) required to shear each core was recorded and the 6 values were averaged for a single WBSF value for each steak.

Proximate analysis

All exterior fat and accessory muscles (*M. multifidus dorsi* and *M. gluteus medius*) were removed from the *M. longissimus dorsi* of each sample for proximate analysis. Samples were submerged in liquid nitrogen and homogenized using a commercial 4 blade blender (Model 33BL 79, Waring Products, New Hartford, CT). Powdered samples were then placed in Whirl-Pac (Nasco, Fort Atkinson, WI) bags and stored (–20°C) until further analysis. The procedures followed for lipid extraction are described by Martin et al. (2013). Moisture content was determined using an oven drying method (AOAC, 2005). Nitrogen content was determined using a combustion method (TruMac N Nitrogen/Protein determination Instruction manual, 2014, Leco Corp., St. Joseph, MI) and multiplied by 6.25 to determine protein content. A muffle furnace was used to determine percent ash following the AOAC ash oven method (AOAC, 2005).

Statistical analysis

For this study, quality treatment was defined as the USDA quality grade/enhancement level combination, so that there were a total of 6 quality treatments (1 enhanced and 1 non-enhanced treatment from each quality grade). This was done to allow for the comparison of means across all 6 quality treatments to best accomplish the study objectives and demonstrate the impact of enhancement on each of the quality grades. SAS (Version 9.4; SAS Inst. Inc., Cary, NC) was used for statistical analyses. Comparisons among treatment means were evaluated for significance using PROC GLIMMIX with $\alpha = 0.05$. All sensory panel and objective data were analyzed as a split-plot arrangement of factors. The model included the whole-plot factor of quality treatment and the sub-plot factors of DOD and the quality treatment × DOD interaction. For sensory data, panel session number was included as a random effect. All consumer acceptability data were compiled as the proportion of "acceptable" responses within each steak and the data were analyzed with a model that included a binomial error distribution using PROC GLIMMIX. All color, pH, and proximate data were analyzed with a model that included the fixed effect of quality treatment. For all analyses, the Kenward–Roger approximation was utilized for estimation of denominator degrees of freedom and the PDIFF option was used to separate treatment means when the F-test on the overall effect was significant ($P < 0.05$). The quality treatment × DOD interaction was nonsignificant ($P > 0.05$) for all dependent variables, unless otherwise denoted. For significant interactions, the SLICE option of the LS MEANS statement was used to restrict comparisons among quality treatments to within the same degree of doneness.

Results

Proximate composition and objective measures

Instrumental color readings, pH values, and percentages of chemical moisture, protein, fat, and ash are presented in Table 1. Enhanced treatments were all similar ($P > 0.05$) for pH and had a higher ($P < 0.05$) pH than all non-enhanced treatments. Moreover, fat percentage increased ($P < 0.05$) with increased USDA quality grade in both enhanced and non-enhanced treatments. Moisture content was inversely related ($P < 0.01$) to fat percentage ($r = –0.75$). Consequently, Prime samples had the lowest ($P < 0.05$) moisture content in both enhanced and non-enhanced treatment groups. It is noteworthy that enhancement resulted in only numerical increases in moisture content for samples from each quality grade, however no statistical differences ($P > 0.05$) were found between enhanced and non-enhanced samples of the same quality grade. Instrumental color readings indicated L* values increased ($P < 0.05$) as quality grade increased in the enhanced and non-enhanced samples (Table 2). The L* values of the non-enhanced Low Choice and Low Select samples were higher ($P < 0.05$) than their enhanced counterparts, and no differences ($P > 0.05$) were found for a* and b* values among non-enhanced

Table 1. Least squares means for objective analyses of grilled beef strip loin steaks cooked to 3 degrees of doneness

Treatment	PJP[1], %	Slice Shear Force, kg	Warner-Bratzler Shear Force value, kg	Consumer panel thaw loss[2],%	Consumer panel cook loss[3], %	Consumer panel total loss[4], %	Trained panel thaw loss[5], %	Trained panel cook loss[6], %	Trained panel total loss[7], %
Quality Treatment									
Non-Enhanced									
Prime	20.10	13.28^{b}	2.31^{bc}	1.92^{c}	18.99^{a}	21.44^{b}	1.82^{bc}	17.69^{b}	19.87^{b}
Low Choice	20.25	12.43^{b}	2.69^{b}	2.56^{b}	18.40^{a}	22.17^{ab}	2.78^{a}	18.95^{ab}	22.05^{a}
Low Select	19.88	17.30^{a}	3.40^{a}	3.11^{a}	19.61^{a}	23.28^{a}	2.47^{ab}	20.17^{a}	23.19^{a}
Enhanced[8]									
Prime	20.02	11.43^{b}	1.74^{d}	1.30^{d}	16.75^{b}	18.54^{c}	1.05^{c}	15.63^{c}	17.28^{c}
Low Choice	20.30	11.08^{b}	1.80^{d}	1.51^{cd}	15.52^{b}	17.28^{c}	1.33^{c}	14.50^{c}	16.32^{c}
Low Select	19.96	11.78^{b}	2.15^{cd}	1.29^{d}	15.97^{b}	17.66^{c}	1.11^{c}	14.78^{c}	16.06^{c}
SEM[9]	0.53	1.04	0.16	0.18	0.53	0.52	0.28	0.52	0.53
P-value[10]	0.99	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Degree of doneness									
Rare (60°C)	23.68^{a}	12.97	2.14^{b}	2.00	11.91^{c}	14.71^{c}	1.73	11.63^{c}	13.98^{c}
Medium (71°C)	20.38^{b}	13.16	2.39^{a}	1.94	16.98^{b}	19.29^{b}	1.77	16.41^{b}	18.51^{b}
Very well done (82°C)	16.20^{c}	12.52	2.51^{a}	1.92	23.72^{a}	26.19^{a}	1.78	22.81^{a}	24.90^{a}
SEM[9]	0.36	0.49	0.08	0.12	0.38	0.36	0.14	0.36	0.38
P-value[11]	< 0.01	0.32	< 0.01	0.87	< 0.01	< 0.01	0.93	< 0.01	< 0.01

[a–d]Least squares means in the same section without a common superscript differ ($P < 0.05$).

[1]PJP = Pressed Juice Percentage. Percentage of weight lost during compression of sample between filter paper at 78.45 N for 30 s.

[2]Consumer thaw loss = [(initial weight- thaw weight) / initial weight] × 100.

[3]Consumer cook loss = [(raw weight- cooked weight) / raw weight] × 100.

[4]Consumer total loss = [(initial weight- cooked weight) / initial weight] × 100.

[5]Trained thaw loss = [(initial weight- thaw weight) / initial weight] × 100.

[6]Trained cook loss = [(raw weight- cooked weight) / raw weight] × 100.

[7]Trained total loss = [(initial weight- cooked weight) / initial weight] × 100.

[8]Enhanced to 108% of raw weight with a water, salt, alkaline phosphate solution.

[9]SE (largest) of the least squares means.

[10]*P*-value for main effect of quality treatment.

[11]*P*-value for main effect of degree of doneness.

treatments. Enhanced and non-enhanced Prime samples were similar ($P > 0.05$) for both a* and b* values and Low Choice samples only had lower ($P < 0.05$) b* values as a result of enhancement.

Table 1 contains results from objective juiciness and tenderness measurements. Objective measures of tenderness (WBSF and SSF) showed similar results, with non-enhanced Low Select samples determined to be the toughest ($P < 0.05$) of all treatment groups and non-enhanced Prime and Low Choice to be similar ($P > 0.05$) for tenderness. However, WBSF indicated non-enhanced Low Choice samples were tougher ($P < 0.05$) than all enhanced treatments. Conversely, SSF indicated a similar ($P > 0.05$) tenderness among all enhanced treatments and non-enhanced Prime and Low Choice samples. No difference ($P > 0.05$) in SSF value was found among DOD treatments. Additionally, WBSF was similar ($P > 0.05$) between Medium and Very Well-Done samples, with Rare samples being more tender ($P < 0.05$) than either.

The percentages of cooking loss, thaw loss, and total (initial raw weight – cooked weight) loss for steaks used for consumer and trained panels are reported in Table 1. The percentage of cooking loss was lower ($P < 0.05$) for all enhanced treatments when compared to non-enhanced treatments. Percentages of thaw loss decreased ($P < 0.05$) for non-enhanced consumer steaks as quality grade increased. Overall, percentages of thaw loss tended to be lower for enhanced treatments when compared to non-enhanced treatments. When comparing steaks cooked to different DOD, it is not surprising that the amount of cooking loss increased ($P < 0.05$) as DOD increased from Rare to Very Well-Done. Rare samples had close to half the amount of weight lost as a result of cooking compared to Very Well-Done steaks in the current study. The total loss

Table 2. Least squares means for proximate, pH, and instrumental color analysis of raw beef strip loin steaks of varying quality and enhancement treatments

	%							
Treatment	Fat	Moisture	Protein	Ash	pH	L*[1]	a*[2]	b*[3]
Non-Enhanced								
Prime	8.03[a]	68.51[c]	22.43[ab]	1.19[d]	5.70[b]	47.55[a]	25.98[a]	18.98[a]
Low Choice	3.51[cd]	71.25[b]	23.12[a]	1.35[cd]	5.66[b]	44.47[b]	26.30[a]	18.52[a]
Low Select	2.34[e]	71.99[ab]	23.24[a]	1.25[d]	5.68[b]	42.64[bc]	26.34[a]	17.78[ab]
Enhanced[4]								
Prime	6.78[b]	69.05[c]	21.29[b]	1.52[bc]	5.87[a]	44.97[ab]	25.95[a]	18.40[a]
Low Choice	3.91[c]	72.37[ab]	21.65[b]	1.76[a]	5.86[a]	40.62[cd]	25.38[ab]	16.75[bc]
Low Select	2.46[de]	73.40[a]	22.03[ab]	1.68[ab]	5.88[a]	39.15[d]	24.50[b]	15.88[c]
SEM[5]	0.40	0.52	0.43	0.07	0.03	1.05	0.43	0.49
P-value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.01

[a–e]Least squares means in the same column without a common superscript differ ($P < 0.05$).

[1]L* = lightness (0 = black and 100 = white).

[2]a* = redness (–60 = green and 60 = red).

[3]b* = blueness (–60 = blue and 60 = yellow).

[4]Enhanced 108% of raw weight with a water, salt, and alkaline phosphate solution.

[5]SE (largest) of the least squares means.

and cooking loss for enhanced treatments were similar ($P > 0.05$) and lower ($P < 0.05$) than the non-enhanced treatments for trained and consumer panel steaks.

Consumer demographics

The demographic profile of the 252 consumers who participated in the consumer sensory analysis are presented in Table 3. Participants were primarily Caucasian/White (87.76%) from a household size of at least three people (61.69%), and at least 30 yr of age (45.13%). The number of males (60%) was greater than females (40%), with close to half (47.58%) of participants married. Most consumers (47.11%) had completed some college/technical school or were college graduates (22.31%). Within the group of participants, 51.21% consumed beef at least 4 times a wk and 65.87% reported their preferred degree of doneness to be medium-rare or medium. Also, beef was chosen as the product preferred for flavor by a large majority (70.56%) of consumers, more than 8 times higher than chicken (8.06%), or pork (7.26%). When asked what palatability trait was most important when eating beef, flavor was chosen by nearly half (49.90%) of the consumers, followed by tenderness (36.55%), and juiciness (14.06%).

Consumer sensory evaluation

Table 4 contains least squares means of consumer ratings of palatability traits. In non-enhanced samples, Prime and Low Choice were similar ($P > 0.05$) for all palatability traits and higher ($P < 0.05$) for juiciness and tenderness than Low Select samples. Moreover, non-enhanced Low Choice samples were similar ($P > 0.05$) to non-enhanced Low Select samples for flavor and overall liking. All enhanced treatments, regardless of quality grade, were similar ($P > 0.05$) for all palatability traits evaluated. Additionally, enhanced treatments had greater ($P < 0.05$) ratings of juiciness, tenderness, flavor liking, and overall liking than all non-enhanced treatments.

A higher ($P < 0.05$) percentage of samples from each enhanced treatment were rated acceptable for juiciness, tenderness, flavor liking, and overall liking than all non-enhanced samples, except for non-enhanced Prime samples for juiciness, tenderness, and overall liking (Table 5). Additionally, no difference ($P > 0.05$) was found among all enhanced treatments for the percentage of samples rated acceptable for all palatability traits, with each trait having more than 85% of samples rated acceptable. No difference ($P > 0.05$) was found between non-enhanced Prime and Low Choice samples for the percentage of samples rated acceptable for all palatability traits. Additionally, non-enhanced Low Select samples were rated unacceptable overall more ($P < 0.05$) than all other treatments for each palatability trait, with more than 40% of samples rated unacceptable overall. A smaller ($P < 0.05$) percentage of Prime and Low Choice enhanced samples were classified as unsatisfactory quality and a greater ($P < 0.05$) percentage of enhanced samples were identified as better than everyday quality and premium quality than all non-enhanced treatments (Table 6). There was no

Table 3. Demographic characteristics of consumers ($n = 252$) who participated in consumer sensory panels

Characteristic	Response	Percentage of consumers
Gender	Male	60.00
	Female	40.00
Household size	1 person	12.90
	2 people	25.40
	3 people	14.92
	4 people	25.40
	5 people	10.48
	6 people	5.24
	> 6 people	5.65
Marital status	Single	52.42
	Married	47.58
Age	Under 20	10.57
	20 – 29	44.31
	30 – 39	15.04
	40 – 49	14.23
	50 – 59	9.76
	Over 60	6.10
Ethnic origin	African-American	3.27
	Asian	3.67
	Caucasian/White	87.76
	Hispanic	2.86
	Native American	0.41
	Other	2.04
Annual household income	Under $25,000	5.28
	$25,000 – $34,999	6.50
	$35,000 – $49,999	12.20
	$50,000 – $74,999	28.86
	$75,000 – $100,000	26.42
	> $100,000	20.73
Education level	Non-high school graduate	1.65
	High school graduate	9.50
	Some college/Technical school	47.11
	College graduate	22.31
	Post graduate	19.42
Weekly beef consumption	1 to 3 times	48.79
	4 to 6 times	46.37
	7 or more times	4.84
Most important palatability trait when eating beef	Flavor	49.40
	Juiciness	14.06
	Tenderness	36.55
Degree of doneness preferred	Very Rare	1.61
	Rare	4.42
	Medium-Rare	39.36
	Medium	26.51
	Medium-Well	21.69
	Well-Done	5.22
	Very Well-Done	1.20
Meat product preferred for flavor	Beef	70.56
	Chicken	8.06
	Fish	2.82
	Lamb	4.84
	Mutton	0.81
	Pork	7.26
	Shellfish	2.02
	Turkey	0.40
	Veal	1.61
	Venison	1.61

Table 4. Least squares means for consumer ($n = 252$) ratings[1] of the palatability traits for grilled beef strip loin steaks of varying quality treatments and degrees of doneness

Treatment	Juiciness	Tenderness	Flavor liking	Overall liking
Quality treatment				
Non-Enhanced				
Prime	61.5^{b}	63.8^{b}	56.0^{b}	57.4^{b}
Low Choice	57.8^{b}	61.1^{b}	51.8^{bc}	52.7^{bc}
Low Select	50.3^{c}	49.8^{c}	48.7^{c}	49.2^{c}
Enhanced[2]				
Prime	69.9^{a}	71.4^{a}	67.6^{a}	69.4^{a}
Low Choice	71.7^{a}	73.5^{a}	66.5^{a}	68.9^{a}
Low Select	72.5^{a}	71.3^{a}	67.6^{a}	67.7^{a}
SEM[3]	1.9	2.5	2.0	2.0
P-value[4]	< 0.01	< 0.01	< 0.01	< 0.01
Degree of doneness				
Rare (60°C)	77.2^{a}	73.1^{a}	62.8^{a}	65.8^{a}
Medium (71°C)	65.7^{b}	65.6^{b}	58.9^{b}	61.4^{b}
Very well done (82°C)	49.0^{c}	56.7^{c}	57.4^{b}	55.5^{c}
SEM[3]	1.5	1.7	1.5	1.4
P-value[5]	< 0.01	< 0.01	0.01	< 0.01

[a–c]Least squares means in the same section of the same column without a common superscript differ ($P < 0.05$).

[1]Sensory scores: 0 = extremely dry/tough/dislike extremely; 100 = extremely juicy/tender/like extremely; 50 = neither dry nor juicy, neither tough nor tender, neither like nor dislike.

[2]Enhanced to 108% of raw weight with a water, salt, and alkaline phosphate solution.

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

[4]*P*-value for main effect of quality treatment.

[5]*P*-value for main effect of degree of doneness.

difference ($P > 0.05$) between non-enhanced Prime and Low Choice samples for the percentage of samples rated unsatisfactory and better than everyday quality. Also, all non-enhanced samples were similar ($P > 0.05$) in the percentage classified as premium quality.

When cooked to Rare and Medium, a smaller ($P < 0.05$) percentage of enhanced samples of each treatment were classified as everyday quality than non-enhanced samples (Table 7). Whereas when cooked to Very Well-Done, no difference ($P > 0.05$) among treatments was found for the percentage of samples identified as everyday quality. When evaluating consumer ratings for steaks differing by DOD, juiciness, tenderness, and overall liking scores increased ($P < 0.05$) as DOD decreased (Rare > Medium > Very Well-Done; Table 4). Moreover, Rare samples were rated higher ($P < 0.05$) for flavor liking than Medium or Very Well-Done samples. Similar results were found in the percentage of samples rated acceptable for each palatability trait,

Table 5. Percentage of beef strip loin steaks of varying quality treatments cooked to different degrees of doneness rated as acceptable for palatability traits by consumers (n = 252)

Treatment	Juiciness	Tenderness	Flavor liking	Overall liking
Quality treatment				
Non-Enhanced				
Prime	85.5^{ab}	93.2^{ab}	73.8^{b}	78.4^{bc}
Low Choice	79.6^{b}	86.6^{b}	71.3^{b}	74.1^{c}
Low Select	64.0^{c}	67.5^{c}	60.7^{c}	58.5^{d}
Enhanced[1]				
Prime	93.7^{a}	96.2^{a}	88.6^{a}	89.4^{a}
Low Choice	93.9^{a}	96.1^{a}	85.3^{a}	86.6^{ab}
Low Select	92.0^{a}	93.6^{a}	85.7^{a}	85.9^{ab}
SEM[2]	4.8	4.9	3.8	4.2
P-value[3]	< 0.01	< 0.01	< 0.01	< 0.01
Degree of doneness				
Rare (60°C)	96.4^{a}	96.5^{a}	82.9^{a}	86.8^{a}
Medium (71°C)	88.0^{b}	91.2^{b}	78.2^{ab}	81.5^{b}
Very well done (82°C)	62.5^{c}	81.9^{c}	75.6^{b}	70.7^{c}
SEM[2]	2.8	2.2	2.2	2.4
P-value[4]	< 0.01	< 0.01	0.03	< 0.01

[a–d]Least squares means in the same section of the same column without a common superscript differ (P < 0.05).

[1]Enhanced to 108% of raw weight with a water, salt, and alkaline phosphate solution.

[2]SE (largest) of the least squares means.

[3]P-value for main effect of quality treatment.

[4]P-value for main effect of degree of doneness.

Table 6. Percentage of beef strip loin steaks of varying treatments and degrees of doneness identified as different perceived quality levels by consumer panelists (n = 252)

Treatment	Unsatisfactory quality	Better than everyday quality	Premium quality
Quality treatment			
Non-Enhanced			
Prime	12.8^{b}	25.2^{b}	3.2^{b}
Low Choice	16.6^{ab}	20.5^{bc}	4.3^{b}
Low Select	26.6^{a}	14.6^{c}	1.9^{b}
Enhanced[1]			
Prime	6.0^{c}	39.9^{a}	11.8^{a}
Low Choice	5.1^{c}	34.7^{a}	17.8^{a}
Low Select	9.2^{bc}	35.4^{a}	11.8^{a}
SEM[2]	4.1	3.2	3.1
P-value[3]	< 0.01	< 0.01	< 0.01
Degree of doneness			
Rare (60°C)	7.0^{c}	35.3^{a}	10.7^{a}
Medium (71°C)	11.2^{b}	25.5^{b}	7.4^{a}
Very well done (82°C)	16.6^{a}	22.2^{b}	3.4^{b}
SEM[2]	2.1	2.2	1.7
P-value[4]	< 0.01	< 0.01	< 0.01

[a–c]Least squares means in the same section of the same column without a common superscript differ (P < 0.05).

[1]Enhanced to 108% of raw weight with a water, salt, and alkaline phosphate solution.

[2]SE (largest) of the least squares means.

[3]P-value for main effect of quality treatment.

[4]P-value for main effect of degree of doneness.

with a greater (P < 0.05) number of samples rated acceptable for juiciness, tenderness, and overall liking as DOD decreased from Very Well-Done to Medium to Rare (Table 5). Additionally, more (P < 0.05) Rare samples were rated acceptable for flavor liking than Very Well-Done samples. A greater (P < 0.05) percentage of Very Well-Done samples were identified as unsatisfactory quality than Medium or Rare samples (Table 6). Moreover, a higher (P < 0.05) percentage of Rare samples were classified as better than everyday quality than Medium and Very Well-Done samples and a lower (P < 0.05) percentage of Very Well-Done samples were rated as premium quality than Rare or Medium samples.

Trained sensory panel evaluation

A quality treatment × DOD interaction was found for initial juiciness (P < 0.05; Table 7). Regardless of quality treatment, initial juiciness scores increased (P < 0.05) as DOD decreased (Rare > Medium > Very Well-Done). Across all three DOD, all enhanced samples were similar (P > 0.05) for initial juiciness. Moreover, non-enhanced Prime was similar (P > 0.05) to all enhanced treatments when cooked to Rare, but was drier (P < 0.05) than enhanced Prime samples at Medium and Very Well-Done degrees of doneness. Within non-enhanced treatments, initial juiciness increased (P < 0.05) with increased marbling scores (Prime > Low Choice > Low Select) when cooked to Medium, however, Prime was similar (P > 0.05) to Low Choice in Rare samples, and Low Choice was similar (P > 0.05) to Low Select when samples were cooked to Very Well-Done.

Trained panel ratings for all other sensory traits are presented in Table 8. Similar to initial juiciness, no difference (P > 0.05) was found among all enhanced treatments, regardless of quality grade for sustained juiciness. Non-enhanced Prime samples were similar to enhanced Low Choice and Low Select samples for sustained juiciness, but juicier (P < 0.05) than non-enhanced Low Choice and Low Select samples, with non-enhanced Low Choice samples rated juicier (P < 0.05) than non-enhanced Low Select samples. When evaluating measures of tenderness, no differences (P > 0.05) were found among enhanced treatments for over-

Table 7. Interaction between degree of doneness and quality treatment for percentage of beef strip loin steaks classified as Everyday Quality ($P = 0.0011$) by consumers and for the initial juiciness trait ($P = 0.0256$) rated[1] by trained sensory panelists

Treatment	Everyday quality	Initial juiciness
Rare (60°C)		
Non-Enhanced		
Prime	53.0^{b}	76.9^{ab}
Low Choice	56.1^{a}	71.1^{b}
Low Select	53.1^{b}	66.4^{c}
Enhanced[2]		
Prime	28.5^{c}	81.9^{a}
Low Choice	23.5^{d}	83.6^{a}
Low Select	28.6^{c}	81.4^{a}
SEM[3]	5.9	2.1
P-value	< 0.01	< 0.01
Medium (71°C)		
Non-Enhanced		
Prime	65.3^{a}	61.0^{b}
Low Choice	54.3^{b}	48.7^{c}
Low Select	60.4^{ab}	42.9^{d}
Enhanced[2]		
Prime	43.2^{c}	70.8^{a}
Low Choice	36.8^{d}	66.7^{ab}
Low Select	37.9^{d}	66.4^{ab}
SEM[3]	5.9	2.1
P-value	< 0.01	< 0.01
Very well done (82°C)		
Non-Enhanced		
Prime	47.0	43.4^{b}
Low Choice	52.6	24.3^{c}
Low Select	47.6	18.6^{c}
Enhanced[2]		
Prime	46.4	51.2^{a}
Low Choice	56.1	45.7^{ab}
Low Select	53.6	47.1^{ab}
SEM[3]	5.9	2.1
P-value	0.79	< 0.01

$^{a–d}$Least squares means in the same section of the same column without a common superscript differ ($P < 0.05$).

[1]Sensory Scores: 0 = Extremely dry, 100 = Extremely juicy; 50 = Neither dry nor juicy.

[2]Enhanced to 108% of raw weight with a water, salt, and alkaline phosphate solution.

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

all and myofibrillar tenderness. Also, non-enhanced Low Select samples were tougher ($P < 0.05$) overall and tougher for myofibrillar tenderness than all other treatments. Little variation in connective tissue amount was found among treatments, with only non-enhanced Low Select samples having a greater ($P < 0.05$) amount of connective tissue than all other treatments.

Beef flavor intensity increased ($P < 0.05$) with increased marbling level in non-enhanced samples. Additionally, both enhanced and non-enhanced Prime samples had a more ($P < 0.05$) intense beef flavor than all other treatments. As was expected, all enhanced treatments had a greater ($P < 0.05$) salt intensity than all non-enhanced treatments, with close to no salt flavor (< 0.14 units) observed in the non-enhanced samples. Despite all enhanced products having a similar salt content, the salt flavor intensity rating decreased ($P < 0.05$) as the quality grade increased. Differences were observed among treatments for off-flavor presence, however only a low amount (< 6 units) of off-flavor was observed within any treatment group.

When comparing different degrees of doneness, initial juiciness, sustained juiciness, myofibrillar tenderness, and overall tenderness all decreased ($P < 0.05$) as DOD increased (Rare > Medium > Very Well-Done). No difference ($P > 0.05$) was found among DOD for connective tissue amount, beef intensity, or off-flavor intensity scores. However, Very Well-Done samples were rated higher ($P < 0.05$) for beef flavor identity than Rare and Medium samples.

Relationships among sensory traits

Relationships among sensory traits were determined by Pearson correlation coefficients (Table 9). Consumer overall liking was correlated ($P < 0.01$) to consumer tenderness rating ($r = 0.76$), juiciness rating ($r = 0.72$), and flavor liking ($r = 0.90$). Also, consumer juiciness scores were correlated ($P < 0.01$) with the percentage of weight lost during thawing ($r = –0.29$), cooking ($r = –0.76$), and overall ($r = –0.79$). The percentage of cook loss for consumer steaks was associated ($P < 0.01$) with total loss ($r = 0.97$). Additionally, consumer juiciness scores were associated ($P < 0.01$) with trained panel traits of initial juiciness ($r = 0.75$) and sustained juiciness ($r = 0.75$). Trained panel initial and sustained juiciness scores were related ($P < 0.05$) to the percentage of cooking loss ($r = –0.88$) and total weight loss ($r = –0.87$). Moreover, consumer tenderness scores were associated ($P < 0.01$) with trained panel myofibrillar tenderness ($r = 0.67$) and overall tenderness ($r = 0.67$) scores. Warner-Bratzler shear force values were also closely associated ($P < 0.01$) with consumer tenderness scores ($r = –0.55$) and trained myofibrillar tenderness ($r = –0.74$) and overall tenderness scores ($r = –0.75$). Values for SSF were also correlated ($P < 0.01$) with consumer tenderness scores ($r = –0.40$) and scores of trained panel myofibrillar tenderness ($r = –0.57$) and overall tenderness

Table 8. Least squares means for trained sensory panel ratings[1] of grilled strip loin steaks of varying quality treatments and degrees of doneness

Treatment	Sustained juiciness	Myofibrillar tenderness	Connective tissue amount	Overall tenderness	Beef intensity	Salt intensity	Off flavor intensity
Quality Treatment							
Non-Enhanced							
Prime	51.8[b]	71.6[bc]	13.9[b]	67.3[bc]	47.5[a]	0.1[d]	5.5[a]
Low Choice	38.5[c]	67.8[c]	12.9[b]	63.6[c]	39.0[b]	0.0[d]	3.0[bc]
Low Select	32.9[d]	55.0[d]	22.7[a]	47.6[d]	32.8[c]	0.1[d]	5.8[a]
Enhanced[2]							
Prime	60.3[a]	78.4[a]	10.0[b]	75.6[a]	51.0[a]	13.4[c]	1.7[c]
Low Choice	57.0[ab]	79.4[a]	9.2[b]	76.9[a]	41.6[b]	20.6[b]	4.9[ab]
Low Select	55.7[ab]	75.3[ab]	11.2[b]	72.1[ab]	39.9[b]	26.0[a]	2.5[bc]
SEM[3]	2.0	2.1	1.8	2.5	1.4	0.9	0.9
P-value[4]	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Degree of doneness							
Rare (60°C)	68.5[a]	76.9[a]	13.1	72.6[a]	40.9	11.6[a]	3.5
Medium (71°C)	50.8[b]	70.2[b]	13.7	66.4[b]	42.0	10.0[ab]	4.3
Very well done (82°C)	28.8[c]	66.5[c]	13.1	62.6[c]	42.9	8.5[b]	3.8
SEM[3]	1.4	1.1	0.9	1.3	0.9	0.7	0.6
P-value[5]	< 0.01	< 0.01	0.49	< 0.01	0.18	< 0.01	0.48

[a–d]Least squares means in the same section of the same column without a common superscript differ ($P < 0.05$).

[1]Sensory scores: 0 = Extremely dry/tough/none/bland; 100 = Extremely juicy/tender/abundant/intense; 50 = neither dry nor juicy, neither tough nor tender.

[2]Enhanced to 108% of raw weight with a water, salt, and alkaline phosphate solution.

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

[4]*P*-value for main effect of quality treatment.

[5]*P*-value for main effect of degree of doneness.

($r = -0.61$). Pressed Juice Percentage was correlated ($P < 0.01$) with consumer juiciness scores ($r = 0.55$), trained panel initial juiciness scores ($r = 0.59$), and trained panel sustained juiciness scores ($r = 0.57$).

Discussion

Objective measures

Fat percentages in our study are slightly lower than those reported in previous studies evaluating beef of the same quality grades (Savell et al., 1986; O'Quinn et al., 2012; Emerson et al., 2013; Legako et al., 2015). In these studies, the authors used either NIR, ether extraction, or Foltch methodology to quantify fat percentage. In the current study, a modified chloroform/methanol extraction protocol described by Martin et al. (2013) was used for fat quantification. This methodological difference may explain the differences between fat percentages observed in the current study and the values reported by previous authors. However, the results of the current study are consistent with authors who have used CEM to quantify the fat percentage of beef of different quality grades (Dow et al., 2011) and show a similar increase in fat percentage and the same relative differences among quality grades for fat percentage as in previous reports.

Studies by Pietrasik and Janz (2009) and Baublits et al. (2006) determined steaks enhanced to 112 to 125% of the raw weight had between 2.97 and 3.30% increase in moisture percentage from non-enhanced controls. However, in the current study steaks were enhanced to 108% and no such increase in moisture percentage was observed. Similar to our results, Stetzer et al. (2008) and Smith et al. (1984) reported no difference in enhanced and non-enhanced steaks moisture content when steaks were enhanced to 108 and 110%, respectively. Additionally, Lucherk et al. (2016) reported Select steaks enhanced to 107% did not differ in moisture content from non-enhanced Select steaks; however, Select steaks enhanced to 112% had a 2.77% increased moisture percentage compared to non-enhanced Select steaks in that study. Collectively these studies indicate for differences to be detected in the percentage of chemical moisture of

Table 9. Pearson correlation coefficients for sensory scores and objective measurements of beef strip loin steaks varying in quality treatment and degree of doneness

	Consumer panel rating							Trained panel rating								Objective measurements	
Measurement	Tenderness	Juiciness	Flavor liking	Overall liking	Thaw loss, %	Cook loss, %	Total loss, %	Initial juiciness	Sustained juiciness	Myofibrillar tenderness	Overall tenderness	Beef flavor identity	Thaw loss, %	Cook loss, %	Total loss, %	PJP[1], %	WBSF[2], kg
Consumer panel																	
Juiciness	0.81**																
Flavor Liking	0.55**	0.53**															
Overall Liking	0.76**	0.72**	0.90**														
Thaw Loss, %	–0.27**	–0.29**	–0.38**	–0.36**													
Cook Loss, %	–0.57**	–0.76**	–0.35**	–0.48**	0.09												
Total Loss, %	–0.60**	–0.79**	–0.41	–0.53**	0.32**	0.97**											
Trained Panel																	
Initial Juiciness	0.59**	0.75**	0.38**	0.51**	–0.28**	–0.78**	–0.81**										
Sustained Juiciness	0.58**	0.75**	0.38**	0.51**	–0.28**	–0.77**	–0.80**	0.99**									
Myofibrillar Tenderness	0.67**	0.59**	0.47**	0.55**	–0.36**	–0.50**	–0.54**	0.69**	0.70**								
Overall Tenderness	0.67**	0.56**	0.46**	0.54**	–0.36**	–0.46**	–0.50**	0.65**	0.65**	0.98**							
Beef Flavor Identity	0.02	–0.07	0.08	0.06	–0.13	0.14*	0.12	0.04	0.04	0.07	0.07						
Thaw Loss, %	–0.24**	–0.25**	–0.25**	–0.27**	0.39**	0.08	0.25**	–0.24**	–0.25**	–0.27**	–0.26**	0.01					
Cook Loss, %	–0.56**	–0.73**	–0.35**	–0.48**	0.27**	0.80**	0.84**	–0.88**	–0.88**	–0.60**	–0.56**	0.11	0.16*				
Total Loss, %	–0.58**	–0.74**	–0.37**	–0.50**	0.31**	0.77**	0.83**	–0.87**	–0.87**	–0.61**	–0.57**	0.12	0.38**	0.97**			
Objective Measurements																	
PJP, %	0.39**	0.55**	0.14*	0.26**	–0.03	–0.65**	–0.62**	0.59**	0.57**	0.34**	0.30**	–0.15*	–0.03	–0.58**	–0.55**		
WBSF, kg	–0.55**	–0.43**	–0.41**	–0.49**	0.34**	0.32**	0.37**	–0.45**	–0.46**	–0.74**	–0.75**	–0.09	0.28**	0.34**	0.38**	–0.25**	
Slice Shear force value, kg	–0.40**	–0.22**	–0.28**	–0.34**	0.21**	0.09	0.12	–0.17*	–0.17*	–0.57**	–0.61**	–0.07	0.18**	0.11	0.15*	–0.02	0.67**

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

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

[1]PJP = Pressed Juice Percentage.

[2]WBSF = Warner-Bratzler Shear Force.

raw samples, enhanced treatments typically require greater than a 10% pump level.

Increased muscle pH as a result of alkaline phosphate enhancement have been previously observed by authors, with increases in pH of 2.90, 2.10, and 7.50% previously reported by Robbins et al. (2003b), Baublits et al. (2006), and Wicklund et al. (2005), respectively. Our study reported pH increases of 2.90 to 3.41% for enhanced treatments. Additionally, Robbins et al. (2003b) found when enhancing beef strip loins with a solution similar to the current study (water, salt, and alkaline phosphates) L* readings of enhanced strip loins were darker (3.91 to 7.93% lower) than non-enhanced control samples. Robbins et al. (2003b) also reported enhanced treatments had 9.09 to 14.38% and 5.69 to 11.19% lower a* and b* values, respectively, than non-enhanced counterparts. Similarly, Wicklund et al. (2005) reported enhanced steaks had lower values of L* by 9.89%, a* by 9.67%, and b* by 17.41% than a non-enhanced control treatment. The current study reported comparable results to previous research, as the enhanced treatments had a 5.43 to 8.18% decrease for L* value. Also, decreases of 6.99% in a* values for enhanced Low Select, and 9.56 to 10.69% decreases in b* values for enhanced Low Choice and Low Select were observed when compared to the non-enhanced treatments. Collectively, these studies indicate enhancement with salt and alkaline phosphate solutions result in darker lean color with lower a* and b* values. This is important as color has been reported as the most influential factor affecting consumer purchasing decisions within the marketplace, with consumers preferring steaks that are bright cherry-red colored rather than dark or dull red in color (Mancini and Hunt, 2005). Robbins et al. (2002), Stetzer et al. (2008), and Wicklund et al. (2005) used trained sensory panelists to evaluate visual color and found results similar to the instrumental color scores reported in the current and previous studies. Though, to date, no studies have evaluated consumer acceptance of the color of enhanced beef.

Degree of doneness

Cox et al. (1997) determined when consumers were served a different DOD than what was ordered at a restaurant, consumer palatability scores decreased, which helps to demonstrate the large role DOD plays in the consumer eating experience. Multiple studies have prescreened consumers and fed only a single, preferred DOD (O'Quinn et al., 2015; Lucherk et al., 2016); however, this often limits the ability to make meaningful comparisons and conclusions across different DOD within the same study. Moreover, other authors have had consumers evaluate steaks of differing DOD under white lighting (Gomes et al., 2014), though this is not recommended (American Meat Science Association, 1995) due to the inherent consumer bias due to DOD preference described by Cox et al. (1997). In our study, similar to Cross et al. (1976) and Parrish et al. (1973), panelists evaluated samples from multiple DOD under red lighting to mask the DOD appearance differences among samples. This was done to allow for consumers to evaluate samples of varying DOD without an inherent bias due to product appearance. Our study reports Rare was rated the most juicy, tender, flavorful, and the highest liked by consumers. Whereas, based on the demographic profile, Rare was the preferred DOD by only 4.42% of consumers, providing evidence that consumer DOD preference did not create a bias within this study. Conversely, the study by Gomes et al. (2014) reported the appearance of cooked samples (under white lighting) influenced consumer sensory ratings as they were asked to rate the internal red and brown color prior to sensory evaluation, thus limiting the ability to make unbiased comparisons among DOD treatments.

Many studies have reported as DOD increases, palatability ratings of juiciness and tenderness decrease (Cross et al., 1976; Savell et al., 1999; Lorenzen et al., 2005; Gomes et al., 2014; Lucherk et al., 2016). Juiciness ratings have been shown to have dramatic decreases (16 to 70%) when DOD was increased from lower endpoint temperatures (55 to 60°C) to higher endpoint temperatures (77 to 90°C) in multiple studies (Parrish et al., 1973; Cross et al., 1976; Lorenzen et al., 2005; Lucherk et al., 2016). Observed tenderness decreases have been similar, with decreased tenderness ratings of 20 to 58% when final endpoint temperature is increased over the same range (Parrish et al., 1973; Cross et al., 1976; Lorenzen et al., 2005). The current study shows a decrease in palatability similar to previous research. As final internal temperature increased from 60°C to 82°C, tenderness and juiciness decreased 22.51 and 36.55%, respectively.

Moreover, the importance of final endpoint temperature and the resulting dehydration of samples due to cooking loss at elevated DOD on beef tenderness is evident. Many authors have reported as DOD increases, WBSF values also increase (Lorenzen et al., 2005; Gomes et al., 2014; Lucherk et al., 2016). It is also well documented that as internal temperature increases, the percentage of cooking loss increases (Parrish et al., 1973; Luchak et al., 1998; Lorenzen et al., 2005). Our results mimic those of previous studies, with increased moisture loss as a result of cooking increasing with increased DOD. However, few differences in shear force values were observed, as the Rare samples had the lowest WBSF values, but Medium and Very-Well Done were similar. Moreover, no differences among DOD were found for SSF. These findings may be attributed to the high level of tenderness (all < 13.2 kg) found among these treatments, likely due in part to the 21 d aging period used in the current study.

Quality treatment

Previous studies evaluating enhancement have focused on either lower palatability muscles or enhancing lower quality grades such as USDA Select. Prior research has found that enhancement increased consumer sensory scores for tenderness, juiciness, flavor liking, and overall liking of USDA Select beef (Miller et al., 1995; Brooks et al., 2010; Igo et al., 2015). The current study agrees with theses previous findings for the Low Select enhanced treatment. Previous studies reported enhancement of steaks resulted in a 11.54 to 35.50% increase in tenderness (Brooks et al., 2010; Igo et al., 2015; Lucherk et al., 2016), and the current study found a 30.21% increase from non-enhanced Low Select to the enhanced counterpart. Additionally, prior research reported enhanced steaks had an increase of 10.53 to 28.26% in consumer juiciness scores, and the current study reported a 30.60% increase (Brooks et al., 2010; Igo et al., 2015; Lucherk et al., 2016). An increase in flavor liking was also reported for enhanced steaks of 5.00 to 28.36% in previous research (Brooks et al., 2010; Igo et al., 2015; Lucherk et al., 2016), with the current study reporting a 27.98% increase for the Low Select enhanced treatment over the non-enhanced Low Select. The current study also reported a 27.33% increase in overall liking for the enhanced Low Select over the non-enhanced counterpart, with similar increases (10.39 to 33.12%) in overall liking observed in previous studies (Brooks et al., 2010; Igo et al., 2015; Lucherk et al., 2016).

However, research has not previously evaluated the enhancement of higher quality cuts. Our study enhanced a range of quality grades, and found that all enhanced treatments were similar, regardless of the marbling level. As quality grade increased the percentage increase in all palatability traits decreased. Our study reported consumer ratings of tenderness increased for enhanced treatments by 30.21% for Low Select, 16.88% for Low Choice, and 10.61% for Prime. Ratings for juiciness were 30.60, 19.44, and 11.92% higher for the enhanced Low Select, Low Choice, and Prime, respectively. Flavor liking was rated greater for the enhanced samples by 27.98% for Low Select, 22.06% for Low Choice, and 17.13% for Prime. Also, overall liking was reported to increase with enhancement, with Low Select increasing 27.33%, Low Choice increasing 23.50%, and Prime increasing 17.28%. Therefore, enhancement has a large positive impact on beef palatability; however, improvement potential is not independent of or additive with quality grade. This demonstrates a more limited benefit to enhancing higher quality beef and indicates the most appropriate use of enhancement technology remains in lower quality beef cuts.

Additionally, enhanced beef has been reported as having a greater salt flavor and greater beef flavor than similar non-enhanced beef products (Robbins et al., 2003a; Pietrasik and Janz, 2009). In the current study, trained panelists indicated an increase in salt intensity in enhanced samples. However, there was an increase in salt intensity among enhanced samples as the quality grade decreased. This dilution effect of salt flavor may be the result of the increased fat percentages of the higher quality grades, perhaps providing some overshadowing effect of the salt flavor due to the increase in beef flavor intensity observed with the higher quality grades.

Previous research indicates as quality grade increases, the palatability traits of juiciness, flavor, and tenderness increase for consumer and trained panelists (Neely et al., 1998; Acheson et al., 2014; Corbin et al., 2015). Furthermore, prior research indicates that as quality grade increases, the percentage of samples rated acceptable by consumers for all palatability traits also increases (Behrends et al., 2005; Corbin et al., 2015; Tatum, 2015; O’Quinn, 2016). In the current study, though differences were found, quality grade did not have as large of an effect as reported in previous studies. Non-enhanced Prime and Low Choice were found to be similar in all consumer panel ratings. The range of palatability traits in samples consumers evaluated in our study was extremely large. Both enhanced and non-enhanced samples of the three quality grades cooked to multiple DOD were served during the same panel sessions. It is possible that DOD and enhancement effects had a greater influence on consumer eating quality than quality grade in the current study, allowing for fewer differences among quality grades to be found than in previous reports that evaluated samples within the same degree of doneness and did not include enhanced samples.

Within the current study it is important to note that with consumer data, no difference was found in palatability ratings, acceptability, or perceived quality levels among the enhanced treatments, regardless of quality grade. Additionally, the enhanced treatments were all similar in acceptability to the non-enhanced Prime treatment. Thus, a consumer eating a Low Select enhanced steak would receive a similar eating experience as a Prime steak. However, there is currently a $13.69/kg premium for Prime strip loins over Select (USDA, 2017a, 2017b). Therefore, a similar eating experience can be attained without the premiums required for the higher quality grade. Additionally, it is notable that in the current study, enhancing the high quality graded cuts did not result in proportional increases in eating quality. This indicates enhancement does not provide an additive effect with quality level for beef palatability. It appears that enhancement improves the palatability of strip loins to a constant level, regardless of product initial quality grade or palatability level. These results give clear evidence that enhancement of higher grading beef (Choice and Prime) is not financially advantageous to producers, as no added benefit is gained when compared to enhancement of lower grading beef. However, these results also indicate the large opportunity for beef eating quality improvement of Select beef through the use of enhancement technology.

Literature Cited

Acheson, R. J., D. R. Woerner, and J. D. Tatum. 2014. Effects of USDA carcass maturity on sensory attributes of beef produced by grain-finished steers and heifers classified as less than 30 months old using dentition. J. Anim. Sci. 92:1792–1799. doi:10.2527/jas.2013-7553

Adhikari, K., E. Chambers Iv, R. Miller, L. Vazquez-Araujo, N. Bhumiratana, and C. Philip. 2011. Development of a lexicon for beef flavor in intact muscle. J. Sens. Stud. 26:413–420. doi:10.1111/j.1745-459X.2011.00356.x

American Meat Science Association. 1995. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. American Meat Science Association, Chicago, IL.

AOAC. 2005. Official Methods of Analysis. 18th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Baublits, R. T., F. W. Pohlman, A. H. Brown, Jr., E. J. Yancey, and Z. B. Johnson. 2006. Impact of muscle type and sodium chloride concentration on the quality, sensory, and instrumental color characteristics of solution enhanced whole-muscle beef. Meat Sci. 72:704–712. doi:10.1016/j.meatsci.2005.09.023

Behrends, J. M., K. J. Goodson, M. Koohmaraie, S. D. Shackelford, T. L. Wheeler, W. W. Morgan, J. O. Reagan, B. L. Gwartney, J. W. Wise, and J. W. Savell. 2005. Beef customer satisfaction: USDA quality grade and marination effects on consumer evaluations of top round steaks. J. Anim. Sci. 83:662–670. doi:10.2527/2005.833662x

Brooks, J. C., J. M. Mehaffey, J. A. Collins, H. R. Rogers, J. Legako, B. J. Johnson, T. Lawrence, D. M. Allen, M. N. Streeter, W. T. Nichols, J. P. Hutcheson, D. A. Yates, and M. F. Miller. 2010. Moisture enhancement and blade tenderization effects on the shear force and palatability of strip loin steaks from beef cattle fed zilpaterol hydrochloride. J. Anim. Sci. 88:1809–1816. doi:10.2527/jas.2009-2383

Corbin, C., T. O'Quinn, A. Garmyn, J. Legako, M. Hunt, T. Dinh, R. Rathmann, J. Brooks, and M. Miller. 2015. Sensory evaluation of tender beef strip loin steaks of varying marbling levels and quality treatments. Meat Sci. 100:24–31. doi:10.1016/j.meatsci.2014.09.009

Cox, R. J., J. M. Thompson, C. M. Cunial, S. Winter, and A. J. Gordon. 1997. The effect of degree of doneness of beef steaks on consumer acceptability of meals in restaurants. Meat Sci. 45:75–85. doi:10.1016/S0309-1740(96)00080-0

Cross, H. R., M. S. Stanfield, and E. J. Koch. 1976. Beef palatability as affected by cooking rate and final internal temperature. J. Anim. Sci. 43:114–121. doi:10.2527/jas1976.431114x

Dow, D. L., B. R. Wiegand, M. R. Ellersieck, and C. L. Lorenzen. 2011. Prediction of fat percentage within marbling score on beef longissimus muscle using 3 different fat determination methods. J. Anim. Sci. 89:1173–1179. doi:10.2527/jas.2010-3382

Emerson, M. R., D. R. Woerner, K. E. Belk, and J. D. Tatum. 2013. Effectiveness of USDA instrument-based marbling measurements for categorizing beef carcasses according to differences in longissimus muscle sensory attributes. J. Anim. Sci. 91:1024–1034. doi:10.2527/jas.2012-5514

Gomes, C. L., S. B. Pflanzer, A. G. Cruz, P. E. de Felício, and H. M. A. Bolini. 2014. Sensory descriptive profiling and consumer preferences of beef strip loin steaks. Food Res. Int. 59:76–84. doi:10.1016/j.foodres.2014.01.061

Hunt, M., C. Corbin, A. Garmyn, J. Legako, T. O'Quinn, R. Rathmann, C. Brooks, and M. Miller. 2014. Consumer assessment of flavor of steak of varying fat levels from four beef muscles. Meat Sci. 96:474–475. doi:10.1016/j.meatsci.2013.07.113

Igo, M. W., A. N. Arnold, R. K. Miller, K. B. Gehring, L. N. Mehall, C. L. Lorenzen, R. J. Delmore, D. R. Woerner, B. E. Wasser, and J. W. Savell. 2015. Tenderness assessments of top loin steaks from retail markets in four U.S. cities. J. Anim. Sci. doi:10.2527/jas.2015-9085

Legako, J. F., J. C. Brooks, T. G. O'Quinn, T. D. J. Hagan, R. Polkinghorne, L. J. Farmer, and M. F. Miller. 2015. Consumer palatability scores and volatile beef flavor compounds of five USDA quality grades and four muscles. Meat Sci. 100:291–300. doi:10.1016/j.meatsci.2014.10.026

Lorenzen, C. L., V. K. Davuluri, K. Adhikari, and I. U. Grün. 2005. Effect of end-point temperature and degree of doneness on sensory and instrumental flavor profile of beef steaks. J. Food Sci. 70:S113–S118. doi:10.1111/j.1365-2621.2005.tb07114.x

Luchak, G. L., R. K. Miller, K. E. Belk, D. S. Hale, S. A. Michaelsen, D. D. Johnson, R. L. West, F. W. Leak, H. R. Cross, and J. W. Savell. 1998. Determination of sensory, chemical and cooking characteristics of retail beef cuts differing in intramuscular and external fat. Meat Sci. 50:55–72. doi:10.1016/S0309-1740(98)00016-3

Lucherk, L. W., T. G. O'Quinn, J. F. Legako, R. J. Rathmann, J. C. Brooks, and M. F. Miller. 2016. Consumer and trained panel evaluation of beef strip steaks of varying marbling and enhancement levels cooked to three degrees of doneness. Meat Sci. 122:145–154. doi:10.1016/j.meatsci.2016.08.005

Lucherk, L. W., T. G. O'Quinn, J. F. Legako, R. J. Rathmann, J. C. Brooks, and M. F. Miller. 2017. Assessment of objective measures of beef steak juiciness and their relationships to sensory panel juiciness ratings. J. Anim. Sci. doi:10.2527/jas2016.0930

Mancini, R. A., and M. C. Hunt. 2005. Current research in meat color. Meat Sci. 71:100–121. doi:10.1016/j.meatsci.2005.03.003

Martin, J. N., J. C. Brooks, L. D. Thompson, J. W. Savell, K. B. Harris, L. L. May, A. N. Haneklaus, J. L. Schutz, K. E. Belk, T. Engle, D. R. Woerner, J. F. Legako, A. M. Luna, L. W. Douglass, S. E. Douglass, J. Howe, M. Duvall, K. Y. Patterson, and J. L. Leheska. 2013. Nutrient database improvement project: The influence of USDA Quality and Yield Grade on the separable components and proximate composition of raw and cooked retail cuts from the beef rib and plate. Meat Sci. 95:486–494. doi:10.1016/j.meatsci.2013.05.031

Miller, M. F., K. L. Huffman, S. Y. Gilbert, L. L. Hamman, and C. B. Ramsey. 1995. Retail consumer acceptance of beef tenderized with calcium chloride. J. Anim. Sci. 73:2308–2314. doi:10.2527/1995.7382308x

Neely, T. R., C. L. Lorenzen, R. K. Miller, J. D. Tatum, J. W. Wise, J. F. Taylor, M. J. Buyck, J. O. Reagan, and J. W. Savell. 1998. Beef customer satisfaction: Role of cut, USDA quality grade, and city on in-home consumer ratings. J. Anim. Sci. 76:1027–1033. doi:10.2527/1998.7641027x

North American Meat Institute. 2014. The meat buyer's guide. 8th ed. North American Meat Institute, Washington, DC.

O'Quinn, T. G. 2016. Evaluation of the contribution of tenderness, juiciness, and flavor to the overall consumer beef eating experience. The Angus Foundation, St. Joseph, MO.

O'Quinn, T. G., J. C. Brooks, and M. F. Miller. 2015. Consumer assessment of beef tenderloin steaks from various USDA quality grades at 3 degrees of doneness. J. Food Sci. 80:S444–S449. doi:10.1111/1750-3841.12775

O'Quinn, T. G., J. C. Brooks, R. J. Polkinghorne, A. J. Garmyn, B. J. Johnson, J. D. Starkey, R. J. Rathmann, and M. F. Miller. 2012. Consumer assessment of beef strip loin steaks of varying fat levels. J. Anim. Sci. 90:626–634. doi:10.2527/jas.2011-4282

Parrish, F. C., Jr., D. G. Olson, B. E. Miner, and R. E. Rust. 1973. Effect of degree of marbling and internal temperature of doneness on beef rib steaks. J. Anim. Sci. 37:430–434. doi:10.2527/jas1973.372430x

Pietrasik, Z., and J. Janz. 2009. Influence of freezing and thawing on the hydration characteristics, quality, and consumer acceptance of whole muscle beef injected with solutions of salt and phosphate. Meat Sci. 81:523–532. doi:10.1016/j.meatsci.2008.10.006

Reicks, A. L., J. C. Brooks, A. J. Garmyn, L. D. Thompson, C. L. Lyford, and M. F. Miller. 2011. Demographics and beef preferences affect consumer motivation for purchasing fresh beef steaks and roasts. Meat Sci. 87:403–411. doi:10.1016/j.meatsci.2010.11.018

Robbins, K., J. Jensen, K. Ryan, C. Homco-Ryan, F. McKeith, and M. Brewer. 2002. Enhancement effects on sensory and retail display characteristics of beef rounds. J. Muscle Foods 13:279–288. doi:10.1111/j.1745-4573.2002.tb00336.x

Robbins, K., J. Jensen, K. J. Ryan, C. Homco-Ryan, F. K. McKeith, and M. S. Brewer. 2003a. Consumer attitudes towards beef and acceptability of enhanced beef. Meat Sci. 65:721–729. doi:10.1016/S0309-1740(02)00274-7

Robbins, K., J. Jensen, K. J. Ryan, C. Homco-Ryan, F. K. McKeith, and M. S. Brewer. 2003b. Dietary vitamin E supplementation effects on the color and sensory characteristics of enhanced beef steaks. Meat Sci. 64:279–285. doi:10.1016/S0309-1740(02)00198-5

Savell, J. W., H. R. Cross, and G. C. Smith. 1986. Percentage ether extractable fat and moisture content of beef longissimus muscle as related to USDA marbling score. J. Food Sci. 51:838–839. doi:10.1111/j.1365-2621.1986.tb13946.x

Savell, J. W., C. L. Lorenzen, T. R. Neely, R. K. Miller, J. D. Tatum, J. W. Wise, J. F. Taylor, M. J. Buyck, and J. O. Reagan. 1999. Beef customer satisfaction: Cooking method and degree of doneness effects on the top sirloin steak. J. Anim. Sci. 77:645–652. doi:10.2527/1999.773645x

Shackelford, S., T. Wheeler, and M. Koohmaraie. 1999. Tenderness classification of beef: II. Design and analysis of a system to measure beef longissimus shear force under commercial processing conditions. J. Anim. Sci. 77:1474–1481. doi:10.2527/1999.7761474x

Smith, G. C., Z. L. Carpenter, H. R. Cross, C. E. Murphey, H. C. Abraham, J. W. Savell, G. W. Davis, B. W. Berry, and F. C. Parrish, Jr. 1985. Relationship of USDA marbling groups to palatability of cooked beef. J. Food Qual. 7:289–308. doi:10.1111/j.1745-4557.1985.tb01061.x

Smith, L. A., S. L. Simmons, F. K. McKeith, P. J. Bechtel, and P. L. Brady. 1984. Effects of sodium tripolyphosphate on physical and sensory properties of beef and pork roasts. J. Food Sci. 49:1636–1637. doi:10.1111/j.1365-2621.1984.tb12869.x

Stetzer, A. J., E. Tucker, F. K. McKeith, and M. S. Brewer. 2008. Quality changes in beef complexus, serratus ventralis, vastus lateralis, vastus medialis, and longissimus dorsi muscles enhanced prior to aging. J. Food Sci. 73:S6–S10. doi:10.1111/j.1750-3841.2007.00582.x

Tatum, J. D. 2015. Recent trends: Beef quality, value and price. Certfied Angus Beef, Wooster, OH.

USDA. 2017a. National weekly boxed beef cutout and boxed beef cuts. USDA Market News, Des Moines, IA

USDA. 2017b. National weekly boxed beef cuts for prime product, USDA Market News, Des Moines, IA.

Wheeler, T. L., S. D. Shackelford, and M. Koohmaraie. 1999. Tenderness classification of beef: III. Effect of the interaction between end point temperature and tenderness on Warner-Bratzler shear force of beef longissimus. J. Anim. Sci. 77:400–407. doi:10.2527/1999.772400x

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. J. Food Sci. 70:S242–S248. doi:10.1111/j.1365-2621.2005.tb07164.x

Wilfong, A. K., K. V. McKillip, J. M. Gonzalez, T. A. Houser, J. A. Unruh, E. A. E. Boyle, and T. G. O'Quinn. 2016. The effect of branding on consumer palatability ratings of beef strip loin steaks. J. Anim. Sci. 94:4930–4942. doi:10.2527/jas.2016-0893