Evaluation of marbling and enhancement's abilities to compensate for reduced beef palatability at elevated degrees of doneness¹

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ABSTRACT: The objectives of this study were to evaluate the extent marbling compensates for reduced beef palatability at elevated degrees of doneness and to determine the relationship of residual moisture and fat in cooked steaks to beef palatability, specifically beef juiciness. Paired strip loins (IMPS # 180) were collected to equally represent five quality treatments [Prime, Top Choice (modest and moderate marbling), Low Choice, Select, and Select Enhanced (110% of raw weight)]. Steaks were grouped into sets of three consecutively cut steaks and randomly assigned a degree of doneness (**DOD**): very-rare (**VR**; 55 °C), rare (**R**; 60 °C), medium-rare (**MR**; 63 °C), medium (**M**; 71 °C), well done (**WD**; 77 °C), or very well done (**VWD**; 82 °C). Samples were subjected to consumer and trained sensory evaluation, Warner–Braztler shear force (**WBSF**), slice shear force (**SSF**), pressed juice percentage (**PJP**) evaluation, and raw and cooked proximate analysis. There were no ($P > 0.05$) quality treatment $\times$ DOD interactions for consumer sensory ratings, indicating increased DOD had the same negative impact regardless of marbling level. There was a quality treatment $\times$ DOD interaction ($P < 0.05$) for the percentage of steaks rated acceptable by

consumers for juiciness. Increased marbling modified the point in which steaks became unacceptable for juiciness. Similarly, there was a quality treatment $\times$ DOD interaction ($P < 0.05$) for trained juiciness ratings. When cooked to MR and lower, Prime was rated only 8% to 18% higher ($P < 0.05$) than Select for trained juiciness ratings, but was rated 38% to 123% higher ($P < 0.05$) than Select when cooked to M and higher. Besides cooking loss, combined cooked moisture and fat percentage was more highly associated ($P < 0.01$) to consumer juiciness ($r = 0.69$) and trained initial ($r = 0.84$) and sustained ($r = 0.85$) juiciness ratings than all other objective evaluations. Using regression analyses, cooked moisture and fat percentages, alone, were poor indicators of consumer and trained juiciness ratings. However, when combined, the regression equations explained 45%, 74%, and 69% of the variation in consumer, trained initial, and trained sustained juiciness ratings, respectively. These results indicate that increased marbling levels only offer “insurance” for juiciness of steaks that are cooked to high degrees of doneness, but not for other palatability traits. Additionally, cooked residual moisture and fat percentages, when combined, are a good indicator of sensory juiciness ratings.

Key words: beef, consumers, cooked moisture and fat, degree of doneness, marbling, palatability

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INTRODUCTION

The beef marbling insurance theory was first proposed by Smith and Carpenter (1974) and states “...the presence of higher levels of marbling allows for the use of high-temperature,

dry-heat methods of cookery and/or the attainment of advanced degrees of final doneness without adversely affecting the ultimate palatability of the cooked meat". In this way, marbling provides some "insurance" for consumers for meats that are either cooked too long, too rapidly, or cooked incorrectly (Savell and Cross, 1988). To date, no study has extensively evaluated the interaction between marbling level and degree of doneness (DOD) on consumer eating satisfaction. Numerous studies have demonstrated the positive effect of marbling level on beef palatability (Smith et al., 1985; O'Quinn et al., 2012; Emerson et al., 2013; Corbin et al., 2015; O'Quinn et al., 2018), but the overwhelming majority of these studies have used only a single DOD. Additionally, previous work evaluating the effects of DOD on beef palatability have used only a limited number or even single marbling levels (Savell et al., 1999; Schmidt et al., 2002; Lorenzen et al., 2005; O'Quinn et al., 2015).

In addition to marbling, moisture enhancement positively affects beef eating quality (Vote et al., 2000; Robbins et al., 2003; Brooks et al., 2010). It is plausible that added moisture through enhancement technology may "protect" these products against elevated DOD in a similar manner as marbling, although, to date, it is unclear if moisture enhanced beef would be consistent with the "insurance theory".

Several studies have shown 51% to 76% of consumers prefer steaks cooked to a medium or higher DOD (Cox et al., 1997; Schmidt et al., 2002; McKillip et al., 2017b) and therefore further examination of this theory could benefit the industry by identifying products that will meet consumer eating expectations based on their preferred degree of doneness. Thus, the objectives of this study were to evaluate the extent marbling and enhancement compensate for reduced beef palatability at elevated degrees of doneness and to determine the relationship of residual moisture and fat in cooked steaks to beef palatability, specifically beef juiciness.

MATERIALS AND METHODS

The Kansas State University (KSU) Institutional Review Board approved all procedures for use of human subjects in the sensory panel evaluations used in this study (IRB 7740.4, November 15, 2017).

Sample Collection

Paired beef strip loins (IMPS #180) were collected from a Midwestern commercial beef

processor from four USDA Quality Grades [Prime, Top Choice (modest¹⁰⁰ to moderate¹⁰⁰ marbling), Low Choice, and Select; $n = 12$ pairs/quality grade]. An additional 12 pairs of USDA Select strip loins were collected for moisture enhancement. During collection, the KSU research team evaluated and collected carcass data which included carcass lean maturity, skeletal maturity, overall maturity, marbling score, preliminary fat thickness, adjusted fat thickness, ribeye area, hot carcass weight, kidney pelvic, and heart fat as well as USDA Yield Grade (data not reported). Subprimals were vacuum packaged, transported under refrigerated temperatures (4 °C) to the KSU Meat Laboratory, and aged at 2 to 4 °C for 21 d from the time of harvest. The 21 d aging period was selected to represent a similar aging time to that commonly found in the U.S. beef market (Savell et al., 2016).

On day 14 of aging, strip loins designated for moisture enhancement were enhanced with an alkaline phosphate solution using a multi-needle injector (Schroder Model IMAX 420, Wolf-Tec Inc., Kingston, NY). The enhancement solution was formulated to result in 0.4% sodium phosphate (Brifisol 512, ICL Food Specialties, Saint Louis, MO) and 0.3% salt at a 10% target pump level (pH = 7.46). Strip loins were weighed before and 30 min after enhancement to determine actual percentage pump ($7.8\% \pm 0.80\%$). Enhanced strip loins were re-vacuum packaged and aged for the final 7 d of the aging period.

After the 21 d aging period, strip loins were fabricated from anterior to posterior into 2.5-cm thick steaks. The most anterior (wedge) steak was designated for raw proximate analysis. A pH meter (model HI 99163; Hannah Instruments, Smithfield, RI) was also used to measure the pH of this steak. The following three consecutive steaks were grouped together, with a total of three groups per strip loin, and a total of six groups per strip loin pair. Within each strip loin pair, groups were randomly assigned one of six DOD based on the Beef Steak Color Guide (National Cattlemen's Beef Association, 2016), which were described as: very-rare (VR; 55 °C), rare (R; 60 °C), medium-rare (MR; 63 °C), medium (M; 71 °C), well done (WD; 77 °C), or very well done (VWD; 82 °C). Within each DOD group, a steak was randomly assigned to either: consumer sensory panel analysis, trained sensory panel analysis, or objective tenderness and juiciness measurement and cooked proximate analysis. All steaks were assigned a randomized four-digit identification number, vacuum packaged, and frozen (−40 °C) until subsequent analysis.

Consumer Sensory Panels

Untrained consumer panelists ($n = 360$) were recruited from around the Manhattan, KS area and were monetarily rewarded for their participation. A total of 45 panels took place at the KSU Meat Science Sensory Laboratory, with eight consumers participating on each panel. Panelists were placed in individual sensory booths and evaluated samples under low intensity (<107.64 lumens) red incandescent lighting to conceal differences in DOD among samples.

Each panelist was given a tablet (Model 5709 HP Steam 7; HewlettPackard, Palo Alto, CA) to fill out a digital survey (Qualtrics Software, Provo, UT). Surveys contained a demographic questionnaire, and eight sample evaluation surveys. Before the start of each panel, consumers were given verbal instructions on how to use the tablets and fill out the survey. Panelists were additionally provided with a napkin, fork, water cup, expectorant cup, apple juice, and unsalted crackers. The apple juice and crackers served as palate cleansers between samples.

Consumers evaluated each sample for juiciness, tenderness, flavor liking, and overall liking on continuous line scales with anchors at 0, 50 (the midpoint), and 100. The 0 anchors were extremely dry, extremely tough, dislike extremely; the 50 anchors were neither dry nor juicy, tough nor tender, like nor dislike; the 100 anchors were extremely juicy, extremely tender, and like extremely. Moreover, consumers rated each trait as either acceptable or unacceptable using yes/no questions.

Steaks were thawed 24 h at 2 to 4 °C prior to sensory evaluation. Raw weights were recorded for cooking loss calculation. Steaks were cooked to their designated DOD on a clamshell grill (Cuisiart Griddler Deluxe, Model GR-150, East Windsor, NJ) with temperatures monitored using a probe thermometer (Super-Fast Thermopen, ThermoWorks, American Fork, UT). Steaks were removed from the grill below their target DOD temperature and allowed to rise to designated DOD. In this way, the temperatures used for DOD determination were steak “peak” temperatures as opposed to “pull” temperatures from the grill. Steaks were allowed to rest for 3 min prior to cutting. Peak temperatures and cooked weights were recorded following the rest period. The longissimus muscle was cut into 2.5-cm thick $\times$ 1-cm $\times$ 1-cm cuboid pieces and two pieces were immediately served to consumers. Consumers were fed eight samples in a random order representing differences in quality treatment

and DOD. This study was designed as an incomplete block design so that each quality treatment $\times$ DOD combination were compared as close to an equal number of times as possible over the 45 panel sessions.

Trained Sensory Panels

Sensory panelists were trained according to the American Meat Science Association (AMSA) Sensory Guidelines (AMSA, 2016). Panelists were trained at 15 training sessions 2 wk prior to panels, using anchors and methods similar to those described by Lucherk et al. (2016) and Vierck et al. (2018). Similar to consumer sensory panelists, trained sensory panelists evaluated samples in individual sensory booths under low intensity (<107.64 lumens) red incandescent lighting. There were a total of 45 trained panel sessions, each consisting of eight trained panelists. Steaks were cooked as described previously for consumer evaluation. Raw weights, cooked weights, and peak temperature were recorded for cooking loss calculation. After cooking, steaks were sliced into 2.5-cm thick $\times$ 1-cm $\times$ 1-cm cuboids and placed into double broilers to keep samples warm before evaluation. In the same manner as with consumer panels, panelists were fed eight samples in random order to represent differences in DOD and quality treatment.

Panelists were provided with a napkin, water cup, expectorant cup, apple slices and unsalted crackers for palate cleansers. Additionally, panelists were provided with the same electronic tablets equipped with a survey created through the same software as for consumer panels. Panelists evaluated samples on 0 to 100 continuous line scales for initial and sustained juiciness, myofibrillar tenderness, connective tissue amount, overall tenderness, beef flavor intensity, salt flavor intensity, and off flavor intensity. The 0 anchors were labeled as extremely dry, extremely tough, none, and bland; and the 100 anchors were labeled as extremely juicy, extremely tender, abundant, and intense. Additionally, there were midpoint (50) anchors for initial juiciness, sustained juiciness, myofibrillar tenderness and overall tenderness that were labeled as: neither dry nor juicy, and neither tough nor tender. If a salt or off flavor was not detected, panelists could select a box labeled as “not applicable”.

Slice Shear Force

All cooking procedures described for sensory panel evaluation were followed. The protocol

outlined by [Shackelford et al. \(1999\)](#) was used to determine slice shear force (SSF) values. Briefly, a cut was made 2 cm from the lateral end of the longissimus lumborum muscle, followed by a second cut made 5 cm from the first cut to determine muscle fiber orientation. A 1-cm $\times$ 5-cm slice was cut at a 45° angle parallel to the muscle fibers using a double-bladed knife. The still warm sample was sheared using SSF machine (Model GR-152; Tallgrass Solutions, Manhattan, KS) to obtain the peak force required to shear perpendicular to the muscle fibers approximately in the middle of the slice.

Pressed Juice Percentage

The methods outlined by [Lucherker et al. \(2017\)](#) were used to determine pressed juice percentage (PJP). In brief, a 1-cm thick slice was removed immediately medial to the SSF sampling and was cut, parallel to the muscle fiber orientation, into three 1-cm wide pieces. Each piece was individually placed on two sheets of filter paper (VWR Filter Paper 415, 12.5 cm, VWR International, Radnor, PA), weighed, and compressed (Instron Model 5569, Canton, MA) at 78.45 N of force for 30 s. Final weights of the filter paper sheets were taken without the sample to determine PJP. The three PJP values were averaged for each steak.

Warner–Bratzler Shear Force

After SSF and PJP sampling, the remainder of the steak was refrigerated (2 to 4 °C) over-night prior to Warner–Bratzler shear force (WBSF) determination. Using the protocol outlined in the AMSA sensory guidelines ([AMSA, 2016](#)), six cores (1.27 cm diameter) were removed and sheared perpendicular to the muscle fiber orientation using an Instron testing machine (Instron Model 5569, Canton, MA) with a crosshead speed of 250 mm/min and a load cell of 100 kg. The peak force was recorded for each core. The six WBSF values were averaged for each steak. The remainder of the WBSF steak and the sheared cores were combined with previous refrigerated SSF steak pieces that contained the same four-digit identification number, and then were diced for same day homogenization for cooked proximate analysis.

Proximate Analysis

Anterior steaks were thawed 24 h prior to homogenization for raw proximate analysis. Steak

pieces remaining after shear force testing were used for determination of cooked moisture and fat percentage. All external fat and accessory muscles were removed prior to being diced and frozen using liquid nitrogen. Steaks were then homogenized (Model S1BL32; Waring Products Division; Hartford, CT) and stored in VWR Sterile Sample Bags (VWR International LLC, Pittsburgh, PA) in a –80 °C freezer until analysis. Moisture analysis was conducted using the approved AOAC drying oven method (AOAC Official Method 950.46, 1995). Furthermore, raw fat analysis was performed using an approved modified methanol–chloroform method as described by [Folch et al. \(1957\)](#).

Statistical Analysis

Statistical analyses were conducted using the procedures of SAS (Version 9.4 SAS Inst., Inc., Cary, NC). The PROC GLIMMIX procedure in SAS was used to evaluate treatment effects and their interactions with an α of 0.05. Data were analyzed as a split-plot with the whole plot factor of quality treatment and sub-plot factor of degree of doneness. A model with a binomial error distribution was utilized for acceptability data. For all analyses, the Kenward–Roger approximation was utilized. When the overall treatment effect or effect interactions were significant ($P < 0.05$), the PDIF option was used to separate means. Moreover, the SLICE option was used for significant ($P < 0.05$) quality treatment $\times$ DOD interactions. PROC REG was used for determination of simple linear regressions and Pearson correlation coefficients among sensory and objective measures were calculated and tested for significance using PROC CORR. Additionally, PROC LOGISTIC was used for calculation of logistic regression models for the probability of a sample being rated as juicy by sensory panelists using objective measures as independent variables.

RESULTS

Consumer Demographics

Demographics of the participants from the consumer sensory evaluation are presented in [Table 1](#). Over half (52.6%) of the participants were male, with the majority being Caucasian (80.9%), and single (54.6%). Additionally, 49.2% of the participants were 20 to 39 years of age, with 35.7% over 40 years of age. Moreover, 41.8% were at least a college graduate, and another 41.6% had some college

Table 1. Demographic profile of consumer study participants ($n = 360$)

Characteristic	Response	Percentage of consumers
Gender	Male	52.6
	Female	47.4
Household size	1 people	12.9
	2 people	13.7
	3 people	13.7
	4 people	29.7
	5 people	19.1
	6 people	5.1
Marital status	> 6 people	5.7
	Married	45.4
	Single	54.6
Age, year	Under 20	15.1
	20 to 29	38.9
	30 to 39	10.3
	40 to 49	19.4
	50 to 59	11.4
	Over 60	4.9
Ethnicity	African American	3.1
	Asian	2.3
	Caucasian/White	80.9
	Hispanic	7.7
	Native American	0.9
	Other	0.9
Annual household income, \$	Mixed race	4.3
	<25,000	23.6
	25,000 to 34,999	8.1
	35,000 to 49,999	7.8
	50,000 to 74,999	14.1
	75,000 to 99,000	11.8
	100,000 to 149,999	19.3
	150,000 to 199,999	8.7
Highest level of education completed	> 199,999	6.6
	Non-high school graduate	3.7
	High school graduate	12.9
	Some college/technical school	41.6
	College graduate	22.9
	Post-college graduate	18.9
Most important palatability trait	Flavor	52.0
	Juiciness	13.1
	Tenderness	34.9
	Very-rare	0.9
Preferred degree of doneness	Rare	8.0
	Medium-rare	41.1
	Medium	24.0
	Medium-well	14.6
	Well-done	7.4
	Very well done	4.0
Beef consumption	1 to 3	43.9
	4 to 6	37.8
	7 to 9	11.3
	>9	7.0

or technical school, with 39.5% of participants having an annual household less than \$50,000, 45.2% between \$50,000 and \$100,000, and 34.6% having a household income over \$100,000.

Consumer Sensory Evaluation

For consumer palatability scores, there was no ($P > 0.05$) quality treatment $\times$ DOD interaction for all palatability traits, including juiciness ($P = 0.06$). The main effects of quality treatment and DOD for consumer palatability ratings are presented in Table 2. For quality treatment, enhanced Select was rated the highest ($P < 0.05$) by consumers for juiciness, tenderness, flavor, and overall like. For the non-enhanced samples, each decrease in quality treatment resulted in a concurrent decrease ($P < 0.05$) in consumer ratings for tenderness, juiciness, flavor, and overall like, with the exception of Top Choice being similar ($P > 0.05$) to Low Choice for all traits, and Low Choice being similar ($P > 0.05$) to Select for tenderness. Consumers rated samples less juicy ($P < 0.05$) as DOD increased from VR to VWD, with R having a similar ($P > 0.05$) juiciness rating to both VR and MR. For tenderness, an increase ($P < 0.05$) in DOD resulted in lower consumer ratings (VR = R = MR > M > WD > VWD). A similar trend was seen for flavor, where samples cooked from VR to M were rated similar ($P > 0.05$) and higher ($P < 0.05$) than those cooked to VWD, with WD being similar ($P > 0.05$) to only M, and higher ($P < 0.05$) than VWD. Samples cooked from VR to M were similar ($P > 0.05$) but higher ($P < 0.05$) than those cooked to WD and VWD for consumer overall liking scores.

Consumers were additionally asked a yes or no question, of whether each trait was acceptable. There was a quality treatment $\times$ DOD interaction ($P < 0.05$) for juiciness (Figure 1), tenderness (Figure 2), and overall like acceptability (Figure 3). For juiciness acceptability, there were no differences ($P > 0.05$) among quality treatments when samples were cooked to VR. At R, Select had the lowest ($P < 0.05$) percentage of samples rated acceptable, with all other quality treatments having similar ($P > 0.05$) percentages; but when cooked to MR, Select was similar ($P > 0.05$) to Prime and Top Choice. At M, enhanced Select samples had the highest ($P < 0.05$) percentage of steaks rated acceptable for juiciness, and Select had the lowest ($P < 0.05$), with no difference ($P > 0.05$) among Prime, Top Choice, and Low Choice samples. When cooked to WD, a similar trend was seen, but Top Choice and Low Choice samples were also similar ($P > 0.05$) to Select. At the highest DOD, enhanced Select and

Table 2. Least squares means for consumer ($n = 360$) ratings¹ of the palatability traits, as well as the percentage of beef strip loin steaks rated acceptable for flavor

Treatment	Juiciness	Tenderness	Flavor	Overall like	Flavor, %
Quality					
Prime	71.3 ^b	70.6 ^b	62.7 ^b	65.5 ^b	85.0 ^b
Top Choice ²	64.1 ^c	60.0 ^c	56.7 ^c	58.2 ^c	78.1 ^c
Low Choice	60.8 ^c	57.7 ^{cd}	55.4 ^c	56.9 ^c	79.4 ^c
Select	55.6 ^d	52.4 ^d	50.9 ^d	50.0 ^d	74.3 ^c
Select enhanced ³	77.9 ^a	77.1 ^a	75.9 ^a	75.7 ^a	94.0 ^a
SEM	1.76	2.12	1.45	1.60	2.22
P-value	<0.01	<0.01	<0.01	<0.01	<0.01
Degree of doneness ⁴					
Very-rare	77.4 ^a	69.4 ^a	62.0 ^a	63.2 ^a	84.6 ^a
Rare	73.9 ^{ab}	68.0 ^a	64.4 ^a	66.0 ^a	85.2 ^a
Medium-rare	72.3 ^b	68.9 ^a	62.0 ^a	65.5 ^a	86.1 ^a
Medium	65.6 ^c	64.1 ^b	61.0 ^{ab}	62.1 ^a	83.7 ^a
Well done	58.1 ^d	58.6 ^c	58.2 ^b	57.1 ^b	82.0 ^a
Very well done	48.8 ^e	52.5 ^d	54.1 ^c	53.6 ^b	76.3 ^b
SEM	1.57	1.69	1.56	1.62	2.16
P-value	<0.01	<0.01	<0.01	<0.01	<0.01
Quality × degree of doneness					
P-value	0.06	0.23	0.76	0.49	0.36

^{a-e}Means lacking a common superscript within DOD or quality treatment, in the same column differ ($P < 0.05$).

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

²Modest⁰⁰ – moderate¹⁰⁰.

³Enhanced to 110% of raw weight with a water, salt, and alkaline phosphate solution.

⁴Degrees of doneness follow the “Beef Steak Color Guide” (National Cattlemen’s Beef Association, 2016): very-rare = 55 °C; rare = 60 °C; medium-rare = 63 °C; medium = 71 °C; well done = 77 °C; very well done = 82 °C.

Figure 1. The quality treatment × degree of doneness interaction ($P < 0.01$) means ($\pm$ SE) for the percentage of steaks rated acceptable by consumers for juiciness of strip steaks from five quality treatments cooked to 6 degrees of doneness; $n = 360$.

Prime samples had the highest ($P < 0.05$) percentage of steaks rated acceptable, with no differences ($P > 0.05$) among Top Choice, Low Choice, and Select.

For tenderness acceptability, when samples were cooked to VR, enhanced Select samples had the highest ($P < 0.05$) percentage of steaks rated

Figure 2. The quality treatment × degree of doneness interaction ($P < 0.01$) means ($\pm$ SE) for the percentage of steaks rated acceptable by consumers for tenderness of strip steaks from five quality treatments cooked to 6 degrees of doneness; $n = 360$.

acceptable with all non-enhanced samples similar ($P > 0.05$). When cooked to R, enhanced Select samples were similar ($P > 0.05$) to Prime, and had the highest ($P < 0.05$) percentages of samples rated acceptable, with no differences ($P > 0.05$)

among Top Choice, Low Choice, and Select. When steaks were cooked to MR, Prime, Top Choice, Low Choice, and enhanced Select all had similar ($P > 0.05$) and higher ($P < 0.05$) percentages of steaks rated acceptable than Select. At M, Select had the lowest ($P < 0.05$) percentage of steaks rated acceptable for tenderness, but enhanced Select had a higher ($P < 0.05$) percentage than Top Choice, and Low Choice, with Prime being intermediate ($P > 0.05$) to enhanced Select samples and both Choice treatments. When cooked to WD, enhanced Select, Prime, and Top Choice were similar ($P > 0.05$), and had the highest ($P < 0.05$) percentage of steaks rated acceptable, with no difference ($P > 0.05$) between Low Choice and Select. At the highest DOD, enhanced Select samples had a higher ($P < 0.05$) percentage of steaks rated acceptable for tenderness than Low Choice and Select, and were similar ($P > 0.05$) to Prime, and Top Choice; however, Top Choice possessed a higher ($P < 0.05$) percentage than Low Choice, but had a similar ($P > 0.05$) percentage of steaks rated acceptable as Select.

For overall like acceptability, at VR, enhanced Select samples had a higher ($P < 0.05$) percentage of steaks rated acceptable than Top Choice, with Prime, Low Choice, and Select being similar ($P > 0.05$) and intermediate to both. Enhanced Select, Prime, and Top Choice all had similar ($P > 0.05$) percentages of steaks rated acceptable overall when cooked to R, MR, WD, and VWD, and were similar ($P > 0.05$) to Low Choice at MR and R. When cooked to M, Select had the lowest ($P < 0.05$) percentage of steaks rated acceptable

overall, but was similar ($P > 0.05$) to Low Choice at VR, R, WD, and VWD.

There was no interaction ($P = 0.36$) for the percentage of samples rated acceptable for flavor (Table 2). For the main effect of quality treatment, enhanced Select samples had the highest ($P < 0.05$) percentage of steaks rated acceptable for flavor, followed by Prime ($P < 0.05$), with Top Choice, Low Choice, and Select all having similar ($P > 0.05$), and lower ($P < 0.05$) percentages. For the main effect of DOD, samples cooked from VR to WD had a similar ($P > 0.05$) percentage of samples rated acceptable for flavor, and had higher ($P < 0.05$) percentages than steaks cooked to VWD.

Trained Sensory Evaluation

There were quality treatment $\times$ DOD interactions ($P < 0.01$) for initial juiciness (Figure 4), sustained juiciness (Figure 5), and salt flavor intensity. Prime and enhanced Select samples were rated similar ($P > 0.05$) for initial juiciness across all DOD. At VR and R, Top Choice was similar ($P > 0.05$) to Prime and enhanced Select samples, as well as Low Choice, while Select samples were rated drier ($P < 0.05$) than all other quality treatments, except were similar ($P > 0.05$) to Low Choice. At MR, Prime was rated juicier ($P < 0.05$) than Low Choice and Select, with Top Choice being intermediate ($P > 0.05$) to Prime and Low Choice. When cooked to M, for non-enhanced samples, each decrease in marbling level resulted in drier ($P < 0.05$) ratings

Figure 3. The quality treatment $\times$ degree of doneness interaction ($P < 0.01$) means ($\pm$ SE) for the percentage of steaks rated acceptable by consumers for overall like of strip steaks from five quality treatments cooked to 6 degrees of doneness; $n = 360$.

Figure 4. The quality treatment $\times$ degree of doneness interaction ($P < 0.01$) means ($\pm$ SE) for trained sensory panel initial juiciness ratings of strip steaks from five quality treatments cooked to 6 degrees of doneness; $n = 360$; 0 = extremely dry; 50 = neither dry nor juicy; 100 = extremely juicy.

Figure 5. The quality treatment $\times$ degree of doneness interaction ($P < 0.01$) means ($\pm$ SE) for trained sensory panel sustained juiciness ratings of strip steaks from five quality treatments cooked to 6 degrees of doneness; $n = 360$; 0 = extremely dry; 50 = neither dry nor juicy; 100 = extremely juicy.

(Prime > Top Choice > Low Choice > Select). However, when cooked to WD and VWD, Low Choice was not different ($P > 0.05$) than Top Choice and Select samples.

For sustained juiciness, Prime and enhanced Select samples had similar ($P > 0.05$) juiciness ratings when cooked to all DOD, except when cooked to MR, at which trained panelists rated enhanced Select samples juicier ($P < 0.05$). Prime was rated juicier ($P < 0.05$) than all other non-enhanced samples when cooked to M, and was similar ($P > 0.05$) to Top Choice at an MR DOD and lower. Moreover, Top Choice steaks were only rated juicier ($P < 0.05$) by trained panelists than Low Choice steaks when cooked to M, and Low Choice was only rated juicier ($P < 0.05$) than Select when cooked to M as well.

As degree of doneness increased, salt flavor intensity decreased (VR = R = MR > WD > VWD; $P < 0.05$) for enhanced Select steaks, with no difference ($P > 0.05$) occurring for all other quality treatments among DOD.

The main effects of quality treatment and DOD were significant ($P < 0.05$) for all other trained sensory traits (Table 3). For myofibrillar and overall tenderness, enhanced Select was similar ($P > 0.05$) to Prime, and both were rated more tender ($P < 0.05$) than all other quality treatments. Top Choice was similar ($P > 0.05$) to Low Choice for myofibrillar and overall tenderness, with Select being rated the toughest ($P < 0.05$) of all treatments. Prime and enhanced Select samples contained the least ($P < 0.05$) amount of connective tissue, with no difference ($P > 0.05$) among all other quality treatments. As quality grade increased, so did

beef flavor intensity, with Prime having the highest ($P < 0.05$) beef flavor scores, and Low Choice and Select having the lowest ($P < 0.05$) and similar ($P > 0.05$) scores. There were no differences ($P > 0.05$) among quality treatments for off flavor intensity.

For the main effect of DOD, WD and VWD samples were rated the toughest ($P < 0.05$) for myofibrillar tenderness, with VR samples being rated more tender ($P < 0.05$) than all other samples, being similar ($P > 0.05$) to only MR. For overall tenderness, as DOD increased, toughness increased (VR = R = MR > M > WD = VWD; $P > 0.05$). Samples cooked to VR contained the greatest ($P < 0.05$) amount of connective tissue, but were similar ($P > 0.05$) to R and WD. Samples cooked to MR and VWD had similar ($P > 0.05$) and lower ($P < 0.05$) connective tissue amounts than samples cooked to VR and R, but were similar ($P > 0.05$) to M and WD as well. Additionally, VWD, WD, and VR samples contained the lowest ($P < 0.05$) beef flavor ratings compared to steaks cooked to all other DOD, except had similar ($P > 0.05$) beef flavor ratings to MR. Furthermore, steaks cooked to M had similar ($P > 0.05$) beef flavor ratings to those cooked to R, but were rated higher ($P < 0.05$) than MR. No differences ($P > 0.05$) were found among DOD for off flavor intensity.

Proximate Composition

Table 4 shows the values for the raw proximate analysis. As expected, an increase in quality grade resulted in an increase ($P < 0.05$) in fat percentage (Prime > Top Choice > Low Choice > Select) with the enhanced Select samples having a similar ($P > 0.05$) fat content with the non-enhanced Select. Additionally, increased quality grade resulted in a decrease ($P < 0.05$) in moisture percentage (Select = Low Choice > Top Choice > Prime) with the enhanced Select samples having the greatest ($P < 0.05$) amount of moisture. For combined raw moisture and fat percentage, enhanced Select and Prime samples were similar ($P > 0.05$) and had a greater ($P < 0.05$) combined percentage than all other quality treatments, with Top Choice having a greater ($P < 0.05$) percentage than Select, and Low Choice being similar ($P > 0.05$) to both Select and Top Choice.

There were quality treatment $\times$ DOD interactions ($P < 0.05$) for cooked moisture (Figure 6), fat (Figure 7), and combined moisture and fat percentage (Figure 8). As DOD increased, moisture percentage decreased (VR > R > MR > M = WD > VWD; $P < 0.05$). For cooked moistures, regardless

Table 3. Least squares means for trained sensory panel ratings¹ of beef strip steaks from five quality treatments cooked to six degrees of doneness²

Treatment	Myofibrillar tenderness	Connective tissue amount	Overall tenderness	Beef flavor	Off flavor
Quality					
Prime	79.8 ^a	5.1 ^b	77.7 ^a	42.8 ^a	0.1
Top Choice ³	70.0 ^b	8.0 ^a	65.8 ^b	40.0 ^b	0.6
Low Choice	67.6 ^b	7.6 ^a	63.4 ^b	35.8 ^d	0.5
Select	61.4 ^c	9.1 ^a	56.4 ^c	35.0 ^d	0.7
Select enhanced ⁴	84.0 ^a	3.6 ^b	82.6 ^a	37.9 ^c	0.3
SEM	1.76	0.75	1.96	0.71	0.22
<i>P</i> -value	<0.01	<0.01	<0.01	<0.01	0.25
Degree of doneness ²					
Very-rare	80.4 ^a	7.8 ^a	76.5 ^a	37.7 ^c	0.7
Rare	77.8 ^b	7.7 ^{ab}	74.6 ^a	39.2 ^{ab}	0.3
Medium-rare	78.9 ^{ab}	5.9 ^c	76.2 ^a	38.0 ^{bc}	0.6
Medium	69.3 ^c	6.4 ^{bc}	65.3 ^b	39.6 ^a	0.6
Well done	65.4 ^d	6.6 ^{abc}	61.7 ^c	37.6 ^c	0.2
Very well done	63.7 ^d	5.6 ^c	60.7 ^c	37.4 ^c	0.2
SEM	1.10	0.57	1.23	0.63	0.21
<i>P</i> -value	<0.01	<0.01	<0.01	<0.01	0.23
Quality × degree of doneness					
<i>P</i> -value	0.11	0.67	0.10	0.74	0.37

^{a-c}Means lacking a common superscript within DOD or quality treatment, in the same column differ ($P < 0.05$).

¹Sensory scores: 0 = extremely tough/bland; 50 = neither tough nor tender; 100 = extremely tender/intense.

²Degrees of doneness follow the “Beef Steak Color Guide” (National Cattlemen’s Beef Association, 2016): very-rare = 55 °C; rare = 60 °C; medium-rare = 63 °C; medium = 71 °C; well done = 77 °C; very well done = 82 °C.

³Modest⁰⁰ – moderate¹⁰⁰.

⁴Enhanced to 110% of raw weight with a water, salt, and alkaline phosphate solution.

Table 4. Least square means ($P < 0.01$) for raw moisture and fat content of beef strip loin steaks from five quality treatments

Treatment	Raw moisture, %	Raw fat, %	Raw moisture + fat, ³ %
Quality			
Prime	63.8 ^d	13.7 ^a	77.5 ^a
Top Choice ¹	67.4 ^c	9.4 ^b	76.8 ^b
Low Choice	69.9 ^b	6.4 ^c	76.3 ^{bc}
Select	71.1 ^b	4.8 ^d	75.9 ^c
Select enhanced ²	72.6 ^a	5.1 ^d	77.6 ^a
SEM	0.41	0.41	0.41
<i>P</i> -value	<0.01	<0.01	<0.01

^{a-d}Means in the same column lacking common superscripts differ ($P < 0.05$).

¹Modest⁰⁰ – moderate¹⁰⁰.

²Enhanced to 110% of raw weight with a water, salt, and alkaline phosphate solution.

³Combined moisture and fat percentage.

of DOD, enhanced Select samples contained the greatest ($P < 0.05$) amount of moisture. For non-enhanced samples, as quality grade increased, moisture percentage decreased ($P < 0.05$) for all DOD. Only at R, M, and VWD were Low Choice samples similar ($P > 0.05$) to Select for moisture content. Regardless of DOD, for cooked fat percentages, enhanced Select samples were similar ($P > 0.05$) to non-enhanced Select, with Prime

having the greatest ($P < 0.05$) fat percentage at each DOD, followed by Top Choice. Low Choice had a similar ($P > 0.05$) fat percentage as enhanced Select and non-enhanced Select samples when cooked to M and higher. Enhanced Select samples had the greatest ($P < 0.05$) combined moisture and fat percentage when cooked to VR, M, WD, and VWD, and was only similar ($P > 0.05$) to Prime at R and MR. Top Choice, Low Choice, and Select had

Figure 6. The quality treatment $\times$ degree of doneness interaction ($P < 0.01$) means ($\pm$ SE) for cooked moisture percentage of strip steaks from five quality treatments cooked to 6 degrees of doneness; $n = 360$.

Figure 7. The quality treatment $\times$ degree of doneness interaction ($P < 0.01$) means ($\pm$ SE) for cooked fat percentage of strip steaks from five quality treatments cooked to 6 degrees of doneness; $n = 360$.

similar ($P > 0.05$) combined cooked moisture and fat percentages when cooked to VR, R, and VWD, but Top Choice had a greater ($P < 0.05$) combined cooked moisture and fat percentage than Select at MR, M, and WD.

Pressed Juice Percentage

There was a quality treatment $\times$ DOD interaction ($P < 0.05$) for PJP (Table 5). Few differences occurred for PJP at VR, with Select having a greater ($P < 0.05$) PJP than enhanced Select samples, and no differences ($P > 0.05$) were found among the other quality treatments. No differences ($P > 0.05$) were observed among quality treatments when cooked to M. Enhanced Select samples were similar ($P > 0.05$) to all other quality treatments at R, with Select

Figure 8. The quality treatment $\times$ degree of doneness interaction ($P < 0.01$) means ($\pm$ SE) for combined cooked moisture and fat percentage of strip steaks from five quality treatments cooked to 6 degrees of doneness; $n = 360$.

having a greater ($P < 0.05$) PJP than Top Choice and Prime. Additionally, when cooked to WD, enhanced Select samples only had a higher PJP than Top Choice and Low Choice ($P < 0.05$), while there were no differences ($P > 0.05$) among non-enhanced samples. Finally, when cooked to VWD, enhanced Select had the greatest ($P < 0.05$) PJP with no differences ($P > 0.05$) among non-enhanced samples.

Objective Measurements of Tenderness

Results for objective measurements of tenderness, as well as cooking loss, are presented in Table 6. There were no quality treatment $\times$ DOD interactions for WBSF ($P = 0.09$), SSF ($P > 0.05$) or cooking loss ($P = 0.36$). Enhanced Select samples had the least ($P < 0.05$) cooking loss among all quality treatments with no differences ($P > 0.05$) found among all non-enhanced samples. Cooking loss increased ($P < 0.05$) as DOD increased (VWD $>$ WD $>$ M $>$ MR $>$ R $>$ VR). For WBSF, Select possessed the highest shear values ($P < 0.05$), while enhanced Select and Prime had the lowest ($P < 0.05$) shear values. Samples cooked to VR had the highest WBSF values, with MR having lower ($P < 0.05$) WBSF values than all other treatments except R. For SSF, an increase in quality treatment generally resulted in a decrease in SSF. Select steaks had a higher ($P < 0.05$) shear value than all other treatments, except was similar ($P > 0.05$) to Top Choice steaks. Top Choice was similar ($P > 0.05$) to Low Choice but had higher ($P < 0.05$) shear values than Prime and enhanced Select samples. Finally, Prime had similar ($P > 0.05$) WBSF values as Low Choice and enhanced

Table 5. Least squares means for the interaction ($P < 0.05$) between quality treatment and degree of doneness¹ for pressed juice percentage (PJP)²

Degree of doneness/quality treatment	PJP, %
Very-rare	
Prime	24.3 ^{ab}
Top Choice ³	24.7 ^{ab}
Low Choice	25.3 ^{ab}
Select	25.4 ^a
Select enhanced ⁴	23.5 ^b
SEM	0.67
Rare	
Prime	23.4 ^c
Top Choice ³	23.9 ^c
Low Choice	25.1 ^{bc}
Select	26.5 ^{ab}
Select enhanced ⁴	25.0 ^{bc}
SEM	0.67
Medium-rare	
Prime	23.5 ^b
Top Choice ³	23.9 ^b
Low Choice	23.4 ^b
Select	26.5 ^a
Select enhanced ⁴	27.0 ^a
SEM	0.67
Medium	
Prime	19.3
Top Choice ³	20.4
Low Choice	19.5
Select	20.4
Select enhanced ⁴	19.0
SEM	0.67
Well done	
Prime	19.8 ^{ab}
Top Choice ³	18.4 ^b
Low Choice	18.0 ^b
Select	19.6 ^{ab}
Select enhanced ⁴	20.7 ^a
SEM	0.67
Very well done	
Prime	16.6 ^b
Top Choice ³	15.7 ^b
Low Choice	16.4 ^b
Select	16.5 ^b
Select enhanced ⁴	18.6 ^a
SEM	0.67

^{a-d}Means within DOD without common superscript differ ($P < 0.05$).

¹Degrees of doneness follow the “Beef Steak Color Guide” (National Cattlemen’s Beef Association, 2016): very-rare = 55 °C; rare = 60 °C; medium-rare = 63 °C; medium = 71 °C; well done = 77 °C; very well done = 82 °C.

³Modest⁰⁰ – moderate¹⁰⁰.

⁴Enhanced to 110% of raw weight with a water, salt, and alkaline phosphate solution.

Select samples. A similar trend was seen in SSF as in WBSF, with VR samples being tougher ($P < 0.05$) than all other DOD.

Relationships Among Traits

Pearson correlation coefficients were used to determine relationships among traits (Table 7). When evaluating the correlation coefficients, cooked moisture was associated ($P < 0.01$) with consumer juiciness ($R = 0.27$), tenderness ($R = 0.17$), flavor liking ($R = 0.23$), and overall liking ($R = 0.19$), while cooked fat was associated ($P < 0.05$) with consumer juiciness ($R = 0.12$) and tenderness ($R = 0.15$). Aside from cooking loss on the samples evaluated during the sensory panels, the strongest ($P < 0.01$) correlations for consumer juiciness, tenderness, flavor liking, and overall liking occurred with combined cooked moisture and fat ($R = 0.69$, $R = 0.56$, $R = 0.45$, and $R = 0.49$, respectively). The highest PJP correlation ($P < 0.05$) was seen for trained initial and sustained juiciness scores ($R = 0.69$ and $R = 0.68$) and was associated ($P < 0.05$) with consumer juiciness ratings ($R = 0.47$). Consumer cooking loss was moderately negatively associated ($P < 0.01$) with consumer juiciness scores ($R = -0.72$) and tenderness ($R = -0.52$). Similarly, trained cooking loss was moderately negatively associated ($P < 0.01$) with trained initial and sustained juiciness scores ($R = -0.89$). Furthermore, SSF and WBSF were negatively associated ($P < 0.01$) with consumer tenderness ($R = -0.34$ and $R = -0.46$, respectively), and were additionally negatively associated ($P < 0.01$) with trained myofibrillar tenderness ($R = -0.41$ and $R = -0.55$, respectively), overall tenderness ($R = -0.43$ and $R = -0.58$, respectively), and positively associated ($P < 0.01$) with connective tissue amount ($r = 0.35$ for both). Marbling score was associated ($P < 0.05$) with trained beef flavor intensity scores ($R = 0.46$), but was not correlated ($P > 0.05$) to consumer flavor liking.

Regression Analysis

Simple linear regression models (Table 8) were calculated using cooked moisture, fat, and the combination of cooked moisture and fat for predicting consumer and trained panelists’ ratings for beef juiciness. All equations were significant ($P < 0.05$). When using cooked moisture as a predictor of juiciness, equations had an adjusted R^2 value of 0.07 and 0.09 for consumer and trained juiciness, respectively. Regression equations using cooked fat had an adjusted R^2 value of 0.01 and 0.03 for predicting consumer and trained juiciness, respectively. However, the equation using combined moisture and fat percentage had adjusted R^2 values of 0.47,

Table 6. Least squares means for beef strip loin measures of Warner–Bratzler shear force (WBSF), slice shear force (SSF), and cooking loss¹

Treatment	WBSF, kg	SSF, kg	Cooking loss, ¹ %
Quality			
Prime	2.2 ^c	12.0 ^{cd}	15.2 ^a
Top Choice ²	2.6 ^b	14.3 ^{ab}	15.1 ^a
Low Choice	2.7 ^b	13.1 ^{bc}	15.7 ^a
Select	3.2 ^a	14.8 ^a	15.6 ^a
Select enhanced ³	2.1 ^c	10.9 ^d	13.4 ^b
SEM	0.10	0.55	0.29
Degree of doneness ⁴			
Very-rare	2.9 ^a	15.6 ^a	8.6 ^f
Rare	2.4 ^{cd}	12.4 ^{cd}	10.7 ^e
Medium-rare	2.3 ^d	11.6 ^d	12.0 ^d
Medium	2.5 ^{bc}	12.1 ^{cd}	16.6 ^c
Well done	2.5 ^c	12.8 ^{bc}	19.4 ^b
Very well done	2.7 ^b	13.5 ^b	22.7 ^a
SEM	0.07	0.38	0.23
Quality × degree of doneness			
P-value	0.09	0.05	0.36

^{a–c}Means lacking a common superscript within DOD or quality treatment, in the same column differ ($P < 0.05$).

¹Cooking loss = [(raw weight – cooked weight)/raw weight] × 100.

²Modest⁰⁰ – moderate¹⁰⁰.

³Enhanced to 110% of raw weight with a water, salt, and alkaline phosphate solution.

⁴Degrees of doneness follow the “Beef Steak Color Guide” (National Cattlemen’s Beef Association, 2016): very-rare = 55 °C; rare = 60 °C; medium-rare = 63 °C; medium = 71 °C; well done = 77 °C; very well done = 82 °C.

0.71, and 0.72 for consumer juiciness, trained initial and sustained juiciness, respectively.

Additionally, logistic regression (Table 9) analyses were performed to predict the probability of a sample being rated juicy (mean juiciness score > 50) by consumers and trained panelists using the same traits discussed above. Similar to the linear regressions, cooked moisture had low adjusted R^2 values, being 0.04, 0.07, and 0.09, as well as cooked fat with adjusted R^2 values of 0.05, 0.06, and 0.03 for consumer, trained initial, and trained sustained juiciness scores, respectively. Conversely, models using cooked moisture and fat possessed adjusted R^2 values of 0.45, 0.74, and 0.69 for consumer, trained initial, and sustained juiciness scores, respectively. The logistic equation determined (Figure 9) for the probability of a consumer rating a steak juicy using cooked moisture and fat percentage was

$$P = \left[e^{(-50.97 + 0.75 \times \text{CM F})} \right] / \left[1 + e^{(-50.97 + 0.75 \times \text{CM F})} \right]$$

where CMF is the cooked moisture and fat percentage. The model had a c -statistic of 0.887 and correctly classified 85.5% of samples as either “juicy” or “not juicy”. The model identified combined cooked moisture and fat percentages of 68.25%, 69.85%, and 71.20% for a 50%, 75%, and 90% chance, respectively, of a consumer rating a steak juicy.

DISCUSSION

Marbling and Degree of Doneness

The insurance theory states increased marbling compensates for the negative effects of increased DOD on beef palatability (Smith and Carpenter, 1974). In our study, there was no interaction for quality treatment × DOD for all consumer rating data, similar to the findings of Lucher et al. (2016), McKillip et al. (2017b), and Lorenzen et al. (1999). In all of these studies, as DOD increased, palatability ratings decreased. Moreover, as quality grade or marbling level increased in each of these studies, palatability ratings for the traits of juiciness, flavor, tenderness, and overall liking increased. The lack of a significant quality treatment × DOD interaction for palatability ratings in our study, as well as these other studies, indicate the negative impact of increased DOD on juiciness, tenderness, flavor, and overall liking is the same across all quality treatments. Thus, the effect of marbling on palatability was independent of DOD, which is not consistent with the insurance theory for the sensory rating data.

However, within our study, clear evidence of the insurance theory lies within the palatability trait of juiciness, specifically shown within the

Table 7. Pearson correlation coefficients for sensory panel ratings in relation to objective measures, and cooked and raw fat and moisture percentages

	Cooking loss, ¹ %				Cooked, %			Raw, %			Marbling score	
	Consumer	Trained	PJP ²	SSF ³	WSF ⁴	Moisture	Fat	Moisture + fat ⁵	Moisture	Fat		Moisture + fat ⁵
Consumer sensory ⁶												
Juiciness	-0.72**		0.47**	-0.24**	-0.37**	0.27**	0.12*	0.69**	-0.05	0.12*	0.23**	0.12*
Tenderness	-0.52**		0.31**	-0.34**	-0.46**	0.17**	0.15**	0.56**	-0.09	0.16**	0.24**	0.14**
Flavor liking	-0.39**		0.17**	-0.29**	-0.37**	0.23**	0.03	0.45**	0.05	0.02	0.21**	0.00
Overall liking	-0.45**		0.24**	-0.32**	-0.42**	0.19**	0.09	0.49**	-0.01	0.09	0.23**	0.07
Trained sensory ⁷												
Initial juiciness		-0.89**	0.69**	-0.12*	-0.33**	0.31**	0.17**	0.84**	-0.11*	0.18**	0.22**	0.15**
Sustained juiciness		-0.89**	0.68**	-0.11*	-0.33**	0.30**	0.18**	0.85**	-0.12*	0.19*	0.22**	0.16**
Myofibrillar tenderness		-0.61**	0.42**	-0.41**	-0.55**	0.20**	0.21**	0.71**	-0.13*	0.24**	0.36**	0.19**
Connective tissue amount		-0.03	0.13*	0.35**	0.35**	0.04	-0.09	-0.07	0.06	-0.11*	-0.17**	-0.08
Overall tenderness		-0.57**	0.37**	-0.43**	-0.58**	0.17**	0.22**	0.68**	-0.14**	0.25**	0.37**	0.21**
Beef flavor intensity		-0.04	0.04	-0.15**	-0.31**	-0.38**	0.55**	0.22**	-0.45**	0.47**	0.16**	0.46**
Salt flavor intensity		-0.22**	0.11*	-0.28**	-0.34**	0.55**	-0.35**	0.40**	0.49**	-0.35**	0.33**	-0.41

¹Cooking loss = [(raw weight – cooked weight)/raw weight] × 100.

²PJP = percentage of moisture loss during compression for 30 s.

³Slice shear force.

⁴Warner–Braztler shear force.

⁵Combined moisture and fat percentage.

⁶Consumer sensory scores: 0 = extremely dry/tough/dislike; 50 = neither dry nor juicy, neither tough nor tender, neither like nor dislike; 100 = extremely juicy/tender/like extremely.

⁷Trained sensory scores: 0 = extremely dry/tough/bland; 50 = neither tough nor tender/dry nor juicy; 100 = extremely juicy/tender/intense.

* $P < 0.05$.

** $P < 0.01$.

acceptability data. Though there was no interaction ($P = 0.06$) between quality treatment and DOD in the consumer rating data, an interaction was found for the percentage of steaks rated acceptable for juiciness by consumers. When evaluating juiciness on an acceptability (yes/no) basis, an increase in marbling modified the point at which a sample became unacceptable. For each quality treatment, there appears to be a DOD threshold where there is a sharp reduction in the percentage of steaks rated acceptable for juiciness. For example, Select steaks had the largest decrease (19%) in the number of steaks rated acceptable when DOD increased from MR to M. Similar to Select, Low Choice samples did not have a marked decrease in the percentage of samples rated acceptable for juiciness as DOD increased from VR to MR, but decreased 13% when DOD increased from MR to M. Prime steaks were able to maintain a steady, slight decline in the percentage of samples rated acceptable across all

DOD, and did not have the same dramatic drop off in the percentage of steaks rated acceptable due to increased DOD observed in the other quality treatments, as the percent decrease was never >5% between consecutive DOD increases, indicating Prime samples were less affected by increased DOD than the lowered marbled steaks. Finally, due to the added moisture, enhanced Select samples were able to maintain acceptable juiciness from VR through WD, but similar to the other quality grades, experienced a dramatic drop (17%) in the percentage of samples rated acceptable for juiciness when DOD increased from WD to VWD.

These results differ from [McKillip et al. \(2017b\)](#) and [Lucher et al. \(2016\)](#), as these authors found no interaction between quality treatment and DOD for the percentage of steaks rated acceptable for all palatability traits. However, in both studies, only three DOD's were evaluated, and only three marbling levels were evaluated by [McKillip et al. \(2017b\)](#).

Table 8. Simple linear regression equations for predicting consumer and trained sensory juiciness ratings¹ for beef strip loins using the percentage of cooked fat, moisture, or combined moisture and fat; $n = 360$

Measurement	Intercept	Regression coefficient	Adjusted R^2	P -value
Consumer juiciness				
Cooked moisture	4.03	0.99	0.07	<0.01
Cooked fat	61.86	0.49	0.01	0.02
Cooked moisture + fat ²	−263.90	4.61	0.47	<0.01
Trained initial juiciness				
Cooked moisture	−33.49	1.56	0.09	<0.01
Cooked fat	56.57	0.89	0.03	<0.01
Cooked moisture + fat ²	−483.76	7.67	0.71	<0.01
Trained sustained juiciness				
Cooked moisture	−47.33	1.65	0.09	<0.01
Cooked fat	47.63	1.03	0.03	<0.01
Cooked moisture + fat ²	−543.11	8.38	0.72	<0.01

¹Mean sensory juiciness rating of >50 on the 100 point scale.²Combined moisture and fat percentage.**Table 9.** Logistic regression equations for predicting a juicy¹ sensory rating using the cooked percentage of fat, moisture, or combined fat and moisture; $n = 360$

Measurement	Intercept	Regression coefficient	Adjusted R^2	P -value
Consumer juiciness				
Cooked moisture	−3.67	0.08	0.04	<0.01
Cooked fat	0.57	0.13	0.05	<0.01
Cooked moisture + fat ²	−50.97	0.75	0.45	<0.01
Trained initial juiciness				
Cooked moisture	−6.14	0.11	0.07	<0.01
Cooked fat	−0.05	0.12	0.06	<0.01
Cooked moisture + fat ²	−100.40	1.44	0.74	<0.01
Trained sustained juiciness				
Cooked moisture	−7.40	0.13	0.09	<0.01
Cooked fat	−0.22	0.08	0.03	<0.01
Cooked moisture + fat ²	−88.71	1.25	0.69	<0.01

¹Mean sensory juiciness rating of >50 on the 100 point scale.²Combined moisture and fat percentage. **Figure 9.** The predicted probability of steak being classified as juicy (mean juiciness rating >50) by consumers based on cooked moisture and fat (CMF) percentage.

Additionally, the study by [Lucherk et al. \(2016\)](#) fed consumers steaks of only their preferred DOD under white florescent lighting as opposed to

feeding consumers all DOD under red lighting as was done in the current study. These methodological differences, perhaps, contributed to the observed differences in results compared to the current study.

This trend of marbling compensating for increased DOD was also observed in our study in the trained sensory panel results, in which a quality treatment $\times$ DOD interaction was found for initial and sustained juiciness. The magnitude of the negative impact of increased DOD was dependent upon quality treatment. When samples were cooked to MR and lower, Prime was rated 12% to 18% higher than Select steaks, but this difference dramatically increased to 66%, 98%, and 123% when cooked to M, WD, and VWD for initial juiciness. A similar trend was found for sustained juiciness, as Prime was only rated 8%, 12%, and 11% higher than Select steaks when cooked to VR, R, and MR, but this difference increased to 38%, 63%, and 87% at

M, WD, and VWD, respectively. The added marbling enabled Prime steaks to maintain a high level of juiciness, even at elevated DOD, with increasing DOD from VR to VWD only reducing the initial juiciness rating of Prime by 45.5%. Conversely, the higher DOD had a much greater negative impact on the Select samples due to their lower marbling content, with Select samples having a reduction in initial juiciness by >72.5% from VR to VWD. The study conducted by [Lucherk et al. \(2016\)](#) produced similar results and reported an interaction for trained sensory panel juiciness ratings, where Prime was rated 18%, 51%, and 54% higher than Select for initial juiciness, and 25%, 68%, and 65% for sustained juiciness when cooked to R, M, and WD, respectively. [McKillip et al. \(2017b\)](#) served trained panelists under red lightning three DOD (R, M, and VWD) and found an interaction only with trained sensory panel initial juiciness ratings, where Prime was rated 15%, 34%, and 80% higher than Select when cooked to R, M, and VWD, respectively. However, our results differ than those produced by [Akinwunmi et al. \(1993\)](#), [Parrish et al. \(1973\)](#), and [Dikeman et al. \(2013\)](#). [Akinwunmi et al. \(1993\)](#) evaluated two marbling degrees (slight and modest) cooked to three DOD (60, 71, and 77 °C) and found no interactions for sensory ratings, and only found differences among DOD, where steaks cooked to 60 °C were rated juicier than all other DOD. Similarly, [Parrish et al. \(1973\)](#) evaluated beef rib steaks of three marbling degrees (slight, modest, and moderately abundant) cooked to three DOD (60, 70, and 80 °C) and reported no interaction between quality grade and DOD, with only DOD having an impact on sensory traits. Moreover, [Dikeman et al. \(2013\)](#) evaluated longissimus muscle steaks from two aging methods (dry and wet aging) of two quality grades (Select and Choice) cooked to two endpoint temperatures (62.8 and 71.1 °C) and found no quality grade $\times$ DOD interaction for any of the trained palatability trait ratings, as well as no differences between quality treatments. Similar to [Akinwunmi et al. \(1993\)](#), samples cooked to 62.8 °C were rated juicier than 71.1 °C ([Dikeman et al., 2013](#)). However, in both studies, limited marbling levels and endpoint temperatures were evaluated, limiting the authors' abilities to draw conclusions across the entire range of quality grades and DOD that were evaluated in the current study.

Though there was an interaction for the objective measurement of juiciness, PJP, very few differences were found within each DOD. Most notably, no differences occurred among non-enhanced samples when cooked to VR or the three highest DOD.

This objective measurement of juiciness has been shown to be associated with consumer juiciness ratings ([Lucherk et al., 2017](#); [McKillip et al., 2017a](#)), with moderate correlations ($r = 0.45$, $r = 0.55$, respectively) found in both studies. In our study, PJP had a similar relationship ($r = 0.47$) with consumer juiciness ratings, but failed to reveal differences among treatments related to marbling that were observed by our sensory panelists.

Our data present limited evidence that increased marbling counteracts the negative impacts of increased DOD on tenderness. There was a quality treatment $\times$ DOD interaction for percentage of steaks rated acceptable by consumers for tenderness. The percentage of samples rated acceptable for tenderness in the enhanced samples and highest quality grades (Prime and Top Choice) was relatively constant across all of the DOD. Yet within the lower marbled samples, the percentage decreased substantially as DOD increased. Low Choice samples had a sharp drop-off as DOD increased from M to WD, with 16% fewer samples rated acceptable at WD. Also, Select samples had a steady decline in the percentage of samples rated acceptable for tenderness as DOD increased from VR to M, with 21% fewer samples rated acceptable at M than VR. When comparing across quality grades, Prime had only 1.6% more samples rated acceptable than Select at VR, but at M, WD, and VWD, Prime had 24%, 18%, and 18%, respectively, of samples rated acceptable for tenderness than Select. Therefore, increased marbling in Prime steaks allowed the samples to have a higher percentage of steaks rated acceptable for tenderness at increased DOD, supporting the insurance theory.

However, no such interaction was observed for both WBSF and SSF measurements of tenderness. For WBSF and SSF, increased marbling resulted in a more tender shear value and increased DOD generally resulted in tougher shear values. Steaks cooked to MR possessed the most tender shear values, except had similar values to R for WBSF as well as M for SSF, which aligns with studies that indicate increased tenderness in beef occurs in the first phase of cooking, up to 65 °C ([Davey and Niederer, 1977](#)). Results from previous authors have produced conflicting results on the combined impact of marbling and degree of doneness on beef tenderness. Our results differ than those of [Obuz et al. \(2004\)](#), which evaluated the effect of two quality grades (Top Choice and Select) cooked to nine (40, 45, 50, 55, 60, 65, 70, 75, 80 °C) endpoint temperatures using two cookery methods. Those authors reported a quality grade $\times$ DOD interaction for the

longissimus muscle, and found Top Choice samples possessed a lower WBSF value than Select samples when cooked to the two highest endpoint temperatures. Similar to [Obuz et al. \(2004\)](#), a DOD $\times$ quality grade interaction was reported for WBSF values when evaluating three endpoint temperatures (57, 68, 74 °C) and two quality grades (Choice and Select) of the longissimus muscle by [Luchak et al. \(1998\)](#). In that study, Choice samples were only lower in shear force than Select when cooked to the highest endpoint temperature, however, no interaction was observed for trained sensory panel tenderness ratings, with no differences reported between the quality grades, but decreasing with increased endpoint temperature (57 °C > 68 °C > 74 °C). Moreover, [Lucherk et al. \(2016\)](#) reported a quality treatment $\times$ DOD interaction for SSF, where no differences occurred among non-enhanced samples when cooked to R, but Prime, Top Choice, and Low Choice produced lower shear values than Select and Standard samples when cooked to WD. Yet, in the trained sensory evaluations, the authors reported no interaction for tenderness ratings. Collectively, these studies combined with the results of the current study offer only limited support of the insurance theory as it relates to beef tenderness, with conflicting reports being found throughout published literature. It is worth noting that steaks used in the current study were frozen prior all analyses. Freezing has been shown to positively impact tenderness ([Leygonie et al., 2012](#)), especially shear force values, through the disruption of the myofibrils by ice crystals formed during freezing. It is unknown how freezing may have impacted the results of the current study or if the results would have differed if all analyses had been conducted on fresh product.

The lack of interaction between quality treatment and DOD for consumer ratings, the percentage of steaks rated acceptable, and trained flavor ratings indicated that there was no added benefit to increased marbling for the trait of flavor when cooked to increased DOD. However, flavor was the trait DOD had the least negative impact on. Though consumers rated higher DOD lower for flavor, in terms of acceptability, only samples cooked to VWD had a lower percentage of steaks rated acceptable than all other DOD, with no difference occurring among all other DOD. Yet, VWD samples still maintained a high (76%) percentage of steaks rated acceptable for flavor. For trained sensory panel beef flavor scores, though there were differences detected by trained sensory panelists, there was only a 2.2-unit difference from the highest

rating to the lowest, supporting the consumer data and the conclusion that there were very few detectable differences in flavor. Multiple studies have found no differences in trained sensory panel flavor ratings across multiple DOD when using similar cooking methods ([Akinwunmi et al., 1993](#); [Lorenzen et al., 2005](#); [Gomes et al., 2014](#)). Thus, flavor is the palatability trait that is impacted the least by marbling level at increased DOD.

Fat, Moisture, and Their Relationships to Beef Palatability

For raw proximate analysis, fat percentages were similar to those reported by [Smith et al. \(2011\)](#) using the same method of fat determination as in the current study (modified [Folch et al. 1957](#) method). Our values for raw moisture percentages were higher than those reported by [Smith et al. \(2011\)](#) but more closely matched the numbers reported by [Lucherk et al. \(2016\)](#), [McKillip et al. \(2017b\)](#), and [O'Quinn et al. \(2012\)](#). In the study conducted by [Smith et al. \(2011\)](#), cooked proximate analysis was conducted, but contrary to our data, those authors found no interaction for quality treatment and DOD. Thus, the reported fat percentages of the steaks were averaged across the three quality grades (Prime, Choice, and Select) and across each DOD, limiting the ability to make a direct comparison to the current work. In [Smith et al. \(2011\)](#), as DOD increased, fat percentage increased as well, with a 32% increase in fat from the averaged raw fat percentage, when cooked to MR and M, and a 37% increase from the raw percentage when cooked to VWD. It has been widely reported that increased DOD results in increased cooking losses, primarily through the evaporation of moisture ([Wheeler et al., 1999](#); [Lorenzen et al., 2005](#); [Yancey et al., 2016](#)), thus explaining the increased concentration of fat in the final cooked product. However, the objective of the [Smith et al. \(2011\)](#) study was to evaluate cooked fat percentage from a nutrient standpoint at various DOD and not to evaluate the impact of fat level or DOD on sensory traits.

Few studies have evaluated cooked moisture and fat, but even fewer, if any, have evaluated their relationship to beef overall palatability. In the current study, the highest correlation to consumer overall liking was seen with combined cooked moisture and fat percentages. In fact, individually, moisture and fat percentage were weakly associated with all consumer palatability traits but had a much closer association to those traits when combined. This indicates the importance of both moisture and

fat percentage, and their relationship to the consumer beef eating experience and provides evidence in support of the insurance theory. A similar trend was seen with trained palatability traits, as alone, moisture and fat were weakly associated with juiciness ($R = 0.17$ to 0.31), and tenderness ($R = 0.17$ to 0.22), but when combined, were highly correlated to initial and sustained juiciness ($R = 0.84$ and 0.85) and to myofibrillar and overall tenderness ($R = 0.71$ to 0.68). Interestingly, aside from cooking loss, cooked moisture and fat had the highest correlation to trained juiciness ratings, even more so than a method developed to measure beef strip steaks juiciness, PJP. Cooking loss has been shown to be moderately to highly negatively correlated to consumer ($R = -0.76$ and $R = -0.51$) and trained juiciness ($R = -0.88$ and $R = -0.75$) ratings (McKillip et al., 2017a; Lucherk et al., 2017, respectively), but has limited predictive power as it is most commonly measured and reported on the steaks evaluated by the sensory panelists. Our results are similar to these previous studies, as cooking loss had the highest correlation to consumer and trained sensory panel juiciness ratings.

Many previous attempts have been made to predict consumer juiciness scores. In one such study, when using a logistic regression, the PJP method had an adjusted R^2 of 0.21 and was the best method (besides cooking loss) for predicting consumer juiciness ratings out of 36 other methods used to determine beef juiciness (Lucherk et al., 2017). Additionally, when using simple linear regressions, PJP possessed higher R^2 than all other methods ($R^2 = 0.48$ and 0.45) when used to predict trained initial and sustained juiciness respectively. However, our data indicate combined cooked moisture and fat are better predictors of consumer and trained juiciness ratings ($R^2 = 0.45$, 0.74 , and 0.69). The logistic regression equation in the current work indicates that a combined cooked moisture and fat percentage of 68.3%, 69.9%, and 71.2% is needed for a 50%, 75%, and 90% chance of a consumer rating a steak as juicy. Our data indicate multiple methods to achieve these various levels. For example, Select when cooked to M possesses enough combined moisture and fat for a 75% chance of a juicy consumer rating, but for Prime, that level occurs when cooked to WD, and at VWD for enhanced Select samples. These data clearly indicate that both fat and moisture can be used interchangeably to ensure juiciness and provides definitive evidence in support of the insurance theory as it relates to beef juiciness.

CONCLUSION

Increased marbling helps to compensate for the negative effects of increased cooking temperatures on beef juiciness, but does not provide the same level of protection for tenderness and flavor in previously frozen steaks. These results can help consumers and foodservice better identify products that will meet their own and their customers' expectations for juiciness, dependent upon their preferred DOD. Additionally, increased marbling or the addition of moisture through enhancement can enable strip loin steaks to maintain an acceptable juiciness level, even at advanced DOD. Therefore, our data supports the insurance theory for the palatability trait of juiciness.

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