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Repeatability and Accuracy of the Pressed Juice Percentage Method at Sorting Steaks into Juiciness Categories

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Abstract: The objective of this study was to evaluate the repeatability of the Pressed Juice Percentage (PJP) as well as to determine the accuracy of previously determined PJP thresholds at sorting beef strip loin steaks into categories based on the probability of being rated juicy by sensory panelists. Beef strip loin steaks representing 3 USDA quality grades (Prime, Low Choice, and Low Select) and Low Select strip loin steaks enhanced to 108% of the raw weight with a water, salt, and alkaline phosphate solution were cooked to three degrees of doneness [DOD; Rare (60°C), Medium (71°C), Very Well-Done (82°C)] to maximize variation in juiciness. Paired steaks were evaluated for PJP, Slice Shear Force (SSF), and Warner-Bratzler shear force (WBSF). Additionally, steaks representing Prime, Low Choice, and Low Select that were non-enhanced or enhanced with the same enhancement solution cooked to three DOD [Rare (60°C), Medium (71°C), Very Well-Done (82°C)] from a previously conducted sensory study were used to evaluate the ability of PJP to sort steaks into juiciness categories. Results indicated PJP had a high repeatability coefficient of 0.70, indicating only a small portion (30%) of the variation observed was due to sample measurement differences between paired samples. The repeatability of SSF and WBSF were 0.68 and 0.85, respectively. The evaluated PJP threshold values accurately segregated strip loin steaks by the probability of a sample being rated as juicy (mean juiciness rating of > 50) by consumers. The actual percentage of juicy samples was determined to be 41.67, 72.31, 89.33, and 98.08% for the predicted < 50%, 50 to 75%, 75 to 90%, and > 90% categories, respectively. Results of this study indicate the PJP juiciness measure is both repeatable and accurate in sorting beef strip loin steaks based on the likelihood of a steak being classified as juicy by consumers.

Introduction

The 3 traits contributing the most to beef palatability are tenderness, juiciness, and flavor (Bratzler, 1971; Platter et al., 2003; Corbin et al., 2015). These traits must not just excel individually, but must interact to deliver an optimal eating experience (Savell and Cross, 1988; Emerson et al., 2013; O'Quinn, 2016). Among these traits, tenderness has been the most re-searched over the past 25 yr and has thus resulted in large improvements in the tenderness of the U.S. beef supply. According to the most recent National Beef Tenderness Survey, 95.9% of beef at retail from the top loin would be considered "very tender" (Savell et al., 2016). With such a large portion of the U.S. beef supply considered tender, the importance of beef products delivering on consumer juiciness and flavor expectations is greater than ever before.

Juiciness has been found to be highly correlated ($r = 0.73$- 0.93) with consumer overall liking (Killinger et al., 2004; O'Quinn et al., 2012; Corbin et al., 2015). Many studies have attempted to use a variety of methods to objectively measure and quantify juiciness, though

with limited success (Sanderson and Vail, 1963; Lee and Patel, 1984; Pearce et al., 2011). Authors of a recent study developed an instrumental juiciness measurement technique that compliments and can be conducted simultaneously with Slice Shear Force (SSF) tenderness evaluation (Lucherk et al., 2017). In that study, the Pressed Juice Percentage (PJP) accounted for 48, 45, and 20% of the variation in trained sensory panel initial juiciness, trained sensory panel sustained juiciness, and consumer juiciness scores, respectively (Lucherk et al., 2017).

The PJP values of 14.64, 18.94, and 23.25% correspond to the probability of a steak being rated "juicy" 50, 75, and 90% of the time, respectively (Lucherk et al., 2017). The objectives of the current study were to validate these proposed threshold values, evaluate the accuracy of PJP at identifying "juicy" steaks, and to determine the repeatability of the PJP method.

Materials and Methods

Experimental treatments and sample preparation – Phase 1

This experiment was conducted in two phases. The first phase was conducted to evaluate the repeatability of the PJP method. For this phase, beef strip loins [IMPS #180; North American Meat Institute (2014)] were collected approximately 48 h postmortem from a beef processor in the Midwest and represented four quality treatments: USDA Prime, Low Choice (Small[00] to Small[100]), Low Select (Slight[00] to Slight[49]), and enhanced Low Select (n = 5/treatment). Upon selection, carcasses were evaluated for skeletal, lean, and overall maturity, marbling score, preliminary yield grade, adjusted yield grade, ribeye area, hot carcass weight, kidney pelvic and heart fat, and USDA yield grade (data not reported). After fabrication, strip loins were vacuum packaged and transported under refrigeration (2°C) to the Kansas State University Meat Laboratory for further processing. Strip loins not allocated for enhancement were stored under vacuum at 2 to 4°C, in the absence of light for a 21 d postmortem aging period. Low Select strip loins (n = 5) designated for enhancement were aged 14 d and then injected with a solution formulated to result in 0.35% salt and 0.40% sodium phosphate (Brifisol 512, ICL Food Specialties, Saint Louis, MO) in the final product at 8% pump. A multi-needle injector (Wolf-tec, IMAX 420 eco, Kingston, NY) was utilized for the injection of the solution (pH = 8.09). Actual enhancement level (8.63 ± 1.53%) was verified by recording weights

of the strip loins before pumping and after a 15 min rest period following injection. Enhanced product was vacuum packaged (3 mil standard barrier, Prime Source Vacuum Pouches; Bunzl Processor Division, Koch Supplies, Kansas City, MO) that possessed an oxygen transmission rate of 3.5 $g^{-1} \times 645.2$ $cm^{-2} \times 24$ h^{-1} at 21°C, and stored at 2 to 4°C, in the absence of light for the remainder of the 21 d aging period.

After aging, strip loins were fabricated into 2.5-cm thick steaks. Prior to cutting, the most anterior (wedge) steak (2.0 to 2.5 cm in thickness) was cut and utilized for pH, objective color analysis (*L**, *a**, *b**), and proximate analysis. Wedge steaks were placed on trays with the fresh cut surface exposed to the environment and permitted to bloom for a 15 min period prior to color evaluation. Each steak was evaluated for pH using a pH meter (model HI 99163; Hanna Instruments, Smithfield, RI) which was calibrated prior to evaluation using 4.0 and 7.0 calibration buffers (Fisher Scientific) and checked for calibration every 1 h. A Hunter Lab Miniscan spectrophotometer (Illuminant A, 2.54-cm aperture, 10° observer; Hunter Associates Laboratory, Reston, VA) was used to measure *L**, *a**, and *b** color space values according to the American Meat Science Association Meat Color Measurement Guidelines (American Meat Science Association, 2012). Scans were taken at 3 areas of each steak and the observations were averaged. Prior to evaluation, the spectrophotometer was calibrated using the manufacturer's black and white color tile standards and checked for calibration every 1 h. After color and pH analysis, steaks were individually packaged, frozen (–20°C), and stored for proximate analysis.

Strip loins were then fabricated from anterior to posterior. Consecutively cut steaks were paired for use in PJP repeatability testing. Each pair was randomly assigned to one of three degrees of doneness [DOD; Rare (60°C), Medium (71°C), Very Well-Done (82°C)]. Two pairs from each strip loin were assigned to each DOD, for a total of 120 pairs in the study. Steaks were weighed fresh, packaged individually, and frozen (–20°C). The use of various quality grades, enhancement, and DOD were chosen to maximize the amount of variation in juiciness observed among the samples.

Experimental treatments and sample preparation – Phase 2

The objectives of the second phase of the study were to evaluate the PJP threshold values previously identified by Lucherk et al. (2017) and evaluate the ability of the PJP method to sort steaks into categories based on the probability of being classified as juicy. For this

phase of the study, a separate set of strip loins [$n = 72$; IMPS #180; North American Meat Institute (2014)] representing 3 USDA quality grades: Prime, Low Choice, and Low Select, were selected on the same day, approximately 48 h postmortem, from the same processor as strip loins used in the first phase. Half ($n = 12$) of the strip loins from each quality grade were enhanced with the same enhancement solution using the same methods as previously described. Steaks from each strip loin were assigned to one of three DOD [Rare (60°C), Medium (71°C), Very Well-Done (82°C)], with grouped samples from each strip loin assigned to consumer sensory evaluation, trained sensory panel evaluation, and objective juiciness (PJP) and tenderness [SSF and Warner-Bratzler shear force (WBSF)] testing. Similar to the first phase of the study, the use of multiple quality grades, DOD, and enhancement levels allowed for a large amount of variation in juiciness for PJP and sensory juiciness evaluation. Greater detail in regards to sample collection, fabrication, cookery, and sensory evaluation of samples used in this phase of the study is provided by McKillip et al. (2017).

Cooked sample preparation

Steaks were thawed (2 to 4°C) for 24 h prior to evaluation. A raw thaw weight was recorded for steaks immediately out of the package for thaw loss calculation. 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 on a clamshell grill (Cuisinart Griddler Deluxe, East Windsor, NJ) to the assigned DOD [Rare (60°C), Medium (71°C), or Very Well-Done (82°C)]. Thermocouples (30-gauge copper and constantan; Omega Engineering, Stamford, CT) were inserted into the geometric center of each steak to monitor 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). Steaks were rested for 2 min (23°C) prior to testing.

Slice shear force

Slice shear force testing was conducted utilizing the procedures described by Shackelford et al. (1999b). In brief, a 1 to 2-cm portion of the lateral end of the steak was removed to expose muscle fiber orientation. With the use of a sizing box, a 5-cm length portion was removed from the lateral end of each steak. A 1-cm thick sample was removed parallel to the muscle fiber orientation from the 5-cm piece from the lateral end at a 45° angle of each

steak using a double-bladed knife. The sample was then center sheared at a crosshead speed of 500 mm/min using a shearing machine (Model GR-152, G-R Manufacturing Co., Manhattan, KS) and the peak force (kg) required to shear through the warm slice was measured using a basic force gauge (BFG500N, Mecmesin Ltd., West Sussex, UK) attached to slice shear force blade.

Pressed Juice Percentage

The PJP protocol used was developed and described by Lucherk et al. (2017). In brief, following SSF sample removal, the double-bladed knife was used to cut a 1-cm thick by steak-width slice immediately medial to SSF sample removal. Three 1-cm width pieces were removed parallel to the muscle fiber orientation from the slice. Each sample was weighed on 2 pre-weighed pieces of filter paper (VWR Filter Paper 415, 12.5cm, VWR International, Radnor, PA) and compressed at 78.45 N of pressure for 30 s on an INSTRON Model 5569 testing machine (Instron, Canton, MA). After sample compression, samples were discarded and filter paper was re-weighed. The PJP was calculated as the weight lost during compression of sample: PJP = Weight Loss/initial sample weight. The 3 values from each steak were averaged for a single PJP value for each steak. To determine if using 6 rather than three samples from each steak improved the precision of the PJP method, an additional 1-cm slice was removed immediately medial to the first slice and an additional set of three samples were compressed and PJP quantified as previously described.

Warner-Bratzler shear force

Following PJP and SSF sample removal, the remaining portion of steaks were cooled for 12 h at 2 to 4°C prior to Warner-Bratzler shear force (WBSF) analysis according to the methods described by the American Meat Science Association (2015). Six 1.27-cm diameter cores were removed parallel to the muscle fiber orientation. The cores were sheared once, perpendicular to muscle fibers with an INSTRON Model 5569 testing machine (crosshead speed of 250 mm/min; 100 kg compression load cell; Instron, Canton, MA) with the use of a Warner-Bratzler shear blade. Values were reported as the peak kg of force required to shear through the core. Values were averaged across all cores from a single steak.

Proximate analysis

For 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. Samples were submerged in liquid nitrogen and then homogenized using a commercial 4 blade blender (Model 33BL 79, Waring Products, New Hartford, CT). Samples were then placed in Whirl-Pac (Nasco, Fort Atkinson, WI) bags and stored (–20°C) until proximate analysis. Lipid extraction was performed following procedures described by Martin et al. (2013). Moisture content was determined using the AOAC approved oven drying method and the percentage of ash was determined using a muffle furnace following the AOAC ash oven method (AOAC, 2005). Nitrogen content was assessed 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.

Statistical analysis

For statistical analyses, SAS (Version 9.4; SAS Inst. Inc., Cary, NC) was used. Comparisons among treatment means were evaluated for significance using PROC GLIMMIX with $\alpha = 0.05$. All shear, PJP, and moisture loss data were analyzed using a model with a split-plot arrangement of factors, with the whole-plot factor of quality treatment and the sub-plot factors of DOD and the quality treatment × DOD interaction. All color, pH, and proximate data were analyzed with a model that included the fixed effect of quality treatment. The Kenward–Roger approximation was utilized for estimation of denominator degrees of freedom for all analyses. The quality treatment × DOD interaction was nonsignificant ($P > 0.05$) for all variables evaluated other than WBSF. For the significant WBSF interaction, the SLICE option of the LS MEANS statement was used to compare means within a single DOD.

The repeatability of PJP, WBSF, and SSF were calculated as described by Shackelford et al. (1999a). Repeatability represented the proportion of the total variance that could be attributed to the steak pair: repeatability = $\sigma^2\text{pair}/(\sigma^2\text{pair} + \sigma^2\text{residual})$. Variance components for repeatability measures were calculated using the GLIMMIX procedure.

Results and Discussion

Instrumental color and proximate composition

Instrumental color readings, pH values, and proximate composition of strip loins used in this study are presented in Table 1. Instrumental color readings of L^* value indicated enhanced Low Select samples were darker ($P < 0.05$) in color than all other treatments, as well as had lower ($P < 0.05$) a^* and b^* values. Additionally, Prime samples had a greater ($P < 0.05$) L^* value than all other treatments. This lighter color reading for Prime samples was likely due to the higher marbling level of these samples and the resulting influence of the white marbling color during measurement. Moreover, no differences ($P > 0.05$) were found in a^* and b^* values among the non-enhanced treatments. Similar results for instrumental color readings of enhanced steaks have been previously reported. Previous studies reported L^* readings of beef strip loins that had been enhanced with a similar salt and alkaline phosphate solution to be darker than non-enhanced control samples (Robbins et al., 2003). Similarly, Kim et al. (2006) reported lower L^*, a^*, and b^* values for enhanced strip loin steaks. Therefore, these studies indicate salt and alkaline phosphate enhancement solutions result in lower a^* and b^* values and darker lean

Table 1. Least squares means for proximate, pH, and color analysis of raw beef strip loin steaks of varying treatments

Treatment	Moisture	Protein	Fat	Ash	pH	L^{*1}	a^{*2}	b^{*3}
		%						
Prime	67.81[c]	23.43	8.74[a]	1.35[b]	5.60[b]	47.76[a]	26.57[a]	19.53[a]
Low Choice	72.02[b]	21.77	3.67[b]	1.39[b]	5.62[b]	43.27[b]	26.58[a]	18.46[a]
Low Select	70.94[b]	22.40	2.84[bc]	1.22[b]	5.64[b]	43.87[b]	26.58[a]	18.59[a]
Low Select enhanced[4]	74.77[a]	21.39	1.91[c]	1.64[a]	5.89[a]	39.40[c]	24.46[b]	15.42[b]
SEM[5]	0.89	1.13	0.36	0.07	0.03	1.02	0.39	0.36
P-value	< 0.01	0.61	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

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

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

color. However, it is unclear if these color changes as a result of enhancement would be detrimental to color preference and desirability to consumers.

Due to the inclusion of alkaline phosphates in the enhancement solution, enhanced Low Select samples had a greater ($P < 0.05$) pH than all non-enhanced samples. Similar results of increased pH from alkaline phosphate enhancement have been reported by previous authors. Increases in pH of 2.9, 2.1, and 7.5% have been previously reported by Robbins et al. (2002), Baublits et al. (2006), and Wicklund et al. (2005), respectively. Alkaline phosphates increase the pH of fresh meat due to the elevated pH of the phosphates, which are typically at a pH of 7 or higher (Sebranek, 2015). Additionally, enhancement resulted in an increase ($P < 0.05$) in moisture content of more than 2.5% in enhanced Low Select samples over all non-enhanced samples in this study.

Fat percentage increased ($P < 0.05$) as USDA quality grade increased from Low Select (2.84%) to Prime (8.74%). Additionally, no difference ($P > 0.05$) in fat percentage was found between Low Select, and enhanced Low Select samples. The results of the current study are consistent with authors who have used CEM to determine the fat percentages of beef (Dow et al., 2011) and show a similar increase in fat percentage and differences among quality grades as shown in other reports. Fat percentages in our study were found lower than those report-

ed in previous studies evaluating the same quality grades (Savell et al., 1986; O'Quinn et al., 2012; Emerson et al., 2013; Legako et al., 2015). However, methodology in those studies consisted of NIR, ether extraction, or Folch methodology to determine fat percentage, likely contributing to this observed difference.

Objective measures of juiciness and tenderness

Objective measurements for PJP and percentages for thaw loss, cooking loss, and total loss of all treatments are presented in Table 2. When evaluating PJP, no quality treatment × DOD interaction ($P > 0.05$) was found, indicating the effect of quality treatment on PJP was similar across all DOD evaluated. No differences ($P > 0.05$) were found among quality treatments for PJP; however, DOD had a large effect on PJP. The PJP decreased ($P < 0.05$) as DOD increased (Rare > Medium > Very Well-Done). Rare samples had, on average, approximately 9% more weight lost during PJP measurement than Very Well-Done samples and greater than 3% more than Medium samples. These results give a clear indication of the importance of DOD to beef juiciness. This large effect of DOD may be in part responsible for the lack of observed differences in PJP among quality treatments, as the reported quality treatment means were pooled across

Table 2. Least squares means for beef strip loin steaks objective measures of Slice Shear Force (SSF), Pressed Juice Percentage (PJP)[1], thaw loss[2], cook loss[3], and total loss[4]

Treatment	SSF, kg	PJP, %	Thaw loss, %	Cook loss, %	Total loss, %
Quality treatment					
Prime	12.31	20.04	1.64[c]	18.94[a]	21.04[a]
Low Choice	14.16	19.44	2.09[b]	18.87[a]	21.44[a]
Low Select	14.35	20.97	2.62[a]	19.23[a]	22.16[a]
Low Select enhanced[5]	10.89	20.70	1.53[c]	15.86[b]	17.52[b]
SEM[6]	1.14	0.63	0.15	0.64	0.73
P-value	0.15	0.35	< 0.01	< 0.01	< 0.01
Degree of doneness					
Rare (60°C)	12.97	24.34[a]	2.17[a]	12.15[c]	14.96[c]
Medium (71°C)	12.74	21.15[b]	1.76[b]	17.76[b]	19.78[b]
Very well done (82°C)	13.07	15.37[c]	1.98[ab]	24.76[a]	26.88[a]
SEM[6]	0.62	0.40	0.10	0.45	0.48
P-value	0.71	< 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]Pressed Juice Percentage (PJP): Percentage of weight lost during compression of sample between filter paper at 78.45 N for 30 s.

[2]Thaw loss = [(initial weight-thaw weight) / initial weight].

[3]Cook loss = [(raw weight-cooked weight) / raw weight].

[4]Total loss = [(initial weight-cooked weight) / initial weight].

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

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

all 3 DOD and this may have overshadowed any potential quality treatment differences.

Pressed Juice Percentage results reported by Lucherk et al. (2017) were similar to the current study among the quality treatments evaluated. In that study, differences were only found among the Select High Enhanced (12% pump) and the Standard quality treatments. Otherwise, Lucherk et al. (2017) found no differences among all other quality grades evaluated. These authors reported results consistent with the current study, with Select Low Enhanced (7% pump) found to be similar for PJP to steaks from Prime to Select quality grades (Lucherk et al., 2017). Similar to our study, among DOD (Rare to Well-Done), Lucherk et al. (2017) found large differences in PJP.

The percentage of weight lost as a result of freezing and thawing samples (thaw loss) is presented in Table 2. As quality grade increased from Low Select to Prime, the amount of thaw loss decreased ($P < 0.05$). Prime samples had a similar ($P > 0.05$) amount of thaw loss as enhanced Low Select samples. However, observed thaw loss differences were minimum across all quality treatments, with the 2 most extreme treatments differing by only slightly more than 1% (1.09%). No differences ($P > 0.05$) were found among non-enhanced samples for the percentage of cooking loss observed; however, enhanced Low Select samples had more than 3% less ($P < 0.05$) cook loss than all other treatments. This is due to the added water-holding capacity associated with alkaline phosphates. Previous studies by Wicklund et al. (2005) and Baublits et al. (2006) have reported improvements in the percentage of cooking loss of 3.2 and 2.5% due to alkaline phosphate enhancement when compared to non-enhanced samples. The same trend was observed in the current study for the percentage of total (initial weight – cooked weight) loss, with no difference ($P > 0.05$) found among non-enhanced samples, and enhanced Low Select samples having a lower ($P < 0.05$) percentage of total loss than all other treatments.

The percentage of cooking loss increased ($P < 0.05$) concurrently with degree of doneness (Rare < Medium < Very Well-Done; Table 2). Rare samples had less than half (12.15 vs. 24.76%) the percentage of cooking loss as samples cooked to Very Well-Done. This large difference in cooking loss is partially responsible for the large observed differences among DOD for PJP, with elevated DOD having less available moisture for juiciness quantification during compression. Moreover, the percentage of total loss increased ($P < 0.05$) as DOD increased from Rare to Very Well-Done. This is due in large part to the relative high percentage ($> 86\%$) of the total weight loss accounted for by cooking loss as opposed to thaw

loss, with only minimal variation observed among DOD groups for the percentage of thaw loss.

No differences ($P > 0.05$) were found among quality treatments or among DOD for SSF (Table 2). Among quality treatments, mean SSF values differed by almost 3.5 kg, however were not significantly different, likely due to the low number of samples used in the first phase of the study and the amount of variation (standard error = 1.14 kg) within treatment groups. Previous authors reported SSF values decrease as quality grades increase (Emerson et al., 2013). In the current study, SSF values indicated a high degree of tenderness among samples, with mean values all below the 15.3 kg threshold established by the USDA for "Certified Very Tender" (ASTM, 2011). This high level of tenderness may be partially responsible for the lack of observed SSF differences among treatments.

When evaluating objective tenderness measures, a quality treatment × DOD interaction were found for WBSF ($P < 0.05$; Table 3). As DOD increased, WBSF values also increased (Very Well-Done > Medium > Rare; $P < 0.05$). When cooked to Rare, no difference

Table 3. Interaction between degree of doneness and treatment ($P = 0.0003$) for Warner-Bratzler shear force (WBSF) values of grilled beef strip loin steaks

Treatment	WBSF value, kg
Rare (60°C)	
Prime	2.16
Low Choice	2.53
Low Select	2.57
Low Select enhanced[1]	1.88
SEM[2]	0.26
P-value	0.24
Medium (71°C)	
Prime	2.57[b]
Low Choice	2.89[ab]
Low Select	3.24[a]
Low Select enhanced[1]	1.90[c]
SEM[2]	0.26
P-value	0.01
Very well done (82°C)	
Prime	2.67[b]
Low Choice	3.55[a]
Low Select	3.56[a]
Low Select enhanced[1]	2.17[c]
SEM[2]	0.26
P-value	< 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, alkaline phosphate solution.

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

($P > 0.05$) was found for WBSF across all quality treatments. However, when cooked to Medium, enhanced Low Select samples had the lowest ($P < 0.05$) WBSF value and Prime samples were more tender ($P < 0.05$) than Low Select samples, but similar ($P > 0.05$) to Low Choice samples. Though when cooked to Very Well-Done, Prime samples were more tender ($P < 0.05$) than both Low Choice and Low Select samples (enhanced Low Select < Prime < Low Choice = Low Select). These results indicate an increased importance of marbling level for beef tenderness when steaks are cooked to elevated degrees of doneness and are consistent with the "insurance theory" associated with beef palatability (Smith and Carpenter, 1974).

It is noteworthy that all of the beef used in this study was very tender and the mean values indicate that a large number of the samples at each DOD and quality treatment would have met WBSF thresholds for "USDA Certified Very Tender" (ASTM, 2011). Steaks in our study were aged a total of 21-d postmortem and this aging period likely contributed to the high level of tenderness observed among samples. Data from the most recent beef tenderness survey indicated that 98.5% to 100% of retail and foodservice beef from the top loin would be considered either "tender" or "very tender" based on WBSF value (Savell et al., 2016). Additionally, the average age time of beef found in U.S. retail markets was 25.9 d (Savell et al., 2016). This indicated that the beef used in the current study is consistent with beef commonly purchased and consumed by U.S. beef consumers at both retail and foodservice.

PJP repeatability

The PJP method had a repeatability coefficient calculated at 0.70 (Fig. 1). This indicates that 70% of the observed variation within the sample set of maximum juiciness variation (4 quality treatments cooked to three DOD) could be attributed to between-pair variation, indicating only 30% of the variation was unexplained or due to within-pair variation between the paired samples. As a point of comparison, SSF in the current study had a comparable repeatability with PJP, with a repeatability coefficient of 0.68. However, WBSF was more repeatable (repeatability = 0.85) than either PJP or SSF in the current study. Our calculated repeatability falls within the range reported previously (0.67 to 0.87) for WBSF (Wheeler et al., 1996; Wheeler et al., 1997). However, Shackelford et al. (1999a) reported the repeatability of SSF at 0.91, which is much higher than the 0.68 calculated in the current study. This difference may be due in part to the differences in cooking protocols used in the 2 studies. Shackelford et al. (1999a) used a belt-grill to cook steaks to a single DOD as opposed to the clamshell grills used in the current study to cook to three DOD. Differences in heat contact and time likely resulted in less between-steak variation for Shackelford et al. (1999a) than in the current study, and may explain some of the differences in reported repeatability. Additionally, the sample set used by Shackelford et al. (1999a) were aged only 3 d and as a result were both tougher and more variable in tenderness than samples used in our study, also potentially contributing to the observed differences.
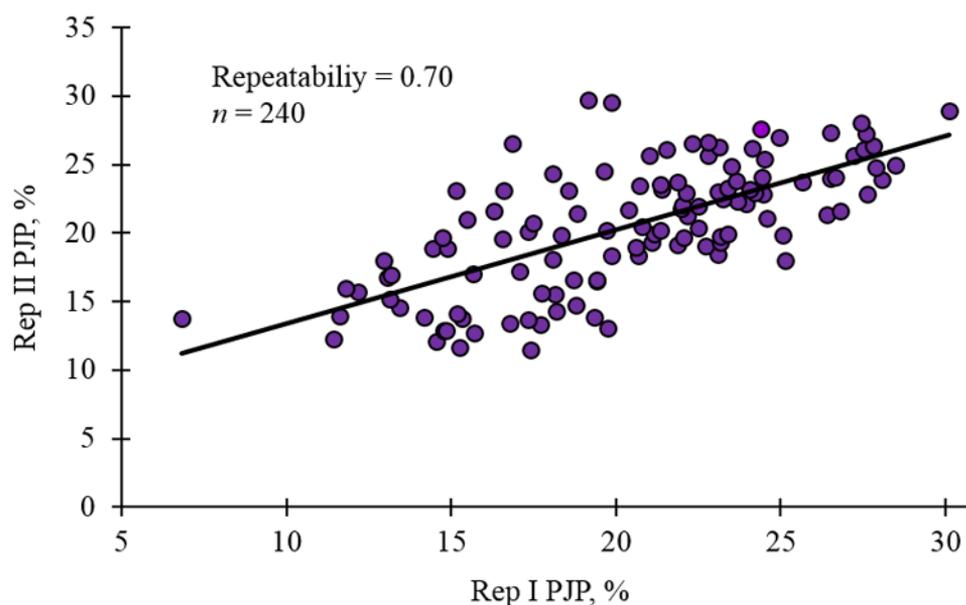

Figure 1. Repeatability of the Pressed Juice Percentage (PJP).

The original PJP method developed by Lucherk et al. (2017) was averaged across 3 samples per steak for PJP determination. Other objective measures of beef palatability (WBSF) often average across at least six samples from each steak for a final sample average. Our study compared the use of 3 vs. 6 samples to determine if the added samples improved the precision and repeatability of the PJP method. The use of 6 PJP samples produced a repeatability coefficient of 0.72 and had an average coefficient of variation of 13.83%. When 3 samples were used for PJP determination, the repeatability was estimated at 0.70 and samples had an average coefficient of variation of 12.64%. Therefore, it was determined that the use of an additional 3 samples did not improve the precision or repeatability of the method enough to justify the added time and costs associated with the additional sampling.

Accuracy of PJP for sorting steaks for juiciness

Through the use of a logistic regression model, Lucherk et al. (2017) proposed multiple PJP threshold levels to predict the likelihood of a sample being rated juicy by consumers: PJP of < 14.64% = < 50% chance of being rated as juicy; PJP of 14.64 to 18.94% = 50 to 75% chance of being rated as juicy; PJP of 18.94 to 23.25% = 75 to 90% chance of being rated as juicy; and PJP of > 23.25% = > 90% chance of being

rated as juicy. It was therefore one of the objectives of the current study to test the accuracy of these threshold values and evaluate the efficacy of PJP at sorting steaks into these juiciness categories.

Steaks representing a variety of USDA quality grades and enhancement levels were cooked to 3 degrees of doneness and evaluated for PJP [data reported by McKillip et al. (2017)]. These PJP values were used to sort the steaks into the various categories identified by Lucherk et al. (2017). Paired samples were then evaluated by both consumer panelists and trained panelists for juiciness on 100 mm line scales, with 0 labeled as extremely dry, 100 labeled as extremely juicy and 50 labeled as neither dry nor juicy [data reported by McKillip et al. (2017)]. Within each threshold range, the percentage of samples rated juicy (average sensory panel juiciness score of > 50) by sensory panelists was determined and compared to the predicted percentage to determine the accuracy of the threshold values.

Threshold results for PJP corresponding to consumer ratings of juiciness are presented in Fig. 2. Within all threshold categories, the actual percentage of samples rated juicy by consumers was within the predicted probability ranges. In the first category with a predicted percentage of samples rated as juicy of less than 50%, the actual percentage rated juicy was 41.67%. In the second category, with a predicted probability of 50 to 75%, the actual percentage of samples rated juicy was 72.31%,
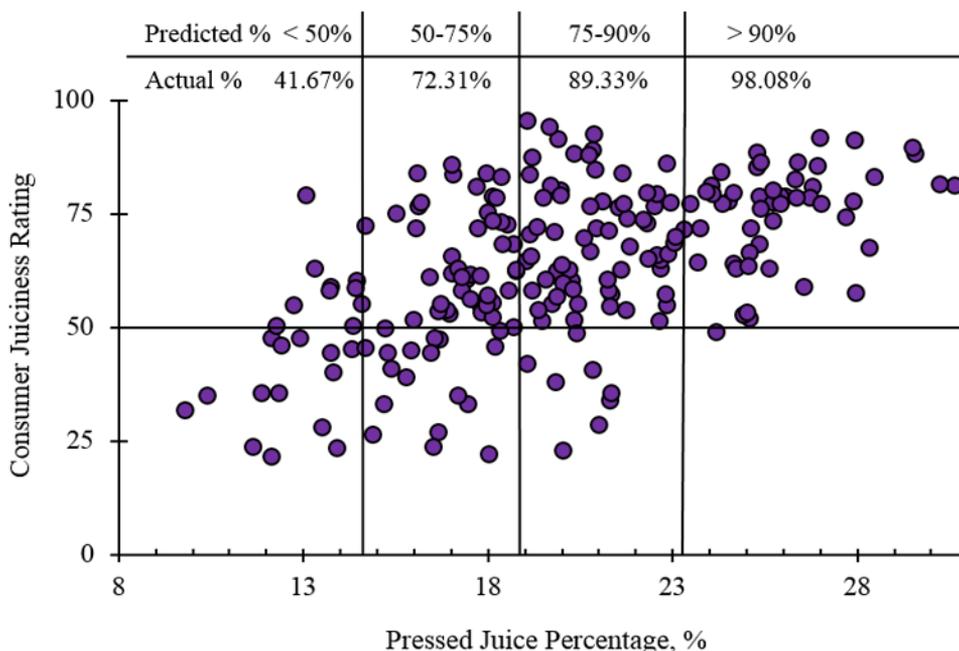

Figure 2. Predicted vs. actual proportion of beef strip loin steaks identified as juicy (mean juiciness rating > 50) by consumers based on Pressed Juice Percentage (PJP). Predicted proportions based on the logistic regression model previously reported by Lucherk et al. (2017). Actual percentages represent the observed proportion of juicy samples in the current study. Plotted data points represent data from the current study. For consumer juiciness rating: 100 = extremely juicy, 0 = extremely dry, and 50 = neither juicy nor dry.

and within the third category (75 to 90% predicted juicy), the actual percentage of samples rated juicy was 89.33%. Lastly, within the final category with an expected probability over 90% rated juicy, the actual percentage rated juicy was 98.08%. These results indicate the established threshold values by Lucherk et al. (2017) were accurate and successful in identifying the probability of a steak being rated as juicy by consumers. Validating these thresholds on an independent data set, as was done with the current study, indicates the PJP as an effective objective juiciness evaluation method and allows for the possibility of identification and marketing of "guaranteed juicy" steaks that will meet consumer expectations for juiciness.

Figure 3 presents results from PJP threshold identification and trained sensory panel ratings of initial juiciness. The established thresholds were accurate in the predicted percentage of samples rated juicy in the first, second, and fourth categories. However, the actual percentage of samples rated juicy in the third (75 to 90%) category did not fall within the predicted range, but was very close (73.33%) to the predicted 75%. Overall, the PJP thresholds accurately sorted steaks for trained panel initial juiciness scores for the majority of the categories. In all categories, a lower percentage of samples were rated as juicy for initial juiciness than was observed with consumer data. This indicates trained panelists had a higher expectation level for what would be considered juicy than the untrained consumers.

The established PJP thresholds were not able to accurately sort steaks for trained panel sustained juiciness (Fig. 4). For all categories except the lowest (< 50%), a lower percentage of samples were rated juicy than was predicted. There was a notable decrease from initial to sustained juiciness. Initial juiciness ratings are a measure of the initial amount of moisture released from the sample within the first few chews. However, sustained juiciness is the result of the slow release of juice from the fat and enacts increased salivary flow throughout the chewing process (Bratzler, 1971). The decrease of sustained juiciness was consistent across all treatment groups, as indicated by both initial and sustained juiciness having a similar relationship with consumer panel juiciness scores (both $r = 0.75$). This decrease in juiciness observed between initial and sustained measures was responsible for the decreased number of samples rated as juicy at each PJP and the corresponding inaccuracy of the PJP thresholds due to the downward shift in sustained juiciness scores.

The PJP thresholds established by Lucherk et al. (2017) and tested in the current study were based on consumer data and were intended to segregate and identify the probability of consumers considering steaks as juicy. Similar threshold values could be established for trained panelists and would likely improve the accuracy of PJP at sorting steaks for initial and sustained juiciness. In our study, the consumer-based thresholds were accu-
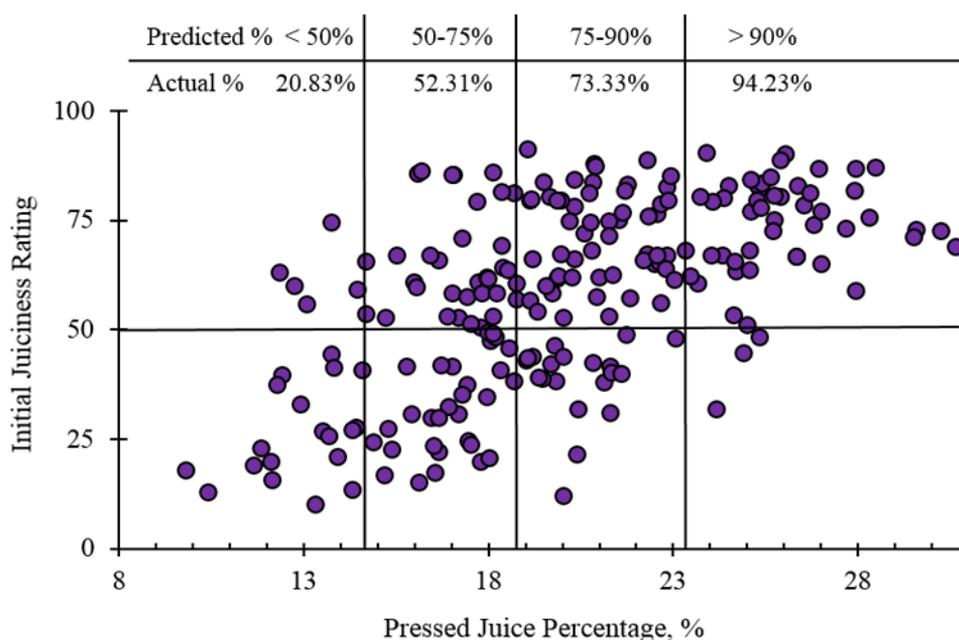

Figure 3. Predicted vs. actual proportion of beef strip loin steaks identified as juicy (mean juiciness rating > 50) for initial juiciness by trained sensory panelists based on Pressed Juice Percentage (PJP). Predicted proportions based on the logistic regression model previously reported by Lucherk et al. (2017). Actual percentages represent the observed proportion of juicy samples in the current study. Plotted data points represent data from the current study. For initial juiciness rating: 100 = extremely juicy, 0 = extremely dry, and 50 = neither juicy nor dry.
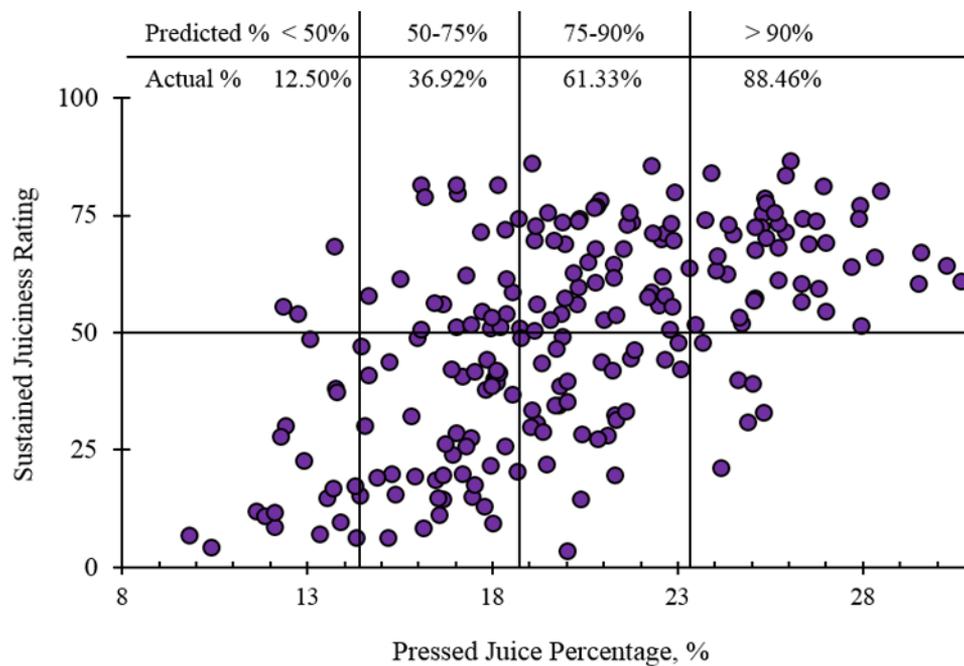
Figure 4. Predicted vs. actual proportion of beef strip loin steaks identified as juicy (mean juiciness rating > 50) for sustained juiciness by trained sensory panelists based on Pressed Juice Percentage (PJP). Predicted proportions based on the logistic regression model previously reported by Lucherk et al. (2017). Actual percentages represent the observed proportion of juicy samples in the current study. Plotted data points represent data from the current study. For sustained juiciness rating: 100 = extremely juicy, 0 = extremely dry, and 50 = neither juicy nor dry.

rate in sorting steaks for trained panel initial juiciness scores, though to a lesser degree than consumer data. By the very nature of trained sensory panels, panelists are trained and orientated with the scaling used for evaluation. Because of this, potential variation among trained panels at various institutions may result in variation in the accuracy of any established trained panel thresholds. Moreover, trained sensory panels in the future could be trained to match and evaluate samples based on the consumer-based threshold values. Data from untrained consumer panelists inherently possesses a greater amount of variation than trained sensory panel data. This is clearly indicated by the amount of variation in sensory panel data accounted for by objective measures of both tenderness (WBSF and SSF) and juiciness (PJP) reported by McKillip et al. (2017). However, thresholds used for juiciness segregation and potential marketing will ultimately be required to meet the standards of consumers who purchase and consume the product in home or in restaurant. This should be considered when developing and implementing thresholds for potential juiciness segregation.

Conclusions

The PJP method was demonstrated to be both repeatable and accurate at sorting steaks into categories based on the likelihood of a steak being juicy. The juiciness thresholds proposed by Lucherk et al. (2017)

were demonstrated to be accurate for consumers in this study. This indicates an opportunity for the use of PJP as a repeatable and reliable method for objective juiciness determination for the beef industry.

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