



## The Effects of Enhancement Strategies of Beef Flanks on Composition and Consumer Palatability Characteristics

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**Abstract:** Beef *rectus abdominis* muscles ( $n = 100$ ; 20/treatment) were assigned randomly to 1 of 5 treatments: untreated control (Control, No Treatment; CNT), vacuum tumbled control without marinade (Tumbled Control, No Treatment; TCNT), vacuum tumbled with marinade (TUMB), injected with marinade (INJ), and injected with marinade plus vacuum tumbled (IPT) to determine how enhancement techniques influence consumer palatability. After processing, flank samples were cooked ( $72^{\circ}\text{C}$ ), cut into 1.3-cm strips, and served as fajita strips for consumer evaluation ( $n = 200$ ). Treatment influenced ( $P < 0.01$ ) the rating and acceptability of all palatability traits, overall liking, and willingness to pay (WTP). Consumers scored IPT and INJ more tender compared to all other treatments ( $P < 0.05$ ). Samples processed using IPT and INJ were juicier ( $P < 0.05$ ) than all other treatments, except INJ and TUMB were similar ( $P > 0.05$ ). Samples processed using TUMB and INJ were similar ( $P > 0.05$ ) for flavor and WTP, and INJ, IPT, and TUMB samples were similar ( $P > 0.05$ ) for overall liking. Thus, consumers were willing to pay more for IPT than TUMB ( $P < 0.05$ ). Consumers scored CNT and TCNT lower for all palatability traits which resulted in lower WTP ( $P < 0.05$ ). Inclusion of a marinade improved the eating quality of samples compared to CNT and TCNT. The delivery method of the brine solution was less important to palatability as the presence of a marinade, as IPT, INJ, and TUMB were all similar ( $P > 0.05$ ) for overall liking. Injection plus tumbling improved tenderness, juiciness, and flavor liking scores over tumbling alone, but not over injection alone. Injection influenced consumer tenderness more than tumbling, but tumbling had greater effects on cooked moisture than injection. While IPT did not surpass either TUMB or INJ in all sensory categories, IPT does excel when considering moisture retention along with palatability.

**Keywords:** beef, consumer, enhancement, fajita, flank

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## Introduction

In recent years, multiple studies have explored the use of non-meat ingredients to enhance beef quality and sensory characteristics (Vote et al., 2000; Baublits et al., 2005a, 2006a; Hardcastle et al., 2018). In each of these studies, scientists have incorporated a polyphosphate, sodium chloride, and water solution into lower value beef cuts via injection. The inclusion of a phosphate and salt blend into beef can increase tenderness, juiciness, and overall liking compared to the untreated controls (Vote et al., 2000; Molina et al., 2005; Baublits et al., 2005a, 2006a, 2006b; Hardcastle et al., 2018). These studies exam-

ined enhancement of beef *longissimus dorsi*, muscles from the chuck (*complexus*, *serratus ventralis*, *splenius*, *subscapularis*, *supraspinatus*, *triceps brachii*), and beef *biceps femoris*, which gives rise for exploring the effects of enhancement on other beef muscles.

The beef *rectus abdominis* (flank steak) is a common beef cut utilized for Mexican fajitas or Asian stir-fry, which involves some sort of marinade or seasoning. In an assessment of palatability, chemical, and cooking properties, Jeremiah et al. (2003a, 2003b) found flank steaks from Canadian AA beef carcasses (equivalent to USDA Select) had overall palatability scores around a 4.5 on a 9-point scale as the overall tenderness was below average compared

to the 32 other muscles that were assessed. Moreover, flank steaks in that study had relatively low thaw-drip loss (2%) compared to other muscles in that study, and cooking loss near 25% (Jeremiah et al., 2003b). Fat and moisture content of the flank steak were approximately 6 and 73%, respectively. In this series of studies, no enhancement or seasoning were used and only trained panelists, as opposed to untrained or consumer panelists were used to assess eating quality. Although Huerta-Montauti et al. (2008) investigated processing techniques of several muscles for thin meat alternatives to the inside and outside skirt steaks for fajitas, no research has been done exploring the use of enhancement on flank steaks.

The use of processing equipment to alter the physical quality, palatability, and functionality of meat has been widely studied since the 1970s (Theno et al., 1978; Solomon et al., 1980; Tatum et al., 1982; Loucks et al., 1984; Wheeler et al., 1990; Vote et al., 2000; Pietrasik and Shand, 2004; Baublits et al., 2005a; Molina et al., 2005; Hardcastle et al., 2018). Ultimately, the objective of these studies was to identify the optimal combination and proportion of non-meat ingredients, the optimal time of processing, or the effect on different muscles; however, little research has been done strictly exploring how the 2 methods of needle injection and vacuum tumbling/massaging interact and differ. Nevertheless, Molina et al. (2005) found that different muscles from the chuck react differently depending on the action by which the ingredients were added (marinade, inject, vacuum tumble); however, no single method was superior across all muscles. While Molina et al. (2005) did look into the effects of different enhancement methods on shear force and sensory characteristics, they did not explore the effects of combining injection and tumbling or tumbling with the absence of a marinade. Therefore, the objective of this study was to determine if the enhancement method or methods for incorporating an enhancement solution, or the absence thereof, into beef *rectus abdominis* has an effect on composition and sensory characteristics.

## Materials and Methods

### *Product procurement and experimental design*

Beef flank steaks (*rectus abdominis*) were procured from a commercial beef packing plant and transported to the Texas Tech University Gordon W. Davis Meat Science Laboratory (Lubbock, TX), where they were processed at 10 d postmortem. USDA Select flanks ( $n = 100$ ; 20/treatment) were randomly assigned to 1 of

5 treatments: untreated control (Control, No Treatment; CNT), a vacuum tumbled control without marinade (Tumbled Control, No Treatment; TCNT), vacuum tumbled with marinade (TUMB), injected with marinade (INJ), and injected with marinade plus vacuum tumbled (IPT). In addition, USDA Choice flanks were utilized as an additional non-injected/non-tumbled sample ( $n = 20$ ) that served as a warm-up sample to orient panelists to the sample format. Excess fat and sinew were removed from the flanks prior to processing. Upon completion of processing, flanks were cut in half lengthwise parallel to the muscle fibers, with one-half being assigned to consumer sensory analysis and the other half being retained for laboratory analyses. Steaks were packaged using a rollstock packaging machine (Baseline F 100, Multivac, Wolfertshwenden, Germany) and a vacuum point of 8 mbars of pressure was reached. After packaging, steaks equilibrated for 24 h before being moved into frozen storage ( $-20^{\circ}\text{C}$ ), where they were held until further analyses. Samples for consumer testing were held in frozen storage for 15 to 18 d, and samples for objective analyses were held in frozen storage up to 70 d.

### *Sample processing*

Control flanks were untreated. After flanks were cut in half and labeled with identification, they were vacuum packaged. Tumbled control flanks were placed in a vacuum tumbler (Koch model LT-15; Koch Equipment LLC, Kansas City, MO) and a vacuum (508 mm Hg) was pulled. Flanks were batch tumbled at 10 RPM for 20 min. Tumbled flanks were enhanced with sodium chloride, NaCl, (Morton Salt Inc., Chicago, IL), sodium tripolyphosphate, STPP (Carfosel 408, Prayon Inc., Augusta, GA), and water. The brine was prepared in  $5^{\circ}\text{C}$  tap water with 4.16% NaCl and 3.33% STPP. For TUMB, brine was poured over the flanks in the vacuum tumbler for a target pickup of 112% ( $111.76\% \pm 1.86$ ) of fresh muscle weight. Flanks were then tumbled in the same manner as described for TCNT. Injected flanks were injected via a Schroeder Imax 350, multi-needle injector (Wolf-Tec, Kingston, NY), to a target pump rate of 112% ( $114.54 \pm 2.00$ ) of fresh muscle weight. Injection plus tumbled flanks were injected using the same process as INJ targeting 112% ( $112.94 \pm 1.38$ ) of fresh muscle weight and subsequently tumbled following the same process as described for TUMB and TCNT. No additional brine was added to the IPT flanks during the tumbling process.

## **pH and pickup percentage**

Prior to processing, pH values were recorded using a hand-held, probe-type pH meter (model WP-80, TPS Pty Ltd, Springwood, Brisbane, Australia). Additionally, green weight was recorded. Immediately after enhancement, flanks were weighed to determine pump weight. All flanks were held for 20 min and a final weight was recorded to determine brine loss. Pickup percentage was calculated by taking final weight divided by green weight, multiplied by 100. Lastly, final pH values were recorded after the 20-min hold period prior to packaging.

## **Consumer sensory evaluation**

The Texas Tech University Institutional Review Board approved procedures (#2017-598) for use of human subjects for consumer panel evaluation of meat sensory attributes.

Samples were thawed overnight at 2 to 4°C. A large commercial convection oven (Accu-Temp by Lang; Lang Manufacturing Company, Everett, WA) set at 205°C was used to cook all flanks on the day of testing using a staggered start time to accommodate slicing. Temperature of flank steaks was monitored using a digital, instant read ThermoPen thermometer (Model Mk4, ThermoWorks, American Fork, UT) until an internal temperature of 72°C was reached. Cook time ranged from 17.5 to 33.5 min, which likely resulted from oven placement and sample size variation. Flanks were rested for at least 3 min prior to slicing. Steaks were sliced perpendicular to the muscle fibers into strips that were 13 mm wide. Resulting strips were then cut in half lengthwise, resulting in strips that were approximately 50 mm long. Flank strips were transferred to pre-heated rectangular stainless steel pans, which were maintained in insulated water bath warming units (Model W-3Vi; American Permanent Ware Company; Dallas, TX) at ~60°C throughout the test session. Each warming unit held 9 pans. Flank strips were served to pre-determined consumers in a designated order. Each sample was served to 10 consumers throughout the testing session, with each consumer receiving 2 strips for evaluation. Total serving time was completed in 35 min.

Each panelist ( $n = 50/\text{night}$ ) was assigned to a numbered consumer booth and provided an iPad (Apple, Cupertino, CA) with a preloaded digital ballot, plastic utensils, toothpick, a napkin, an expectorant cup, a cup of water, and palate cleansers to use between samples (unsalted crackers and a 10% apple juice, 90% water solution). Prior to the start of each panel, panelists were given verbal instructions about the ballot and the procedure for the testing of samples and palate cleansing.

Panels were conducted in a large room under fluorescent lighting with tables that had been divided into individual sensory booths. Each panelist filled out a demographic questionnaire to characterize the participants.

Consumers ( $n = 200$ ) were asked to rate each sample for palatability attributes using digital ballots utilizing online survey software (Qualtrics, Seattle, WA). Sessions were conducted over 4 consecutive nights with 50 people participating each night. Palatability attributes were collected on line scales, 0 to 100, representing tenderness, juiciness, texture, flavor liking, saltiness, and overall liking. Zero represented extremely tough, extremely dry, much too soft, dislike extremely, not at all salty, and dislike extremely, and 100 represented extremely tender, extremely juicy, much too firm, like extremely, much too salty, and like extremely, respectively. An intermediate point (50) was labeled as neither tough nor tender, neither dry nor juicy, just about right, neither like nor dislike, just about right, and neither like nor dislike, for tenderness, juiciness, texture, flavor liking, saltiness, and overall liking, respectively. Consumers were asked to state whether the samples were acceptable or unacceptable for each palatability attribute, as well as how much they would be willing to pay for the sample if purchased at retail from \$0- \$40/lb (also on an anchored line scale).

## **Slice shear force analysis and cook loss determination**

Flanks were thawed and cooked as described above for consumer testing. After thawing and prior to cooking, anterior and posterior tips were removed from each steak for moisture percentage and water holding capacity analyses. Individual steaks were identified with numbered metal tags to maintain identification of treatment and flank number. Raw steaks were weighed prior to cooking, and cooked weight was recorded. Cook loss percentage was calculated by subtracting the cooked weight from the raw weight, dividing by the raw weight, and multiplying by 100. In addition, total cook time was recorded. Slice shear force was conducted using the modified procedure established by Shackelford and Wheeler (2009) for beef muscles other than the *longissimus* muscle. After steaks reached 72°C and were removed from the oven, steaks were rested for at least 3 min, cut perpendicular to the muscle fibers into 25-mm slices, rotated 180 degrees, and sliced to 12.5 mm pieces parallel to the muscle fibers. Slices were then sized down to 5-cm in length to fit in the flat, blunt blade attachment for the slice shear force machine (model DFS 500 N, Nextech, Sapansoong,

Bangkok). Flank slices were sheared perpendicular to the muscle fiber orientation at 500 mm/min per slice using the “hot” shear force protocol as described by Shackelford and Wheeler (2009) but adapted for this muscle. Three slices (anterior, middle, and posterior ends) were obtained from each flank, and the 3 values were averaged for statistical analysis. All remaining pieces that were not sheared were cubed and snap frozen in liquid nitrogen. Frozen and cubed samples were then homogenized in a food processor (Model Blixer 3 Series D, Robot Coupe, Ridgeland, MS), blended into an ultrafine powder, and transferred into a labeled Whirl-Pak bag (Nasco, Fort Atkinson, WI). Bags were stored in a freezer at  $-80^{\circ}\text{C}$  until subsequent analysis.

### Percent moisture

Moisture percentages were obtained for both raw and cooked samples. Raw moisture was conducted following the same homogenization procedure as described above for cooked samples. Both raw and cooked samples moisture percentages were obtained in accordance to an AOAC protocol (950.46; AOAC, 2006). Five grams ( $\pm 0.05$  g) of powdered sample were weighed into crucibles. The weight of each crucible and crucible plus sample weight were recorded. Samples were placed in a drying oven (Isotemp Oven, Thermo Fischer Scientific, Waltham, MA) at  $100^{\circ}\text{C}$  for 24 h. Upon completion of drying, crucibles were removed from the oven and placed into desiccators for 30 min to cool. Crucibles were then weighed to determine the percentage of moisture in each sample. Percent moisture was obtained by taking the difference of pre- and post-dried crucibles divided by pre-dried crucibles and multiplied by 100. Total moisture was calculated by taking sample weight and multiplying by percent moisture for water holding capacity determination.

### Water holding capacity

Water holding capacity of raw meat samples was performed through a modification of the methods set forth by Wierbicki and Deatherage (1958). Flank samples were hand minced and 1 g was weighed onto VWR 415 Filter paper (VWR International, Radnor, PA) that was previously stored in a desiccator overnight. The samples were then pressed between Plexiglas plates at  $35\text{ kgf/cm}^2$  (498 psi) using an Instron Universal Testing Machine (Model 5542, Instron Corp., Canton, MA) for 1 min and the area of the meat film and moisture area were traced. Meat film and moisture area were then recorded using a compensation digital planimeter (Planix

7, Sokkia Corp., Overland Park, KS). All samples and recordings were run in duplicate and averaged for statistical analysis. Percent free water was then calculated by incorporating the total moisture determined above (sample weight  $\times$  percent moisture) into the following equation obtained from Wierbicki and Deatherage (1958):

Percent Free Water =

$$\frac{(\text{Moisture surface area} - \text{Meat surface area}) \times 61.1}{\text{Total moisture}} \times 100$$

### Statistical analysis

Data were analyzed in SAS using PROC GLIMMIX (version 9.4, SAS Inst. Inc., Cary, NC). For all analyses, processing method was included as a fixed effect. Panelist nested within testing night was included as random effect for consumer analyses. Acceptability data for each palatability trait were analyzed with a binomial model using the same fixed and random effects. Cooking loss was included as a covariate for slice shear force (SSF;  $P = 0.01$ ). Treatment least squares means were separated with the PDIF option of SAS using a significance level of  $P \leq 0.05$ . The Kenward-Roger approximation was used for estimating denominator degrees of freedom for all analyses. The PROC FREQ of SAS was used to summarize consumer demographic information.

## Results and Discussion

### pH and pump percentage

Initial pH was similar ( $P > 0.05$ ) for all treatments as shown in Table 1. Samples processed via INJ and IPT resulted in the highest ( $P < 0.05$ ) final pH, followed by TUMB and CNT; however, CNT and TCNT samples did not differ ( $P > 0.05$ ). The change in pH from initial to final was greatest for INJ and IPT, intermediate for TUMB, and lowest for the non-enhanced samples, which did not change. We expected that pH would increase in the enhanced samples (INJ, IPT, and TUMB) due to the addition of salt and phosphate, which should increase the ionic strength (Puolanne et al., 2001; Baublits et al., 2005a). Ku et al. (2013) also observed differences in pH following injection, vacuum tumbling, or injection plus vacuum tumbling; however, injection plus vacuum tumbling yielded a greater pH than injection or vacuum tumbling alone, which were similar. Although there were slight differences in final pump



**Table 1.** The main effects of enhancement method on processing characteristics (pH, pump percentage, brine loss) of beef flank steaks ( $n = 100$ )<sup>1</sup>

Trait	Treatment					SEM <sup>2</sup>	P-value <sup>3</sup>
	CNT	TCNT	INJ	IPT	TUMB		
Initial pH	5.76	5.71	5.77	5.75	5.72	0.022	0.23
Final pH	5.76 <sup>bc</sup>	5.71 <sup>c</sup>	6.15 <sup>a</sup>	6.06 <sup>a</sup>	5.83 <sup>b</sup>	0.035	< 0.01
pH change	0.00 <sup>c</sup>	0.00 <sup>c</sup>	0.38 <sup>a</sup>	0.31 <sup>a</sup>	0.11 <sup>b</sup>	0.031	< 0.01
Green weight, kg	0.86 <sup>b</sup>	1.00 <sup>a</sup>	0.88 <sup>b</sup>	0.74 <sup>c</sup>	0.90 <sup>b</sup>	0.029	< 0.01
Pump weight, kg	–	1.00 <sup>a</sup>	1.00 <sup>a</sup>	0.85 <sup>b</sup>	1.00 <sup>a</sup>	0.032	< 0.01
Final weight, kg <sup>4</sup>	–	–	0.98 <sup>a</sup>	0.85 <sup>b</sup>	1.00 <sup>a</sup>	0.033	< 0.01
Initial pump, %	–	99.93 <sup>d</sup>	114.54 <sup>a</sup>	112.94 <sup>b</sup>	111.76 <sup>c</sup>	0.362	< 0.01
Final pump, %	–	–	111.90 <sup>ab</sup>	112.90 <sup>a</sup>	111.52 <sup>b</sup>	0.396	0.04
Brine loss, %	–	–	2.30 <sup>a</sup>	0.03 <sup>b</sup>	0.21 <sup>b</sup>	0.112	< 0.01

<sup>a-d</sup>Within a row, least squares means without a common superscript differ ( $P < 0.05$ ) due to enhancement method.

<sup>1</sup>USDA Select flanks: CNT, control, no treatment ( $n = 20$ ); TCNT, tumbled control, no treatment ( $n = 20$ ); INJ, injected with marinade ( $n = 20$ ); IPT, injected with marinade plus tumbled ( $n = 20$ ); TUMB, tumbled with marinade ( $n = 20$ ).

<sup>2</sup>Pooled (largest) SE of least squares means.

<sup>3</sup>Observed significance level for effects of enhancement method.

<sup>4</sup>Product weight after 20 min drip.

percentage between the enhanced samples in the current study (111.5 to 112.9%), we believe the difference in pH between TUMB and INJ/IPT would more likely be attributed to the timing and technique of the final pH measurement. Samples were only allowed to equilibrate for 20 min after enhancement. At this time, a majority of the buffering ingredients would have still resided at the exterior portion of the subprimal, especially for TUMB. Injection supports faster ingredient absorption time (Williams, 2012), which could explain the difference in pH between TUMB and INJ or IPT given pH was measured 20 min after processing. Although we did not evaluate pH using a benchtop device, we might have seen similar final pH between the enhanced samples using a homogenate sample as opposed to the pH of the internal muscle 20 min post-processing. Additionally, waiting 24 h for samples to more fully equilibrate might have also resulted in similar final pH values between the enhanced samples. Extending the holding time after marination of broiler meat from 4 to 8 h resulted in increased pH values (Gamage et al., 2017). Moreover, previous studies have shown additional marination or tumbling time increases the pH in pork and lamb (Gao et al., 2015; Vlahova-Vangelova et al., 2017).

Initial pump percentage for INJ was greatest ( $P < 0.05$ ), followed by IPT, TUMB, and TCNT, with a significant difference between each treatment, where  $INJ > IPT > TUMB > TCNT$ . Tumbled control samples were weighed after processing to ensure there was no change

**Table 2.** The main effects of enhancement method on moisture content, cook loss, and free water of beef flank steaks ( $n = 100$ )<sup>1</sup>

Trait	Treatment					SEM <sup>2</sup>	P-value <sup>3</sup>
	CNT	TCNT	INJ	IPT	TUMB		
Moisture (raw), %	71.83 <sup>c</sup>	72.19 <sup>c</sup>	73.96 <sup>b</sup>	74.48 <sup>ab</sup>	75.28 <sup>a</sup>	0.361	< 0.01
Moisture (cooked), %	58.47 <sup>b</sup>	58.84 <sup>b</sup>	61.61 <sup>a</sup>	62.86 <sup>a</sup>	62.45 <sup>a</sup>	0.572	< 0.01
Cook loss, %	26.38 <sup>b</sup>	29.76 <sup>a</sup>	25.04 <sup>b</sup>	26.70 <sup>b</sup>	24.54 <sup>b</sup>	1.095	< 0.01
Free water, % <sup>4</sup>	26.48	27.38	26.62	28.18	25.95	0.651	0.14

<sup>a-d</sup>Within a row, least squares means without a common superscript differ ( $P < 0.05$ ) due to enhancement method.

<sup>1</sup>USDA Select flanks: CNT, control, no treatment ( $n = 20$ ); TCNT, tumbled control, no treatment ( $n = 20$ ); INJ, injected with marinade ( $n = 20$ ); IPT, injected with marinade plus tumbled ( $n = 20$ ); TUMB, tumbled with marinade ( $n = 20$ ).

<sup>2</sup>Pooled (largest) SE of least squares means.

<sup>3</sup>Observed significance level for effects of enhancement method.

<sup>4</sup>Free water percentage calculated as a percent of total water.

in weight or loss of moisture, which there was not. The final pump percentages differed among enhanced samples, with IPT having a greater final pump percentage than TUMB ( $P < 0.05$ ), but INJ did not differ ( $P > 0.05$ ) from IPT or TUMB. Additionally, INJ resulted in greater ( $P < 0.05$ ) brine loss percentage compared to IPT and TUMB, which were similar ( $P > 0.05$ ). Tumbling provides a controlled environment to add precise amounts of added non-meat ingredients with maximum absorption (Williams, 2012), which would explain the better retention of TUMB and IPT compared to INJ.

### Water-holding capacity, cook loss, and moisture percentage

Results for cook loss percentage, cooked moisture percentage, raw moisture percentage, and water-holding capacity can be found in Table 2. Water-holding capacity, expressed as percent free water, did not differ ( $P > 0.05$ ) between treatments. These results differ from Baublits et al. (2005a), who found beef *biceps femoris* injected (112%) with a similar solution and concentration of NaCl and phosphate had significantly different water-holding capacity from the untreated control, despite similar results for raw moisture percentage between their study and the current study. Differences in the results between these 2 studies could be attributed to the muscles that were evaluated. According to Jeremiah et al. (2003b), the outside flat (*biceps femoris*) had greater thaw-drip and cooking losses, as well as lower fat and greater moisture content compared to the flank steak. Compositional differences between these 2 muscles could explain the alternative outcomes between the current results and those of Baublits et al. (2005a).

**Table 3.** Demographic characteristics of consumers ( $n = 200$ ) who participated in consumer sensory panels at Texas Tech University, Lubbock, TX

Characteristic	Response	% of consumers	
Age group	< 20	12.5	
	20 to 29	16.5	
	30 to 39	27.0	
	40 to 49	24.5	
	50 to 59	12.0	
	> 60	7.5	
Gender	Male	42.5	
	Female	57.5	
Occupation	Tradesperson	10.0	
	Professional	20.5	
	Administration	13.5	
	Sales and service	13.5	
	Laborer	9.0	
	Homemaker	5.5	
	Student	19.5	
	Unemployed/retired	8.5	
	Ethnic origin	African-American	14.0
		Asian	0
Caucasian/White		35.5	
Hispanic		45.0	
Native American		0.0	
Household size (adults)	Mixed race	2.0	
	Other	3.5	
	1	12.0	
	2	55.5	
	3	13.5	
	4	12.5	
	5	4.5	
	6	1.5	
> 6	0.5		
Household size (children)	0	39.0	
	1	11.5	
	2	26.5	
	3	17.5	
	4	3.0	
	5	2.0	
	6	0.5	
> 6	0		
Annual household income	< \$20,000	18.0	
	\$20,000-\$50,000	30.5	
	\$50,001-\$75,000	24.5	
	\$75,001-\$100,000	13.0	
	> \$100,000	14.0	
Level of education	Non-high school graduate	8.5	
	High school graduate	28.0	
	Some college/technical school	36.5	
	College graduate	22.0	
	Post-college graduate	5.0	

**Continued****Table 3.** (cont.)

Beef consumption	Daily	19.5
	4 to 5 times a week	30.5
	2 to 3 times a week	32.5
	Weekly	12.5
	Every other week	1.5
	Monthly	2.5
Preferred beef degree of doneness	Never	1.0
	Blue	0
	Rare	2.5
	Medium-rare	28.5
	Medium	24.5
	Medium-well	24.5
	Well-done	20.0

In the current study, raw moisture percentages were greater ( $P < 0.05$ ) for enhanced treatments, with TUMB resulting in a greater percentage than INJ. Similar results were observed for cooked moisture, with INJ, IPT, and TUMB having a greater cooked moisture percentage than TCNT and CNT. Cook loss was also influenced ( $P < 0.05$ ) by treatment, as TCNT had greater ( $P < 0.05$ ) cook loss percentage than all other treatments, which were similar ( $P > 0.05$ ).

### Consumer demographics

The demographic information of consumers who participated in this study is presented in Table 3. The panel consisted of slightly more females (57.5%) than males (42.5%) which is somewhat higher than the national female to male ratio (US Census Bureau, 2017). In addition, the majority of participants were 30 to 49 yr old (51.5%), with participants under 30 yr old representing 29%. This percentage could be in part to the 19.5% of consumers occupied as students. Otherwise, 66.5% of participants had full-time employment outside of the home. The majority of consumers had an annual household income between \$20,000 and \$75,000. Furthermore, the majority of consumers lived in a household consisting of 2 adults (55.5%) and no children (39%). The level of education with the highest proportion of participants was for “some college/technical school” (36.5%). Additionally, the majority of consumers ate beef at least twice per week (82.5%), while a split proportion preferred medium-rare (28.5%), medium (24.5%), medium-well (24.5%), and well-done (20%) degree of doneness when consuming beef. Lastly, the ethnic origin was predominantly Hispanic (45%) and Caucasian/White (35.5%).

**Table 4.** The main effects of enhancement method on slice shear force and consumer scores ( $n = 200$ ) for tenderness, juiciness, texture, flavor liking, saltiness, overall liking, and willingness to pay of beef flank steaks<sup>1</sup>

Trait	Treatment					SEM <sup>2</sup>	P-value <sup>3</sup>
	CNT	TCNT	INJ	IPT	TUMB		
SSF, kg	26.78 <sup>a</sup>	26.29 <sup>a</sup>	18.85 <sup>bc</sup>	18.41 <sup>c</sup>	20.66 <sup>b</sup>	0.79	< 0.01
Tenderness <sup>4</sup>	45.56 <sup>c</sup>	47.06 <sup>c</sup>	67.22 <sup>a</sup>	68.56 <sup>a</sup>	61.87 <sup>b</sup>	1.67	< 0.01
Juiciness <sup>4</sup>	50.77 <sup>c</sup>	52.19 <sup>c</sup>	67.55 <sup>ab</sup>	70.82 <sup>a</sup>	65.60 <sup>b</sup>	1.50	< 0.01
Texture <sup>4</sup>	58.44 <sup>ab</sup>	60.70 <sup>a</sup>	54.13 <sup>c</sup>	56.19 <sup>bc</sup>	58.26 <sup>ab</sup>	1.10	< 0.01
Flavor liking <sup>4</sup>	47.93 <sup>c</sup>	49.38 <sup>c</sup>	69.19 <sup>ab</sup>	70.84 <sup>a</sup>	66.79 <sup>b</sup>	1.55	< 0.01
Saltiness <sup>4</sup>	32.09 <sup>b</sup>	32.55 <sup>b</sup>	45.70 <sup>a</sup>	48.13 <sup>a</sup>	45.81 <sup>a</sup>	1.40	< 0.01
Overall liking <sup>4</sup>	47.80 <sup>b</sup>	48.15 <sup>b</sup>	69.95 <sup>a</sup>	70.33 <sup>a</sup>	67.83 <sup>a</sup>	1.60	< 0.01
WTP <sup>5</sup>	5.72 <sup>c</sup>	5.33 <sup>c</sup>	8.79 <sup>ab</sup>	9.65 <sup>a</sup>	8.43 <sup>b</sup>	0.46	< 0.01

<sup>a-d</sup>Within a row, least squares means without a common superscript differ ( $P < 0.05$ ) due to enhancement method.

<sup>1</sup>USDA Select flanks: CNT, control, no treatment ( $n = 20$ ); TCNT, tumbled control, no treatment ( $n = 20$ ); INJ, injected with marinade ( $n = 20$ ); IPT, injected with marinade plus tumbled ( $n = 20$ ); TUMB, tumbled with marinade ( $n = 20$ ).

<sup>2</sup>Pooled (largest) SE of least squares means.

<sup>3</sup>Observed significance level for effects of enhancement method.

<sup>4</sup>Line scale: 0 = extremely tough, extremely dry, much too soft, not salty at all, and dislike extremely of flavor and overall; 100 = extremely tender, extremely juicy, much to firm, much too salty, and like extremely for flavor and over; 50 = neither tough nor tender, neither dry nor juicy, just about right for texture and saltiness, and neither like nor dislike for flavor and overall.

<sup>5</sup>Consumer willingness to pay recorded on an anchored line scale in \$/lb, range = \$0/lb to \$40/lb.

### Slice shear force and consumer sensory

Enhancement technique influenced SSF ( $P < 0.01$ ; Table 4). Samples subjected to enhancement (INJ, IPT, and TUMB) had lower ( $P < 0.05$ ) shear force values than TCNT and CNT, which were similar ( $P > 0.05$ ). Among the enhanced samples, IPT had a lower ( $P < 0.05$ ) shear force value than TUMB; however, INJ did

not differ from IPT or TUMB ( $P > 0.05$ ). The lower shear force values of IPT compared to TUMB could be attributed to the disruption of the muscle fibers from needle penetration during the injection process (Jeremiah et al., 1999). Although INJ and TUMB were similar, the SSF value of INJ was numerically lower compared to TUMB. This would also align with tenderness scores, where IPT and INJ were scored more tender by consumers than TUMB.

As seen in Table 4, enhancement strategy influenced ( $P < 0.01$ ) consumer tenderness, juiciness, texture, flavor liking, saltiness, and overall liking. Samples processed using INJ and IPT were more tender ( $P < 0.05$ ) than all other treatments, while CNT and TCNT were less tender ( $P < 0.05$ ) than all other treatments. Enhanced flanks were more tender than non-enhanced flanks, regardless of the delivery method of enhancement (injection, tumbling, or combination), which is in agreement with previous research (Vote et al., 2000; Baublits et al., 2005b, 2006b; Rose et al., 2010; Hardcastle et al., 2018) for enhanced beef. In addition, a higher percentage ( $P < 0.05$ ) of consumers found enhanced flanks had acceptable tenderness (Table 5). Tenderness acceptability percentage was similar ( $P > 0.05$ ) and greater ( $P < 0.05$ ) for INJ, IPT, and TUMB than CNT or TCNT, which were also similar ( $P > 0.05$ ).

Consumers scored non-enhanced flanks (CNT and TCNT) as less juicy ( $P < 0.05$ ) than enhanced flanks. Samples subjected to IPT were juicier ( $P < 0.05$ ) than all other treatments, except INJ; however, INJ and TUMB were also similar ( $P > 0.05$ ). Increased juiciness can be attributed to enhancement through the decrease in free water as a result of increased pH and water binding ability (Baublits et al., 2006b). Theoretically, this decrease in free water results in less water loss during the cooking process, promoting moisture retention and improved

**Table 5.** The main effects of enhancement method on the proportion of consumers ( $n = 200$ ) that classified tenderness, juiciness, texture, flavor liking, saltiness, and overall liking of beef flank steaks as acceptable<sup>1</sup>

Trait	Treatment					SEM <sup>2</sup>	P-value <sup>3</sup>
	CNT	TCNT	INJ	IPT	TUMB		
Tenderness acceptability, %	69.08 <sup>b</sup>	67.55 <sup>b</sup>	93.40 <sup>a</sup>	93.40 <sup>a</sup>	90.99 <sup>a</sup>	3.55	< 0.01
Juiciness acceptability, %	73.36 <sup>c</sup>	74.89 <sup>c</sup>	94.82 <sup>ab</sup>	97.20 <sup>a</sup>	91.92 <sup>b</sup>	3.38	< 0.01
Texture acceptability, %	75.21 <sup>b</sup>	78.76 <sup>b</sup>	93.51 <sup>a</sup>	94.46 <sup>a</sup>	92.56 <sup>a</sup>	3.29	< 0.01
Flavor acceptability, %	71.67 <sup>b</sup>	73.70 <sup>b</sup>	93.45 <sup>a</sup>	93.93 <sup>a</sup>	93.45 <sup>a</sup>	3.42	< 0.01
Saltiness acceptability, %	64.88 <sup>c</sup>	67.73 <sup>c</sup>	94.28 <sup>a</sup>	93.43 <sup>ab</sup>	88.43 <sup>b</sup>	4.15	< 0.01
Overall acceptability, %	68.60 <sup>b</sup>	71.68 <sup>b</sup>	92.07 <sup>a</sup>	94.44 <sup>a</sup>	91.11 <sup>a</sup>	3.57	< 0.01

<sup>a-c</sup>Within a row, least squares means without a common superscript differ ( $P < 0.05$ ) due to enhancement method.

<sup>1</sup>USDA Select flanks: CNT, control, no treatment ( $n = 20$ ); TCNT, tumbled control, no treatment ( $n = 20$ ); INJ, injected with marinade ( $n = 20$ ); IPT, injected with marinade plus tumbled ( $n = 20$ ); TUMB, tumbled with marinade ( $n = 20$ ).

<sup>2</sup>Pooled (largest) SE of least squares means.

<sup>3</sup>Observed significance level for effects of enhancement method.

juiciness during consumption. However, despite a lack of difference in percent free water in the current study between non-enhanced and enhanced samples, enhancement still improved juiciness. Our results did show that cooked moisture percentage was greater in enhanced than non-enhanced samples, which could explain why consumers scored those samples as juicier. In addition, enhanced product, regardless of high cooking temperatures can sustain juiciness as explained by Vote et al. (2000), scoring greater than non-enhanced beef at lesser degrees of doneness. Following similar trends to juiciness ratings, a greater proportion of consumers found juiciness acceptable for IPT and INJ than the non-enhanced samples ( $P < 0.05$ ); however, INJ and TUMB had similar ( $P > 0.05$ ) juiciness acceptability (Table 5).

Consumers scored texture using “Just about right” scales, where 50 was “Just about right”. Scores above 50 indicated firmer texture, and scores below 50 suggested softer texture. As seen in Table 4, INJ and IPT samples had the lowest texture scores, which were closest to 50, suggesting consumers found the texture most suitable for these samples compared to the other treatments ( $P < 0.05$ ). However, IPT had similar texture ( $P > 0.05$ ) to TUMB and CNT. As seen in Table 5, IPT, INJ, and TUMB had similar and greater ( $P < 0.05$ ) texture acceptability than TCNT or CNT, which were also similar ( $P > 0.05$ ).

Consumers scored IPT greater ( $P < 0.05$ ) than TUMB for flavor liking, yet there was no difference ( $P > 0.05$ ) between INJ and IPT, or between INJ and TUMB. Both control samples (TCNT and CNT) were scored lower ( $P < 0.05$ ) than all other treatments for flavor liking. These findings are supported by multiple studies that found enhanced beef was scored with more beefy flavor than untreated controls (Papadopoulos et al., 1991; Vote et al., 2000; Stetzer et al., 2008; Hardcastle et al., 2018). Sutton et al. (1997) found enhanced pork loins exhibited an alkaline or soapy flavor, which contradicts the findings of Vote et al. (2000), who reported that enhanced beef exhibited less of a soapy flavor than non-enhanced beef. While consumers in the current study were not asked to identify off-flavors, such as alkaline or soapy, enhancement improved ( $P < 0.05$ ) flavor acceptability compared to CNT and TCNT in the current study (Table 5).

Vote et al. (2000) further explained that beef enhanced with sodium chloride was scored as more salty than untreated controls. In our study we found that consumers scored enhanced flanks closer ( $P < 0.05$ ) to ideal saltiness than non-enhanced flanks; however, no treatment exhibited means of overly salty. Consumers scored saltiness using “Just about right” scales, where 50 was

“Just about right”. Scores above 50 indicated samples were too salty, and scores below 50 suggested samples were not salty enough. There was no difference ( $P > 0.05$ ) in saltiness between INJ, IPT, or TUMB. While NaCl percentages were similar in this study to that of Vote et al. (2000), consumers in the current study did not believe the enhanced steaks were ever too salty. As seen in Table 5, saltiness acceptability was greater ( $P < 0.05$ ) for INJ and IPT compared to all other treatments; however, IPT was similar to TUMB ( $P > 0.05$ ). Huerta-Montauti et al. (2008) evaluated several muscles from the beef carcass in combination with marination and blade tenderization to find suitable alternatives to the inside and outside skirt for beef fajita options. Their papain treatment was delivered via a brine solution that contained 6.5% salt and 3.5% STPP, which has a greater salt concentration than the current study. Those authors found that papain treatments (with or without blade tenderization) were scored with greater flavor and salt intensity and also tended to have less undesirable flavors according to consumers (Huerta-Montauti et al., 2008).

Similar to previously reported palatability traits, consumers liked enhanced flanks more overall ( $P < 0.05$ ) than non-enhanced flanks (Table 4). All samples involving enhancement (INJ, IPT, and TUMB) had similar overall liking according to consumers ( $P > 0.05$ ). Moreover, overall acceptability percentages were greater ( $P < 0.05$ ) for IPT, INJ, and TUMB than CNT and TCNT (Table 5). Similar to these results, Vote et al. (2000) found enhanced beef strip steaks had greater overall liking than non-enhanced controls. This can be attributed to the increased palatability of tenderness and juiciness of enhanced beef, even when cooked to a high degree of doneness (77°C).

Consumers were willing to pay more ( $P < 0.05$ ) for enhanced flanks than non-enhanced flanks (Table 4). Consumers were willing to pay more for IPT than TUMB, but no differences for WTP were observed between INJ and IPT or between INJ and TUMB ( $P > 0.05$ ). Likewise, Huerta-Montauti et al. (2008) found consumers were more likely to purchase various muscles that were treated with papain or papain plus blade tenderization delivered via a brine solution, as opposed to muscles that were not treated or were only blade tenderized. Hardcastle et al. (2018) also found consumers were willing to pay more for enhanced strip loin steaks compared to their non-enhanced counterparts for a variety of experimental beef finishing diets. Consumers consistently scored enhanced samples more favorably than non-enhanced samples for the various palatability traits in the current study, which ultimately led to greater overall liking and acceptability. Garmyn and Miller



(2019) showed consumers are willing to pay more for beef as their perception of the eating quality is elevated from good to premium quality. Since consumers in the current study liked the enhanced samples more than non-enhanced samples, it is not surprising they were also willing to pay more for those products that they perceived to have a greater overall eating quality.

## Conclusion

The results from this study indicated that enhancement method can influence composition and consumer sensory characteristics of beef *rectus abdominis*. Ultimately, enhanced samples were consistently scored more favorably across all sensory traits. In addition, the combination of injection and tumbling accumulated the greatest overall improvement to palatability and moisture retention. While IPT did not supersede either TUMB or INJ in all sensory categories, IPT exhibited superior moisture retention. These results provide opportunities for the beef industry to utilize a combination of both enhancement methods to achieve increased yields, improved palatability, and add value to lower valued beef cuts.

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