Meat and Muscle Biology™

Maceration Frequency Impacts *Semitendinosus* and *Biceps femoris* Surface Area, Cooking Loss, and Palatability Outcomes

Kade E. Lawrence[1], Megan E. Eckhardt[2], Loni W. Lucherk[2], and Ty E. Lawrence[2]*

[1]Canyon FFA, Canyon High School, Canyon, TX 79015, USA
[2]Department of Agricultural Sciences, West Texas A&M University, Canyon, TX 79016, USA
*Corresponding author. Email: tlawrence@wtamu.edu (Ty E. Lawrence)

Abstract: We examined the effect of maceration frequency on surface area, purge loss, and palatability of eye of round and bottom round steaks. Beef eye of round ($n = 12$) was cut into 8 steaks each and randomly assigned to 0, 1, 2, or 3 macerations and uncooked or cooked slice shear force (SSF) tenderness determinations. Bottom round muscles ($n = 12$) were cut into 12 steaks and randomly assigned to 0, 1, 2, or 3 macerations and uncooked or cooked SSF or trained sensory evaluations. Steaks were trimmed to a common size (50 cm^2 for eye of round and 80 cm^2 for bottom round) prior to maceration with a commercial steak tenderizer. Data were analyzed via mixed ANOVA models using a randomized complete block design. Surface area increased ($P < 0.001$) by 15.4%, 38.6%, and 62.4% for eye of round steaks and 22.0%, 51.3%, and 70.3% for bottom round steaks after 1, 2, or 3 macerations, respectively. Purge losses did not differ ($P \geq 0.247$) for either muscle due to maceration frequency. Uncooked SSF values for eye of round steaks were decreased ($P < 0.001$) by 6.6%, 19.5%, and 40.0% after 1, 2, and 3 macerations; however, cooked SSF values did not differ ($P = 0.077$). For bottom round steaks, uncooked SSF values were decreased ($P < 0.001$) by 32.0%, 45.5%, and 67.2% after 1, 2, and 3 macerations; cooked SSF values for steaks macerated 3 times were 26.6% lower ($P = 0.022$) than steaks macerated 0, 1, or 2 times. Cooking losses were greater ($P < 0.001$) for macerated eye of round (5.4% to 7.2%) and bottom round steaks (7.6% to 10.8%). Maceration decreased ($P < 0.001$) sensory juiciness and connective tissue ratings and increased ($P < 0.001$) sensory tenderness ratings. Maceration increased surface area and improved tenderness.

Key words: biceps femoris, maceration, semitendinosus, sensory, surface area, tenderness
Meat and Muscle Biology 8(1): 17710, 1–7 (2024) **doi:10.22175/mmb.17710**
Submitted 5 February 2024 Accepted 15 March 2024

Introduction

Tenderness, juiciness, and flavor are widely considered the 3 main factors affecting palatability of steaks (O'Quinn et al., 2018), leading to overall consumer satisfaction. The practice of tenderizing meat through mechanical means, such as pounding, dates back to ancient times (Arroyo and de la Torre, 2016). Early humans used stone mortars to pound fresh and dried meat, likely offering a more appealing option than completely intact meat that required greater jaw strength (Schroth, 1996). Throughout more recent history, humans have utilized various tools, such as mallets or soda bottles, to tenderize meat (Daly-Koziel and Walters, 2006; Weaver, 2010; Duran and Ardic, 2014). Mechanical tenderization is often accomplished via blade tenderization (Savell et al., 1977; Seideman et al., 1977, 1986) or maceration (Maddock, 2008). Blade or needle tenderization uses rows of needles or blades to pierce through and cut muscle and connective tissue. Maceration is typically used to transform tougher cuts into *cubed* or *tenderized* steaks (Maddock, 2008) that are often marketed as "minute" (Yang et al., 2017), "Swiss" (Maddock, 2008), or "chicken-fried steaks" (Weaver, 2010). Maceration utilizes sharp rotating blades to slice

uncooked muscle from both sides simultaneously, leading to dramatically increased surface area (Maddock, 2008). Prior research has suggested that when macerating meat, tenderness can be improved (Recio et al., 1988; Divakar et al., 2019); however, maceration frequency and resulting changes in surface area and tenderness as a result of mechanical maceration do not appear in the published literature. Increasing surface area typically results in a loss of water-holding capacity and greater purge losses (Huff-Lonergan and Sosnicki, 2002), which in turn decreases juiciness, tenderness, and overall palatability. Thus, the objective of this experiment was to determine the effects of mechanical maceration frequency upon surface area, purge loss, and tenderness of eye of round and bottom round steaks.

Materials and Methods

Because muscle samples for this study were acquired postmortem and no live animals were used in this study, Institutional Animal Care and Use Committee approval was not necessary.

Muscle source and steak preparation

Twelve eye of round (*M. semitendinosus*) and 12 bottom round (*M. biceps femoris*) muscles were sourced from fed beef harvested at Caviness Beef Packers (USDA Establishment 675; Hereford, TX). Vacuum-packaged muscles were shipped in a refrigerated trailer to the Caviness Meat Science and Innovation Center at West Texas A&M University (USDA Establishment 7124; Canyon, TX) and held until 14 d postmortem at 2.2°C prior to beginning experimental methods. Individual muscles were sliced into steaks, 25 mm thick, using an auto-slicing and portion cutter (TREIF, model LION F, Oberlahr, Germany). Eye of round steaks were trimmed into squares (Figure 1; 0 maceration) approximately 50 cm^2, whereas bottom round steaks were trimmed to approximately 80 cm^2 to achieve a consistent area and mass between muscles. Steaks were weighed (±1 g; Yamato Corporation, model PPC-300WP, Mequon, WI) to determine initial weight.

Treatment randomization and application

Eight steaks per eye of round muscle were randomly allocated, each to 1 of 4 treatments (0, 1, 2, or 3 macerations) and uncooked or cooked slice shear force (SSF) using a one-way treatment structure. Twelve steaks per bottom round muscle were randomly allocated, each to 1 of 4 treatments (0, 1, 2, or 3 macerations) and uncooked or cooked SSF or sensory palatability evaluation using a one-way treatment structure. Maceration treatments were applied using a commercial macerator (Sir Steak Machinery, Inc., model PRO-9, Mansfield, OH). For steaks receiving 2 passes through the macerator, the second pass was perpendicular to the first. For steaks receiving 3 passes through the macerator, the second and third passes were approximately 120° clockwise from the preceding pass. Steaks were then placed onto a calibrated grid surface and digitally imaged for surface area determination, reweighed, and then packaged in vacuum pouches (19 × 23 cm, UltraSource, Kansas City, MO) and sealed using a vacuum sealer (Ultravac, model UV2100, UltraSource). Eye of round steaks were aged until 28 d postmortem in a cooler at 2.2°C prior to uncooked and cooked SSF. Bottom round steaks were aged in a cooler at 2.2°C until 28 d postmortem and then frozen (−26.1°C).

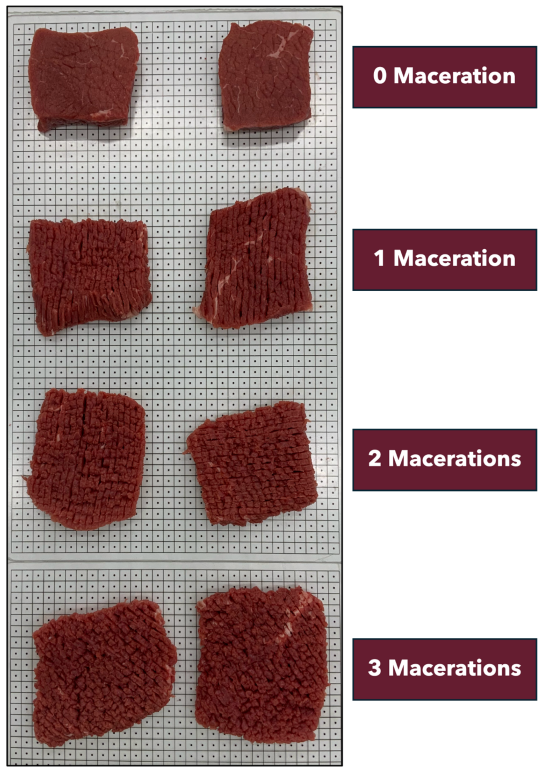

Figure 1. Surface area change of *semitendinosus* steaks macerated 0, 1, 2, or 3 times.

Surface area measurement

Each set of 8 steaks per muscle were imaged together. Digital JPEG images were evaluated with image analysis software (ImageJ, National Institutes of Health, Bethesda, MD) to objectively quantify

surface area of each individual steak. Each image was calibrated by measuring the length of 4 centrally located squares (3.2 cm) on the dot-grid to ensure accuracy of measurements across images. The perimeter of each steak was manually traced; the program compared the tracing to the calibration to determine surface area.

Uncooked slice shear force determination

Eye of round steaks were removed from their vacuum pouches, had surface moisture removed with absorbent cloths, and were weighed to establish purge losses. Two slice samples (20 × 50 mm) were hand-cut using the SSF sizing box (part no. ZB-150, Tallgrass Solutions Inc., Manhattan, KS). Slices were then sheared using an Instron (model 5944, Norwood, MA) equipped with a 2 kN load cell operating at a crosshead speed of 500 mm/min, with an SSF device attached; peak force (kg) to slice through each sample was recorded and the 2 values were averaged. Bottom round steaks followed the same procedure as eye of round steaks after thawing for 24 h at 2.2°C.

Cooked slice shear force determination

Eye of round steaks were removed from their vacuum pouches, had surface moisture removed with absorbent cloths, and were weighed to establish purge losses and precooked weight. Thermocouple wires (copper-constantan, Type T, Omega Engineering, Stamford, VT) were inserted into the geometric center of each uncooked steak. Temperature was monitored via a 10-channel benchtop thermometer (Omega Engineering, model MDSSi8-TC). Steaks were then placed into a forced-air convection oven (Blodgett, model DFG-100-3, G.S. Blodgett Co., Burlington, VT), where they were cooked at 177°C and removed to reach a target 71°C endpoint temperature. Steaks were allowed to cool and drip for 5 min, then reweighed to establish cooked weight. Cooked steak samples for SSF were obtained using the same procedure used for uncooked SSF samples. Bottom round steaks followed the same procedure as eye of round steaks after thawing for 24 h at 2.2°C.

Trained sensory panel evaluation

Procedures for sensory analysis were approved by the Institutional Review Board (WTAMU IRB#2023.05.006). Panelists were trained according to the American Meat Science Association Research Guidelines (AMSA, 2015) and were required to attend 3 trainings prior to sensory evaluations. Bottom round steaks were removed from frozen storage (−28.9°C) and placed in a 2.2°C cooler for 24 h to thaw. For each panel, a striploin steak (*M. longissimus dorsi*) and eye of round steak (*M. semitendinosus*), each 2.54 cm in thickness, were cooked to 71°C and 77°C, respectively, in a forced-air convection oven set at 177°C. These steaks were sliced into small 1 cm^3 samples and served to 6 to 8 trained panelists to set anchor tenderness and juiciness values. The striploin steak anchor represented a tenderness rating of 55 and a juiciness rating of 50, whereas the eye of round steak anchor represented a tenderness rating of 30. Simultaneously, bottom round steaks were removed from their vacuum packages, inserted with thermocouple wires, and cooked in the same manner as previously stated for cooked SSF determinations. Steaks were removed from the oven at 71°C and cut into 1 cm^3 samples. Panelists were provided reverse osmosis softened water, apple slices as a palate refresher, and unsalted crackers as palate cleansers; panelists were instructed to rinse with water between samples and after use of palate refreshers/cleansers. Panelists were served 8 samples per session for 2 sessions per day over a 3 d period. Samples were rated for 4 factors (initial juiciness, sustained juiciness, overall tenderness, and connective tissue) on a scale from 0 to 100 (0 = none; 100 = strong), with a midpoint anchor (50 = moderate) on electronic tablets (iPad, Air2, Apple Inc., Cupertino, CA) using electronic surveys (Qualtrics, Provo, UT).

Statistical analysis

For each muscle, the one-way treatment structure was utilized within a randomized complete block experimental design structure. An individual roast (eye of round or bottom round) represented a block; 8 or 12 subsamples (steaks) were cut per block—1 of 4 treatments (0, 1, 2, or 3 passes through the macerator) was applied to an individual subsample. Within each complete block, treatments were applied to 2 eye of round steaks and 3 bottom round steaks and then randomly assigned to uncooked SSF, cooked SSF, or trained sensory evaluation (bottom round only). Data were analyzed by analysis of variance with the MIXED procedure of SAS (SAS v. 9.4, Cary, NC). The fixed effect was maceration treatment frequency, and the random effect was the block. Eye of round and bottom round muscles were analyzed independently. Means were generated via the LSMEANS statement and separated when significant ($\alpha = 0.05$) using the PDIFF statement.

Results and Discussion

Surface area

Initial weights ($P \geq 0.290$) and post-maceration ($P \geq 0.290$) weights did not differ between treatments for eye of round or bottom round steaks (Table 1). Surface area of eye of round steaks increased ($P < 0.001$) from 50.8 cm^2 for non-macerated steaks to 58.6 cm^2, 70.4 cm^2, and 82.5 cm^2 for steaks macerated 1, 2, or 3 times, respectively. Likewise, surface area of macerated bottom round steaks increased ($P < 0.001$) from 83.6 cm^2 for steaks macerated 0 times to 102.0 cm^2, 126.5 cm^2, and 142.4 cm^2 after 1, 2, and 3 passes through the macerator, respectively.

Minimal previous research has documented the change in surface area concomitant with maceration of muscle tissue. These data illustrate the dramatic increase in surface area of approximately 15% to 22%, 39% to 51%, and 62% to 70% that occurs after beef round muscles are macerated 1, 2, or 3 times. In agreement with the current study, Ahrens (2012) indicated that steaks passed through a tenderizer multiple times were thinner and had a larger surface area. The increased surface area resulting from maceration will allow for more batter and breading pickup in the manufacture of "chicken-fried" steaks and will likely improve the palatability and sensory experience of such. The range in surface area change between the muscles is likely due to the notable difference in elastin content; *semitendinosus* contains 15-fold more elastin than *biceps femoris* (Bendall, 1967). Elastin was more likely to stretch and less likely to be cut during maceration and likely muted surface area expansion of eye of round steaks.

Purge loss and cooking losses

Vacuum-packaged steaks were aged after maceration and prior to uncooked or cooked SSF analysis. During the aging period, eye of round steaks lost 4.25% to 4.86% of their weight as purge, but purge losses did not differ ($P = 0.247$) as a result of maceration frequency (Table 1). Similarly, bottom round steaks lost 5.88% to 6.19% of their weight as purge during the aging procedure, but purge losses were not different ($P = 0.834$) based on maceration treatment. In addition to purge losses during storage, cooking also results in notable moisture and fat losses. Cooking losses (Table 2) for macerated eye of round steaks ranged from 26.0% to 27.8% and were greater ($P < 0.001$) than non-macerated steaks (20.6%). Likewise, bottom round steak cooking losses were increased ($P < 0.001$) from 20.1% for non-macerated steaks to 27.7% to 30.9% for steaks macerated 1, 2, or 3 times.

Data from the current experiment suggest that purge losses resulting from maceration are not different from purge losses of intact steaks. Ahrens (2012) also reported no difference in purge losses of round muscles macerated up to 3 times. This outcome is further supported by the results of Divakar et al. (2019) that previously reported drip loss did not differ related to buffalo muscle tissue maceration. Cooking losses in

Table 1. Outcomes of maceration frequency treatment on steak weight, surface area, purge loss, and uncooked objective tenderness of eye of round and bottom round steaks

	Maceration treatment					
	0 maceration	1 maceration	2 macerations	3 macerations	SEM	*P* value
Eye of round						
Initial weight, g	97.4	97.5	99.4	96.0	1.57	0.311
Post-maceration weight, g	97.3	97.3	99.0	95.5	1.55	0.290
Surface area, cm^2	50.8^{d}	58.6^{c}	70.4^{b}	82.5^{a}	1.95	<0.001
Purge loss, %	4.86	4.72	4.25	4.44	0.39	0.247
Uncooked SSF,[1] kg	55.3^{a}	51.6^{ab}	44.5^{b}	33.2^{c}	4.24	<0.001
Bottom round						
Initial weight, g	143.4	139.4	146.2	143.5	2.68	0.290
Post-maceration weight, g	143.3	138.9	145.5	143.2	3.10	0.301
Surface area, cm^2	83.6^{d}	102.0^{c}	126.5^{b}	142.4^{a}	1.60	<0.001
Purge loss, %	5.89	6.00	6.19	5.88	0.32	0.834
Uncooked SSF,[1] kg	71.0^{a}	48.3^{b}	38.7^{b}	23.3^{c}	4.23	<0.001

SEM = standard error of the mean.

[a–d]Means within a row without a common superscript differ ($P < 0.05$).

[1]Sliced shear force.

Table 2. Outcomes of maceration frequency treatment on cooking time, cooking loss, and cooked objective tenderness of eye of round and sensory evaluation[1] of bottom round steaks

	Maceration treatment					
	0 maceration	1 maceration	2 macerations	3 macerations	SEM	*P* value
Eye of round						
Cooking time, min	14.9	15.4	13.8	13.1	0.94	0.080
Cooking loss, %	20.6[b]	26.8[a]	26.0[a]	27.8[a]	1.36	<0.001
Cooked SSF,[2] kg	18.7	20.9	21.3	19.7	1.02	0.077
Bottom round						
Cooking time, min	14.6[a]	13.1[ab]	12.4[ab]	10.4[b]	0.99	0.042
Cooking loss, %	20.1[b]	27.7[a]	30.9[a]	28.2[a]	1.16	<0.001
Cooked SSF,[2] kg	29.7[a]	27.1[a]	27.7[a]	20.7[b]	2.04	0.022
Initial juiciness	54.9[a]	46.1[b]	42.7[b]	47.2[b]	2.90	<0.001
Sustained juiciness	51.1[a]	42.1[b]	37.3[b]	43.2[b]	3.09	<0.001
Overall tenderness	42.7[b]	53.6[a]	52.3[a]	56.8[a]	3.10	<0.001
Connective tissue amount	20.9[a]	11.6[b]	13.3[b]	11.9[b]	1.60	<0.001

SEM = standard error of the mean.

[a,b]Means within a row without a common superscript differ ($P < 0.05$).

[1]Sensory attributes = evaluated on a 100-point line scale, with a midpoint anchor (0 = none, 50 = moderate; 100 = strong).

[2]Slice shear force.

this experiment were 5.4% to 10.8% greater for macerated steaks as compared to non-macerated steaks; those outcomes are similar to the 7.2% cooking loss reported by Recio et al. (1988) for macerated inside and outside skirt steaks. Moreover, Canon (2012) reported cooking losses for round steaks macerated twice were 27% greater than those not macerated.

Cooking time

Because surface area differences were quite notable, the time required to cook steaks from refrigerated temperature to 71°C was documented (Table 2). Cooking time for eye of round steaks tended ($P = 0.080$) to differ between maceration treatments; steaks macerated 3 times cooked 0.7 to 2.3 min faster than the other maceration treatments. For bottom round steaks, cooking time differed ($P = 0.042$); steaks macerated 3 times reached the endpoint temperature 4.2 min faster than non-macerated steaks, whereas steaks macerated 1 or 2 times were intermediate. These outcomes are different than reported by Recio et al. (1988), who reported no difference in cooking time as a result of maceration. Cooking time is not an outcome that has been reported in other research utilizing maceration as a means of mechanical tenderization.

Slice shear force

To provide an understanding of the importance of cooking to improve the tenderness of macerated muscles, uncooked steaks were sheared as a representation of each treatment and both muscles. Uncooked SSF values for eye of round steaks (Table 1) indicated notable tenderness improvement ($P < 0.001$); non-macerated steaks required 55.3 kg to shear, and steaks macerated 1, 2, or 3 times had shear values of 51.6 kg, 44.5 kg, and 33.2 kg. SSF of uncooked bottom round steaks were also decreased to 48.3 kg, 38.7 kg, and 23.3 kg following maceration 1, 2, or 3 times as compared to non-macerated steaks (71.0 kg). Cooked SSF values of eye of round steaks were 56.3% lower than uncooked values but did not differ ($P = 0.077$; 18.7 to 21.3 kg) as a result of maceration. Cooking macerated bottom round steaks decreased SSF values by 42.0% as compared to uncooked values. Additionally, cooked SSF values of bottom round steaks macerated 3 times (20.7 kg) were more tender ($P = 0.022$) than steaks macerated 0, 1, or 2 times (27.7 to 29.7 kg).

Use of SSF to assess objective tenderness of macerated steaks does not appear in the published literature and is likely novel. One prior publication (Recio et al., 1988) assessed tenderness via a trained sensory panel and reported an 18% improvement in sensory detected muscle fiber tenderness when inside and outside skirt steaks were macerated once. The other previous publication (Divakar et al., 2019) assessed tenderness via Warner-Bratzler shear force and reported a 47% decrease in the force required to shear through buffalo *longissimus* muscle following maceration. Additionally, Canon (2012) reported increased myofibril fragmentation index

of *pectoralis* subjected to 2 passes of mechanical maceration yet no change for *biceps femoris*. Uncooked SSF of eye of round steaks in the current study was reduced 6% to 40% in a quadratic manner as maceration frequency increased and suggested that macerating eye of round 3 times is most desirable for improved tenderness outcomes. That outcome did not hold true for cooked eye of round steaks; cooked steaks were not different in force required to shear through the steak slice regardless of whether they had been macerated 0, 1, 2, or 3 times. Uncooked SSF of bottom round steaks was reduced 32% to 67% in a logarithmic manner as maceration frequency increased and also suggested that macerating bottom round steaks 3 times is most desirable for maximum tenderness. Cooked bottom round steaks did not become more tender until 3 passes through the macerator. The simple act of cooking macerated steaks resulted in a 56% reduction in SSF values of eye of round steaks and a 42% reduction in SSF values of bottom round steaks.

Trained sensory evaluations

Trained panelists rated macerated bottom round steaks 17.4% lower ($P < 0.001$) for initial juiciness scores and 20.0% lower ($P < 0.001$) for sustained juiciness scores than non-macerated steaks. However, no difference in initial ($P \geq 0.114$) or sustained ($P \geq 0.112$) juiciness was detected between steaks macerated 0, 1, or 2 times. Overall tenderness ratings of macerated round steaks were 27.0% greater ($P < 0.001$) than non-macerated steaks; however, sensory tenderness did not differ ($P \geq 0.135$) due to number of macerations. Connective tissue amount ratings of macerated steaks were 41.3% lower ($P < 0.001$) than non-macerated steaks, yet maceration frequency did not influence ($P \geq 0.359$) connective tissue ratings.

Previous research (Recio et al., 1988) utilizing trained panelists to detect palatability differences of macerated steaks indicated that juiciness and connective tissue amount were decreased concomitant with increased tenderness, agreeing with the current study. Canon (2012) also reported diminished initial and sustained juiciness scores when round steaks were passed twice through a macerator as compared to those not mechanically tenderized; however, sensory tenderness or overall acceptability was not altered.

Conclusions

These results suggest that maceration treatment typically utilized to manufacture cubed steaks improved objective and sensory tenderness values of 2 round muscles. Surface area was maximized, purge losses did not differ, and uncooked steaks were most tender when round steaks were macerated 3 times; however, that level of tenderization was not consistently maintained after the cooking process. Although not consistent across muscles, these results do support macerating cubed steaks 3 times to maximize surface area and tenderness potential. Future research similar to this experiment should explore tenderness outcomes of other muscles (i.e., *latissimus dorsi*) commonly used for the manufacture of cubed steaks. Other future research that can be built upon these learnings includes documentation of how batter and breading pickup is influenced by the surface area changes caused by multiple macerations.

Literature Cited

Ahrens, C. R. 2012. Mechanical tenderization can alter surface color characteristics of steaks from the beef round. M.S. thesis. Tarleton State Univ., Stephenville, TX.

AMSA. 2015. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. 2nd ed. Am. Meat Sci. Assoc. Champaign, IL.

Arroyo, A. and I. de la Torre. 2016. Assessing the function of pounding tools in the Early Stone Age: A microscopic approach to the analysis of percussive artefacts from Beds I and II, Olduvai Gorge (Tanzania). J. Archaeol. Sci. 74:23–34. https://doi.org/10.1016/j.jas.2016.08.003

Bendall, J. R. 1967. The elastin content of various muscles of beef animals. J. Sci. Food Agr. 18:553–558. https://doi.org/10.1002/jsfa.2740181201

Canon, J. A. 2012. Effects of various tenderization strategies on non-fed beef palatability and tenderness. M.S. thesis, Angelo State Univ., San Angelo, TX.

Daly-Koziel, K. and J. Walters. 2006. Meat and Bean Group: Go lean with protein [facilitator's guide]. https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=1029&context=fcs_reports. (Accessed 11 June 2023.)

Divakar, N., R. Nayar, Chetan, S. Khanapur, K. Rajagopal, S. Rajkumar R., M. Thomas, and Sunanda C. 2019. Quality and shelf life attributes of carabeef treated with curd, lemon juice and blade tenderization. Indian Journal of Natural Sciences 9:17089–17096.

Duran, A. and M. Ardic. 2014. Meat tenderness. International Journal of Multidisciplinary Thought 4:259–263.

Huff-Lonergan, E. and A. Sosnicki. 2002. Water-holding capacity of fresh meat. PIG 12-04-05. https://porkgateway.org/wp-content/uploads/2015/07/water-holding-capacity-of-fresh-meat.pdf. (Accessed 11 June 2023.)

Maddock, R. 2008. Mechanical tenderization of beef. https://www.beefresearch.org/resources/product-quality/fact-sheets/mechanical-tenderization-of-beef. (Accessed 10 June 2023.)

O'Quinn, T. G., J. F. Legako, J. C. Brooks, and M. F. Miller. 2018. Evaluation of the contribution of tenderness, juiciness, and flavor to the overall consumer beef eating experience.

Translational Animal Science 2:26–36. https://doi.org/10.1093/tas/txx008

Recio, H. A., L. C. Fradella, H. R. Cross, G. C. Smith, and J. W. Savell. 1988. Palatability of beef skirt steaks as influenced by grade/maturity group, anatomical location and mechanical tenderization. J. Food Sci. 53:1628–1630. https://doi.org/10.1111/j.1365-2621.1988.tb07801.x

Savell, J. W., G. C. Smith, and Z. L. Carpenter. 1977. Blade tenderization of four muscles from three weight-grade groups of beef. J. Food Sci. 42:866–870. https://doi.org/10.1111/j.1365-2621.1977.tb12625.x

Schroth, A. B. 1996. An ethnographic review of grinding, pounding, pulverizing, and smoothing with stones. Pacific Coast Archaeological Society Quarterly 32:55–75.

Seideman, S. C., H. R. Cross, and J. D. Crouse. 1986. Use of mechanical tenderization to increase the tenderness of bullock beef. J. Food Quality 9:49–56. https://doi.org/10.1111/j.1745-4557.1986.tb00854.x

Seideman, S. C., G. C. Smith, Z. L. Carpenter, and W. H. Marshall. 1977. Blade tenderization of beef psoas major and semitendinosus muscles. J. Food Sci. 42:1510–1512.

Weaver, B. D. 2010. Chicken-fried steak. The Encyclopedia of Oklahoma History and Culture. https://www.okhistory.org/publications/enc/entry?entry=CH039. (Accessed 11 June 2023.)

Yang, X., J. Devos, and M. D. Klassen. 2017. Inactivation of *Escherichia coli* O157:H7 in minute steaks cooked under selected conditions. J. Food Protect. 80:1641–1647. https://doi.org/10.4315/0362-028X.JFP-17-081