Evaluation of sampling, cookery, and shear force protocols for objective evaluation of lamb longissimus tenderness[1]

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ABSTRACT: Experiments were conducted to compare the effects of two cookery methods, two shear force procedures, and sampling location within non-callipyge and callipyge lamb LM on the magnitude, variance, and repeatability of LM shear force data. In Exp. 1, 15 non-callipyge and 15 callipyge carcasses were sampled, and Warner-Bratzler shear force (WBSF) was determined for both sides of each carcass at three locations along the length (anterior to posterior) of the LM, whereas slice shear force (SSF) was determined for both sides of each carcass at only one location. For approximately half the carcasses within each genotype, LM chops were cooked for a constant amount of time using a belt grill, and chops of the remaining carcasses were cooked to a constant endpoint temperature using open-hearth electric broilers. Regardless of cooking method and sampling location, repeatability estimates were at least 0.8 for LM WBSF and SSF. For WBSF, repeatability estimates were slightly higher at the anterior location (0.93 to 0.98) than the posterior location (0.88 to 0.90). The difference in repeatability between locations was probably a function of a greater level of variation in shear force at the anterior location. For callipyge LM, WBSF was higher ($P < 0.001$) at the anterior location than at the middle or posterior locations. For non-callipyge LM, WBSF was lower ($P < 0.001$) at the anterior location than at the middle or posterior locations. Consequently, the difference in WBSF between callipyge and non-callipyge LM was largest at the anterior location. Experiment 2 was conducted to obtain an estimate of the repeatability of SSF for lamb LM chops cooked with the belt grill using a larger number of animals (n = 87). In Exp. 2, LM chops were obtained from matching locations of both sides of 44 non-callipyge and 43 callipyge carcasses. Chops were cooked with a belt grill and SSF was measured, and repeatability was estimated to be 0.95. Repeatable estimates of lamb LM tenderness can be achieved either by cooking to a constant endpoint temperature with electric broilers or cooking for a constant amount of time with a belt grill. Likewise, repeatable estimates of lamb LM tenderness can be achieved with WBSF or SSF. However, use of belt grill cookery and the SSF technique could decrease time requirements which would decrease research costs.

Key Words: Cookery, Lamb, Longissimus, Shear Force, Tenderness

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Introduction

Warner-Bratzler shear force (**WBSF**) and trained sensory panel tenderness data are more repeatable when beef longissimus steaks are cooked for a constant amount of time using a belt grill rather than cooking to a constant endpoint temperature using open-hearth electric broilers (Wheeler et al., 1998). Also, shear force data are more strongly related with sensory panel tenderness rating using the slice shear force (**SSF**) protocol developed for beef tenderness classification (Shackelford et al., 1999a), rather than the traditional WBSF protocol (Shackelford et al., 1999a). Considering improvements noted in beef, one would think that these technologies could be used to improve the repeatability of lamb shear force data. However, because of differences between species in the cross-sectional area of LM, it is unclear if these technologies would impact the repeatability of shear force measurements in lamb. Moreover, because of differences in the shape and the cross-sectional area of LM across the length of the muscle, it is unclear if the magnitude or repeatability of shear force will differ among sampling locations. Because belt grill cookery is less labor intensive than traditional cooking procedures and SSF is less labor intensive than WBSF, development of these procedures for lamb would

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Table 1. Assignment of chops to shear force method and sampling location

Chop	Left side	Right side
1[a]		
2	WBSF left posterior[b]	WBSF right posterior[b]
3		
4		
5	WBSF left middle	WBSF right middle
6		
7	SSF_left	SSF_right
8		
9		
10	WBSF left anterior	WBSF right anterior
11		

[a]Chops were numbered beginning near the posterior end of the longissimus muscle at a point near the anterior tip of gluteus medius. For most carcasses, the 12th to 13th-rib interface was at the posterior side of Chop 8.

[b]WBSF = Warner-Bratzler shear force, and SSF = slice shear force. For WBSF, three chops were used to obtain the six cores needed for each observation, whereas for SSF, two chops were sampled for each observation.

reduce the cost of conducting tenderness research in those species. Thus, the present experiments were conducted to compare the effects of two cookery methods (belt grill vs open-hearth electric broiler), two shear force procedures (WBSF vs SSF), and sampling location (anterior, middle, and posterior) within non-callipyge and callipyge lamb longissimus muscle on the magnitude, variance, and repeatability of LM shear force data.

Materials and Methods

Experiment 1

Animals. The Roman L. Hruska U.S. Meat Animal Research Center (**MARC**) Animal Care and Use Committee approved the use of animals in this study. Normal (n = 15) and callipyge (n = 15) crossbred (¼ Dorset, ¼ Romonav, ½ Finnsheep) lambs were produced by mating homozygous normal (n = 7) and homozygous callipyge (n = 7) Dorset × Romonav rams to Finnsheep ewes. Rams were obtained from a third production year of the F_2 generation of the mating scheme described by Freking et al. (1998). Any lamb produced by mating a homozygous normal ram with a Finnsheep ewe (assumed to be homozygous normal at the callipyge locus) would be expected to have the normal lamb phenotype and any lamb produced by mating a homozygous callipyge ram with a Finnsheep ewe would be expected to have the callipyge phenotype (Cockett et al., 1996).

Lambs were reared in an indoor/outdoor production facility. From 1 wk of age (creep fed) to slaughter (222 to 231 d old), lambs were given ad libitum access to long-stem alfalfa hay and a diet that contained 88% DM and 77% total digestible nutrients. Carcasses were dressed conventionally and chilled for 48 h at 1°C. The entire dorsal section (loin and rack) was removed from each carcass, vacuum-packaged, aged (2°C) until 14 d postmortem, and frozen (–30°C). Using a band saw, each frozen dorsal section was sliced to yield 11 double chops (2.54 cm thick). Each double chop was then split down the middle of the vertebral column. Thus, 22 LM chops were obtained from each carcass.

Within each genotype, approximately one-half (n = 8 normal and n = 8 callipyge) of the carcasses were assigned to open-hearth electric broiler cookery and approximately one-half of the carcasses (n = 7 normal and n = 7 callipyge) were assigned to belt grill cookery (Table 1). Within each carcass side, nine of the chops were used to make three independent measurements of WBSF (three chops per measurement) and two of the chops were used to make a single measurement of SSF (Table 1). A single SSF measurement was made using the thickest portion of LM because it is not known whether variation in the muscle fiber angle across the length of LM would permit accurate SSF measurement at other locations.

Cooking. Chops were thawed (5°C) until an internal temperature of 5°C was reached, deboned, and trimmed free of s.c. fat. Belt grill cooking was conducted with a

Table 2. Analysis of variance of Warner-Bratzler shear force and cooking loss of chops cooked for Warner-Bratzler shear force

		Cooking loss		Warner-Bratzler shear force	
Source	df	Mean square	*F*-value	Mean square	*F*-value
Genotype (G)	1	287.4	12.0***	354.5	41.0***
Cooking method (C)	1	444.4	18.5***	10.5	1.2
G × C	1	12.2	0.5	2.0	0.2
Animal (G × C)	26	24.0	2.0***	8.6	37.0***
Location (L)	2	22.9	2.0	2.2	9.6***
G × L	2	5.7	0.5	7.6	32.6***
C × L	2	15.8	1.4	0.3	1.3
G × C × L	2	0.8	0.1	0.2	0.9
Animal (G × C) × L	52	10.8	0.9	1.0	4.4***
Error	90	11.7		0.2	

***$P < 0.001$.

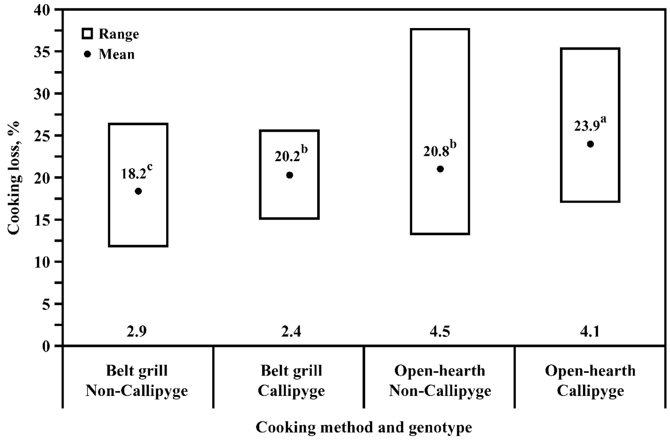

Figure 1. Cooking method ($P < 0.001$) and genotype ($P < 0.01$) effects on cooking loss. Means (SEM = 0.4) that do not share a common letter differ ($P < 0.01$). Vertical bars represent the range for each cell. Numbers located just above the x-axis indicate the SD for each cell.

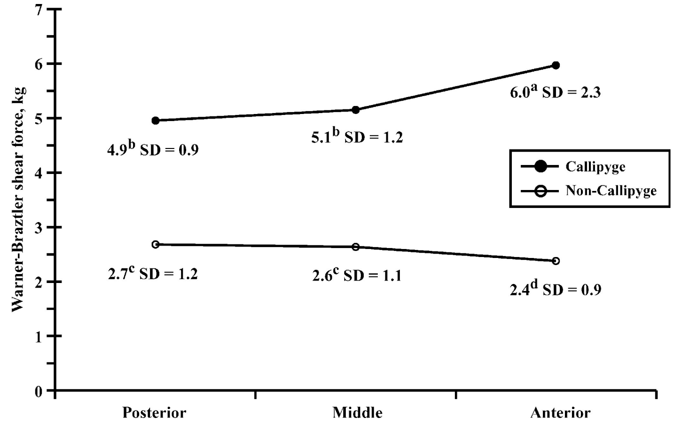

Figure 2. Genotype × location interaction on Warner-Bratzler shear force ($P < 0.001$). Means (SEM = 0.09) that do not share a common letter differ ($P < 0.05$).

model TBG-60 Magigrill (MagiKitch'n Inc., Quakertown, PA). Belt grill settings (top heat = 163°C, bottom heat = 163°C, preheat = 149°C, height [gap between platens] = 2.16 cm, and cook time = 5.3 min) were designed to achieve a final internal temperature of 71°C for 2.54-cm-thick LM chops. After the chops exited the belt grill, a needle thermocouple probe was inserted into the geometric center of the chop and postcooking temperature rise was monitored with a hand-held thermometer (Cole-Parmer, Vernon Hills, IL). The maximum temperature, which occurred about 2 min after the chop exited the belt grill, was recorded as the final cooked internal temperature.

Electric broiler cooking was conducted with a model 450N Open Hearth electric broiler (Farberware, Bronx, NY). Chops were turned after reaching 40°C, and then removed from the grill after reaching 71°C internal temperature. Temperature was monitored with iron constantan thermocouple wires inserted into the geometric center of each chop and attached to a Beckman Industrial model 205 data logger (Beckman Industrial, San Diego, CA).

Warner-Bratzler Shear Force. Cooked chops were cooled for 24 h at 4°C before removal of two 1.27-cm diameter cores from each chop parallel to the longitudinal orientation of the muscle fibers. Each core was sheared once with a WBSF attachment using an electronic testing machine (model 4411; Instron Corp., Canton, MA). The crosshead speed was set at 200 mm/min.

Table 3. Analysis of variance of slice shear force data

Source	df	Mean square	F-value
Genotype (G)	1	5,468.2	31.1***
Cooking method (C)	1	88.2	0.5
G × C	1	207.5	1.2
Animal (G × C)	26	175.8	6.1***
Error	30	28.9	

***$P < 0.001$.

Slice Shear Force. Immediately after cooking, SSF was determined using a modification of the protocol developed for assessment of beef LM tenderness (Shackelford et al., 1999 a,b). For each of two chops from each carcass side, a 1-cm-thick, 2.5-cm-long slice was removed from each cooked chop parallel to the muscle fibers following procedures similar to those of Shackelford et al. (1999b), except that the slice had to be limited to a length of 2.5 cm because of the small size of some lamb LM chops. Thus, to achieve the same slice length (5 cm) as that used for beef, the 2.5-cm-long slices from each chop from a given carcass side were laid end to end in the shearing apparatus. Each sample was sheared once with a flat, blunt-end blade (Shackelford et al., 1999a) using an electronic testing machine (model 4411, Instron Corp.). As with beef (Shackelford et al., 1999 a,b), the crosshead speed was set at 500 mm/min.

Statistical Analysis. To help ensure repeatable WBSF data, six cores per sample are typically obtained; however, in the case of lamb LM, three chops are usually needed to obtain six cores (two cores per chop). Thus, the experimental unit was the average WBSF value for the six cores from a set of three consecutive chops within a given carcass side. Specifically, values were averaged for Chops 1, 2, and 3 and denoted posterior; values were averaged for Chops 4, 5, and 6 and denoted middle; and values were averaged for Chops 9, 10, and 11 and denoted anterior (Table 1).

Analysis of variance was conducted using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC). Warner-Bratzler shear force data were analyzed using a model that included the main effects of genotype (G), cooking method (C), and sampling location (L) and their interactions (G × C, G × L, C × L, and G × C × L). Animals (A) nested within genotype and cooking method served as the error term for G, C, and G × C. Also, A × L was

Table 4. Animal × location interaction ($P < 0.001$) on Warner-Bratzler shear force (kg)[a]

Genotype	ID	Posterior	Middle	Anterior
Non-callipyge	57	2.30 ± 0.16	2.19 ± 0.02	1.63 ± 0.08
Non-callipyge	94	2.08 ± 0.25	1.90 ± 0.01	1.68 ± 0.01
Non-callipyge	81	2.18 ± 0.10	1.93 ± 0.08	1.88 ± 0.19
Non-callipyge	82	2.16 ± 0.01	2.10 ± 0.18	1.99 ± 0.38
Non-callipyge	117	2.22 ± 0.18	1.96 ± 0.03	2.01 ± 0.31
Non-callipyge	66	1.95 ± 0.03	2.18 ± 0.24	2.06 ± 0.03
Non-callipyge	65	2.85 ± 0.04	2.39 ± 0.08	2.10 ± 0.06
Non-callipyge	43	2.84 ± 0.77	2.49 ± 0.40	2.18 ± 0.15
Non-callipyge	46	2.47 ± 0.04	1.97 ± 0.10	2.21 ± 0.14
Non-callipyge	58	2.87 ± 0.15	2.85 ± 0.01	2.25 ± 0.20
Non-callipyge	73	1.95 ± 0.08	2.37 ± 0.23	2.26 ± 0.09
Non-callipyge	111	2.62 ± 0.35	2.94 ± 0.15	2.37 ± 0.22
Non-callipyge	40	2.35 ± 0.11	2.79 ± 0.06	2.57 ± 0.05
Non-callipyge	79	2.69 ± 0.28	2.83 ± 0.12	3.03 ± 0.39
Non-callipyge	44*	6.61 ± 0.77	6.43 ± 0.14	5.20 ± 0.29
Callipyge	35	4.10 ± 0.37	3.38 ± 0.03	3.90 ± 0.46
Callipyge	6	4.06 ± 0.40	4.62 ± 0.01	3.95 ± 0.15
Callipyge	8*	3.62 ± 0.41	4.59 ± 0.67	4.05 ± 0.12
Callipyge	17	4.22 ± 0.28	4.70 ± 0.11	4.49 ± 0.24
Callipyge	107	4.96 ± 0.20	5.22 ± 0.88	5.08 ± 0.36
Callipyge	9	4.88 ± 0.21	5.46 ± 0.51	5.15 ± 0.10
Callipyge	16	5.14 ± 0.81	5.62 ± 0.07	5.17 ± 0.59
Callipyge	97	4.69 ± 0.06	4.99 ± 0.05	5.32 ± 0.17
Callipyge	29	5.17 ± 0.20	5.25 ± 0.37	5.39 ± 0.05
Callipyge	122	5.38 ± 0.70	5.12 ± 0.44	5.83 ± 0.07
Callipyge	37*	5.76 ± 0.25	4.84 ± 0.16	6.24 ± 0.17
Callipyge	119*	4.70 ± 0.34	4.52 ± 0.52	6.43 ± 0.33
Callipyge	120*	5.36 ± 0.01	5.04 ± 0.34	7.36 ± 1.40
Callipyge	118*	5.13 ± 0.68	4.89 ± 0.08	8.47 ± 0.51
Callipyge	62*	6.99 ± 0.28	8.84 ± 0.06	12.79 ± 0.05

*Locations differences within animal exceeded the LSD ($P < 0.05$).
[a]Values are the mean (±SE) of the two observations (left side and right side) for each location (SEM = 0.34 and LSD = 0.96 kg; $P < 0.05$).

tested. Slice shear force data were analyzed using a model that included the main effects of G and C and their interaction (G × C). Animals nested within G and C served as the error term for G, C, and G × C.

Repeatability of WBSF was calculated for each sampling location, whereas the repeatability of SSF was calculated for the single location examined. Repeatability was calculated as the proportion of the total variance that could be attributed to animal variance: repeatability = $s^2_{animal}/(\sigma^2_{animal} + \sigma^2_{error})$. Variance components were estimated with the MIVQUEO option of the VARCOMP procedure of SAS.

Experiment 2

Animals used in this experiment were produced using the same matings as in Experiment 1 and were reared in the same contemporary group. There were 44 noncallipyge and 43 callipyge lambs. Lambs were slaughtered and their carcasses were processed as in Exp. 1. Loin sections were aged, frozen, and sliced as in Exp. 1. Chops 7 and 8 of each carcass side were used to measure SSF. All chops were cooked with the belt grill as described previously. Repeatability of SSF was calculated as in Exp. 1.

Table 5. Correlation of Warner-Bratzler shear force values among locations

		Left			Right		
Side	Location	Posterior	Middle	Anterior	Posterior	Middle	Anterior
Left	Posterior		0.93***	0.88***	0.92***	0.92***	0.87***
Left	Middle	0.93***		0.89***	0.90***	0.94***	0.86***
Left	Anterior	0.88***	0.89***		0.84***	0.90***	0.96***
Right	Posterior	0.92***	0.90***	0.84***		0.92***	0.84***
Right	Middle	0.92***	0.94***	0.90***	0.92***		0.89***
Right	Anterior	0.87***	0.86***	0.96***	0.84***	0.89***	

***$P < 0.001$.

Table 6. Variance component analysis and repeatability of Warner-Bratzler shear force and slice shear force for chops cooked with belt grill (BG) and open-hearth electric broilers (OH)

Cooking method	Location	n	Variance			Repeatability
			Carcass	Error	Total	
	Warner-Bratzler shear force					
BG	Posterior	14	2.04	0.29	2.33	0.88
OH	Posterior	16	2.24	0.25	2.49	0.90
BG	Middle	14	1.87	0.15	2.02	0.93
OH	Middle	16	3.59	0.19	3.78	0.95
BG	Anterior	14	5.01	0.35	5.36	0.93
OH	Anterior	16	7.39	0.17	7.56	0.98
	Slice shear force					
BG		14	147.2	37.8	185.0	0.80
OH		16	183.5	21.1	204.7	0.90

Results and Discussion

Analysis of variance of cooking loss data is presented in Table 2. Cooking loss was lower ($P < 0.001$) for lamb LM chops cooked with the belt grill (19.2%) compared with open-hearth electric broilers (22.3%; Figure 1). This finding agrees with our comparison of these cooking methods for beef LM steaks (Wheeler et al., 1998). Cooking loss was lower ($P < 0.01$) for non-callipyge (19.5%) LM chops as compared to callipyge chops (22.0%). Although several experiments (Rawlings et al., 1994; Koohmaraie et al., 1995; Carpenter et al., 1997) have investigated the effect of callipyge on tenderness, we could only find one other study that reported the effects of callipyge on cooking loss. Shackelford et al. (1997) observed a tendency ($P = 0.11$) for cooking loss to be higher for callipyge LM chops.

Despite the effect of cooking method on cooking loss, cooking method did not affect WBSF ($P = 0.28$) or SSF ($P = 0.49$) of lamb LM (Tables 2 and 3). Regardless of cooking method, WBSF and SSF values were greater ($P < 0.001$) for callipyge LM. There was a significant genotype × sampling location interaction on WBSF ($P < 0.001$; Figure 2). For callipyge LM chops, WBSF was higher ($P < 0.001$) at the anterior location than at the middle or posterior locations. For non-callipyge LM, WBSF was lower ($P < 0.001$) at the anterior location than at the middle or posterior locations. Consequently, the difference in WBSF between callipyge and non-callipyge chops was largest at the anterior location. Differences among studies in the magnitude of the effect of the callipyge phenotype on LM shear force may be due in part to the location within the LM that was studied.

There was an interaction ($P < 0.001$) between animals and location. This interaction was primarily due to variation in the magnitude of the location effect within the callipyge LM (Table 4). Among the 15 callipyge carcasses, the range in mean (averaged over sides) shear force among locations ranged from 0.2 to 5.8 kg. A consequence of this interaction was that WBSF values of the anterior location of the left and right sides were more strongly correlated with each other than they were with WBSF values for the other locations (Table 5).

Regardless of cooking method and sampling location, repeatability estimates were at least 0.8 for WBSF and SSF (Table 6). For WBSF, repeatability estimates were highest at the anterior location and lowest at the posterior location. The difference in repeatability between locations was largely a function of the greater level of variation in shear force at the anterior location. Repeatability estimates were slightly higher for chops cooked to a constant endpoint temperature with open-hearth electric broilers than for chops cooked for a constant amount of time using a belt grill. Whereas Wheeler et al. (1998) reported that the repeatability of beef LM WBSF was higher if steaks were cooked with a belt grill (0.85) vs. with open-hearth electric broilers (0.64), the present results indicate that the repeatability of lamb LM WBSF is slightly lower for lamb LM chops cooked with a belt grill.

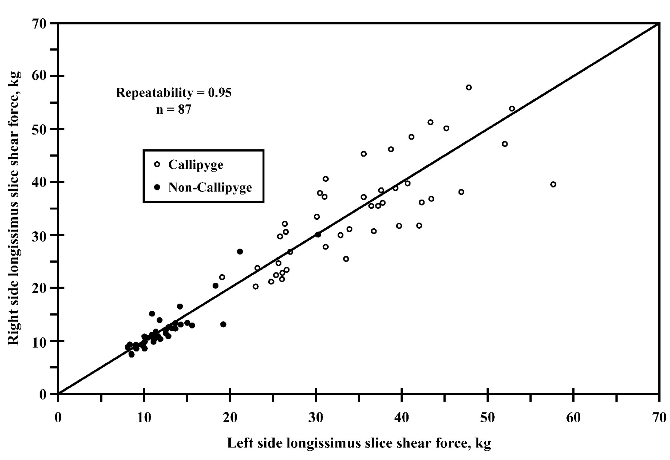

Figure 3. Repeatability of slice shear force for lamb longissimus muscle chops cooked with a belt grill. Samples were obtained from 44 non-callipyge and 43 callipyge lamb carcasses.

Repeatability estimates were higher for WBSF than for SSF (Table 6). This finding is somewhat contradictory with our comparison of SSF and WBSF in beef LM (Shackelford et al., 1999a). Shackelford et al. (1999a) reported that shear force data were more strongly related with sensory panel tenderness rating using the SSF protocol than with the traditional WBSF protocol. Given this contradiction, Exp. 2 was conducted to obtain an estimate of the repeatability of SSF for lamb LM chops cooked with the belt grill using a larger number of animals (n = 87 vs. 14). In Exp. 2, the repeatability of lamb LM SSF was 0.95 (Figure 3), which is comparable to the estimate of beef LM SSF (0.91; Shackelford et al., 1999a).

Implications

Highly repeatable estimates of lamb longissimus muscle tenderness can be achieved either by cooking to a constant endpoint temperature with electric broilers or cooking for a constant amount of time with a belt grill. Likewise, highly repeatable estimates of lamb longissimus muscle tenderness can be achieved with Warner-Bratzler shear force or slice shear force. Use of belt grill cookery and the slice shear force technique could, however, decrease time requirements, which would decrease research costs. Additionally, location effects on shear force of lamb, particularly callipyge, must be considered when evaluating longissimus muscle tenderness.

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