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Effects of harvest season on carcass characteristics of lambs in the Intermountain West*

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ABSTRACT

Objective: The objectives of this study were to survey characteristics including hot carcass weight (HCW), 12th rib fat thickness (RFT), body-wall thickness (BWT), longissimus muscle area (LMA), USDA yield grade (USDA YG), percentage closely trimmed retail cuts (RC), and calculated yield grade (Calc YG) of lamb carcasses in the Intermountain West to determine the effects of season of slaughter and interrelationships among carcass characteristics.

Materials and Methods: Lamb carcass characteristics were evaluated in 2 commercial Intermountain West processing plants over one year (n = 10,027). Carcasses were evaluated by season: spring (December–April, n = 2,322) and summer (May–August, n = 7,705).

Results and Discussion: Carcasses of lambs slaughtered in the spring had 3.4 kg heavier HCW ($P = 0.04$) than those slaughtered in the summer. Subcutaneous fat (RFT; $P = 0.06$) and Calc YG ($P = 0.09$) tended to be greater in the spring than summer. Correlation coefficients and models of fit with a linear covariate of HCW indicated negative relationship between HCW and RC and positive relationship with all other carcass traits ($P < 0.001$). Overall, graded lamb carcasses exceeded commercial processing plant preferred HCW (38.6 kg) by 5% (mean = 40.5 kg) and industry acceptable RFT (6 mm) by 25% (mean = 8.03 mm). Furthermore, 70% of lamb carcasses exceed 6 mm RFT.

Implications and Applications: Season of slaughter contributed to differences in HCW and USDA YG but no other carcass characteristics. Still, carcass data surveyed from the largest lamb-producing region of the United States suggests that the degree of fatness exceeds industry preferences. Although abattoirs mitigate adverse effects of excessive fat through trimming and diverse market outlets, industry-wide efforts that agree on acceptable standards of trimness are needed. Transparent dialog across industry segments should be prioritized in addition to consistent integration of value-based pricing to reduce the proportion of excessively finished lambs.

Key words: carcass, lamb, lamb quality, seasonality

INTRODUCTION

Disappearance is the industry's estimate for consumption and is measured as the amount of meat sold through restaurants and retail outlets, calculated as total supply minus exports and ending stocks (USDA ERS, 2021a). Despite historical decreases in US lamb consumption since the 1970s, per capita disappearance of lamb in the United States has recently increased 56% from 2011 to 2020 (USDA ERS, 2021b). To help meet this emerging demand, the United States imported 63% of its lamb supply in

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2020 (USDA ERS, 2021a), with 98% of total lamb imports from Australia and New Zealand (USDA ERS, 2021c). Therefore, improving the quality of and preference for domestically produced lamb is at the forefront of US industry efforts (American Lamb Industry, 2014). Historically, excessive fat on retail cuts has been shown to adversely affect consumer satisfaction and lamb purchasing behavior (Carpenter, 1966; Hughes, 1976; Jeremiah et al., 1993). This constraint is not attributable to a single sector of the US lamb industry but is an inherent challenge due to the seasonality of sheep production systems (Beermann et al., 1995). Approximately 85% of the US lamb crop is born between January and May (USDA APHIS, 2011), which ultimately requires feeders to extend the time that lambs are fed, to fulfill year-round demand. Feeding lambs beyond optimal finish weight results in increased adipose deposition, and yet pricing structures of US slaughter lambs do not aggressively account for cutability differences (Tatum et al., 1989; Purcell 1995; Ward, 1998). Although subcutaneous fat can be trimmed during fabrication, controlled studies have estimated that greater costs are required to trim carcasses that are high in external fat (Hopkins et al., 1995), and intermuscular fat is more challenging to mitigate depending on fabrication methods. Despite these concerns, an in-depth lamb carcass survey has not been conducted in the US since the 1980s (Tatum et al., 1989), let alone in the Intermountain West, where a large proportion of US lamb is produced. Therefore, the objectives of this study were to characterize seasonal differences and interrelationships of lamb carcass characteristics at 2 large commercial processing plants located in the US Intermountain West.

MATERIALS AND METHODS

Carcass Data Collection

No live animals were used in this study, and, therefore, approval of an Institutional Animal Care and Use Committee was not required.

Data from lamb slaughter and carcass characteristics was collected at 2 commercial processing plants located in the US Intermountain West region on 30 separate dates over the course of a calendar year (May 2018–May 2019). Data collection days were selected to target 1% and 5% of regional fabrication during the spring (December–April) and summer months (May–August), respectively. Lambs were slaughtered using standard procedures, and carcasses were assigned lot numbers based on slaughter day and order in which the lot was slaughtered. Hot carcass weight (**HCW**) and lot numbers were printed on carcass identification tags. After carcasses were chilled for approximately 24 to 48 h at 0 to 2°C, USDA AMS-certified graders applied a yield and quality grade (USDA YG and USDA QG, respectively) to each carcass based on official ovine grading standards (USDA AMS, 1992). Carcasses were separated between the 12th and 13th rib by trained personnel, and research assistants captured images of the interface using a digital camera (SEREE, 24-megapixel). The camera was mounted on an aluminum support with a perpendicular crossbar for stabilization that ensured uniform placement and photograph distance across carcasses. Carcass identification tags, complete with corresponding HCW, USDA YG, and USDA QG, were included in the image frame to maintain carcass identity. A carcass probe was also held within the image frame and level with the cut surface of the longissimus dorsi for calibration reference during image analysis.

ImageJ (v.1.52a, National Institutes of Health) was used to measure and calculate 12th rib fat thickness (**RFT**), body-wall thickness (**BWT**), and longissimus muscle area (**LMA**) from carcass images. Fat thickness was measured at the midpoint of the length of the longissimus dorsi muscle, and BWT was measured along the 12th rib at a point approximately 12.7 cm from the dorsal midline (USDA AMS, 1992). Longissimus muscle area was measured by tracing the muscle and using the "area" function of ImageJ. Fat measurements, RFT and BWT, were measured (mm) on both sides of each carcass image and averaged. To verify the accuracy of image analysis, RFT, BWT, and LMA were collected on a subset of 20 lamb carcasses using traditional measurement methods (i.e., ribeye area grid and carcass grid) and compared with those estimated from digital images. Pearson correlation coefficients between these 2 methods were positive and strong (0.84–0.96; $P < 0.001$).

Two prediction equations were used to assess carcass composition from measured traits. Calculated yield grade (**Calc YG**) was described by USDA AMS (1992) as follows: $YG_{Calc} = (0.394 \times RFT)$, which was rounded down to the nearest whole number in the range of 1 to 5, to match the range of USDA YG values. Any Calc YG values less than 1 were rounded up to 1 (n = 89), and Calc YG values greater than 5 were rounded down to 5 (n = 660), respectively. Percentage of closely trimmed retail cuts (**RC**) was calculated according to Berg et al. (1997) as follows: $RC = 46.41 - (0.174 \times HCW) - (0.12 \times RF) - (0.154 \times BWT) + (0.825 \times LMA)$.

Statistical Analysis

Data were collected from a total of 10,027 carcasses. Descriptive statistics of traits were calculated across slaughter season for both graded and ungraded carcasses. Of the carcasses surveyed, 892 did not receive a grade by trained USDA graders, due to inferior quality indicators such as deficient fat cover, significant amounts of lean muscle removed from major primal cuts, or other carcass defects (USDA AMS, 1992). Based on USDA grading standards (1992), yearling or mutton can receive grades, but this is not currently employed by trained graders, given that grading is a service paid for by the processing plant. Data from ungraded carcasses were not included in the remaining analyses, as these carcasses did not receive an official

USDA grade due to inferior quality attributes. Hot carcass weight and RC were analyzed in the MIXED procedure of SAS (v9.4; SAS Institute Inc.) with the fixed effects of season (spring or summer), commercial processing plant (1 or 2), and their interaction. Slaughter lot (nested within season and commercial processing plant; 71 levels) was fit as a random effect, and those containing <5 carcasses were treated as missing values. All other carcass traits were analyzed in the same model but with an additional linear covariate of HCW to better estimate effects of season and commercial processing plant independent of carcass weight.

Remaining analyses were pooled across slaughter season and commercial processing plant. Associations between HCW, RFT, BWT, and LMA were first assessed as Pearson correlation coefficients that were estimated using the CORR procedure. Carcasses were then classified as light (<29.5 kg), moderate (29.5–38.6 kg), or heavy (>38.6 kg) HCW based on communication with commercial processing plant personnel who indicated these levels as lightweight, ideal, and overweight, respectively, based on perceived efficiency of processing and potential market outlets. To evaluate the association of carcass traits with carcass weight and conformation, the MIXED procedure was used to analyze carcass traits with the fixed effect of HCW class (all traits except HCW) or USDA YG (all traits except USDA YG) and the random effect of slaughter lot (nested within season and commercial processing plant). Similarity between USDA YG and Calc YG was evaluated as their difference (i.e., USDA YG − Calc YG) and was analyzed in the previous model. Where possible, descriptive comparisons were made between present data and past studies conducted in the US, to infer trends in carcass characteristics over time. Additionally, results were contrasted to those from Australian and New Zealand sheep industries, as they are the largest competitors of the US lamb industry (USDA ERS, 2021c).

RESULTS AND DISCUSSION

Summary of Carcass Characteristics

Compared with estimates from internal USDA documentation of historic fabrication frequency, the number of carcasses evaluated in this study represented approximately 1% and 4% (average number of carcasses sampled daily over a 30-d period, n = 334) of the regional fabrication occurring in the spring and summer months, respectively. Descriptive statistics of graded and ungraded carcasses across slaughter season are presented in Table 1. Frequency of ungraded carcasses was greater in summer than spring months (11% vs. 2%). Ungraded lamb carcasses had numerically greater HCW, RFT, BWT, and Calc YG and lower RC than graded carcasses. Although ungraded lamb carcasses are a part of the consumer supply chain, only graded carcasses were included in the remaining analyses.

Frequency distributions of traits measured on graded carcasses are displayed in Figure 1. In the current study, 55% of carcasses exceeded the upper HCW limit of packer preferences in the Intermountain West (29.5–38.6 kg). Tatum et al. (1989) reported that 65% of US lamb carcasses slaughtered at commercial facilities in 1987 had an HCW range between 25 and 34 kg, and 11% of carcasses exceeded 34 kg. Lamb carcasses were heavier in this study, as 74% had HCW greater than 34 kg (Figure 1a). Historical

Table 1. Descriptive statistics of graded and ungraded lamb carcasses across slaughter season (2018–2019) in the US Intermountain West

Class, n	Trait[1]	Mean	SD	Minimum	Maximum
Graded, n = 9,135	HCW, kg	40.5	8.76	15	85.5
	RFT, mm	8.03	3.64	0	33.2
	BWT, mm	31.0	8.87	7.29	76.1
	LMA, cm^2	17.0	3.01	7.16	33.8
	USDA YG	3.37	0.97	1	5
	Calc YG	2.97	1.20	1	5
	RC, %	47.6	2.66	34.2	60.2
Ungraded, n = 892	HCW, kg	43.1	11.8	10.7	90.1
	RFT, mm	9.25	4.62	0	30.5
	BWT, mm	34.2	11.5	5.92	71.1
	LMA, cm^2	16.7	3.08	5.32	32.1
	Calc YG	3.31	1.28	1	5
	RC, %	46.4	3.17	33.5	56.9

[1]HCW = hot carcass weight, RFT = 12th rib fat thickness, BWT = body-wall thickness, LMA = longissimus muscle area, USDA YG = yield grade assigned by a USDA-certified lamb carcass grader, Calc YG = calculated yield grade rounded down to the nearest whole number, RC = percentage closely trimmed retail cuts.

USDA data support this continued increase in HCW over time, as lamb carcasses in 2020 were 9% heavier than in 1990 (USDA ERS, 2021d). Meanwhile, in 2019, Australian and New Zealand lamb carcasses weighed, on average, 23.3 kg and 19.1 kg, respectively (MLA, 2020; Beef and Lamb New Zealand, 2021).

Ideal RFT is 6.4 mm (USDA AMS, 1992), and 64% of lamb carcasses in the present survey exceeded that level (Figure 1b). The average RFT of carcasses >6.44 mm was 10.02 mm. In the United States, RFT is used as an indicator of whole-carcass trimness. However, grading standards in Australia and New Zealand are based on grade rule (**GR**) measurement (NZMCA, 2004; AUS-MEAT, 2020), which is more similar to BWT than RFT. The GR measurement is recorded at 110 mm from the dorsal midline (compared with 127 mm in BWT) across the 12th rib interface (AUS-MEAT, 2020). In New Zealand, excessively fat carcasses are considered those with a GR measurement $\geq$15 mm (NZMCA, 2004). In the current study, nearly all carcasses (98%) had BWT $\geq$15 mm (Figure 1c). However, greater BWT should be expected, given a 10.9 kg (30.0 vs. 19.1 kg) greater average HCW in the United States than New Zealand in 2019 (USDA ERS, 2021c; Beef and Lamb New Zealand, 2021). Fat thickness differences between sheep industries may also be a function of differences in breeds and finishing methods (Southam and Field, 1969).

Across the industry, the area of the longissimus muscle is used to assess muscle composition of live animals either by palpation or by ultrasound. Although LMA is unlikely to be measured in commercial processing plants because lamb carcasses are typically not ribbed, it may be valuable in differentiating domestic from imported lamb and identifying consumer preference. Hoffman et al. (2016) reported that the LMA of US loin chops (19.5 cm^2) was greater than that of Australian or New Zealand-sourced loin chops (16.8 and 14.5 cm^2, respectively) available in US retail stores. Although weight and size of lamb cuts may have less influence than other quality characteristics, such as eating satisfaction and composition (Hoffman et al., 2015), improving LMA can increase dressing percentage and carcass value (Leeds et al., 2008).

The RC equation used in the present study was developed by Berg et al. (1997) using carcass data captured from commercial market lambs. It approximates the proportion of boneless lean that can be trimmed and fabricated into retail cuts from common carcass measurements by applying negative coefficients to HCW, RFT, and BWT and a positive coefficient to LMA. A similar RC equation was developed by Tschirhart et al. (2002) for use in show lambs and uses the same component traits weighted by coefficients of the same direction but different magnitude from Berg et al. (1997). However, show lamb carcass composition is generally not reflective of the larger commercial lamb industry. Lamb carcasses in the present study had greater HCW (40.5 vs. 29.3 kg), RFT (8.03 vs. 5.3 mm), BWT (31.0 vs. 24.3 mm), and LMA (17.0 vs. 13.8 cm^2) and, consequently, lower RC (47.6 vs. 48.3%) than those sampled in Berg et al. (1997), which may be due to differences in genetics and feeding strategies at that time compared with current practices.

More common estimates of carcass lean yield are USDA YG and Calc YG, with USDA YG being assigned visually by a USDA grader (USDA AMS, 1992) and Calc YG based on objective measurements of RFT. Greater USDA YG and Calc YG are indicative of increased carcass fat composition. In the present study, 38%, 30%, and 13% of carcasses received USDA YG of 3, 4, and 5, respectively. Similar percentages were observed among industry data from 2018, which summarized that 39%, 18%, and 11% of lamb carcasses were assigned USDA YG of 3, 4, and 5, respectively (USDA AMS, 2021). Furthermore, the proportion of carcasses receiving USDA YG 4 and 5 was approximately 3% greater in 2018 than in the 2 years prior (USDA AMS, 2021), which may further validate industry concerns over increased carcass fatness.

Currently, the majority of graded lamb carcasses receive a USDA QG of Choice or Prime. For example, 95% and 4% of graded carcasses in the current study and 91% and 9% of industry-reported carcasses (USDA AMS, 2021) in 2018 received Choice or Prime USDA QG, respectively. Quality grades in the US are assigned based on visual assessment of carcass conformation (i.e., flank streaking, thickness of muscling, and distribution of external finish; USDA AMS, 1992). Grading standards in other countries also base standards upon muscle and fat composition, but fat indicators are based on GR and include the weight as part of the quality standard. New Zealand has the most differentiated grading system, with 7 fat classifications, 5 weight classifications, and a requirement for adequate muscle to qualify for export markets (NZMCA, 2004). A more refined quality grading system may better quantify the quality attributes of US lamb carcasses.

Results from this survey indicate that lamb carcasses sampled in commercial processing plants in the Intermountain West during 2018 and 2019 were representative of recent carcass trends throughout the United States and were heavier and fatter than both domestic and international industry preferences.

Effects of Slaughter Season and Commercial Processing Plant on Carcass Characteristics

The slaughter season × commercial processing plant interaction was significant in the analyses of LMA and RC ($P \leq 0.04$), and their least squares means are displayed in Table 2. For LMA, the interaction was due to a numerical re-ranking between commercial processing plants across slaughter season, but no subclass means were significantly different from one another ($P \geq 0.13$). During the summer months, carcasses processed at commercial processing plant 2 had greater RC than those processed at commercial processing plant 1 ($P = 0.02$), but there were no commercial processing plant differences during the spring ($P = 0.69$). The slaughter season × commercial processing

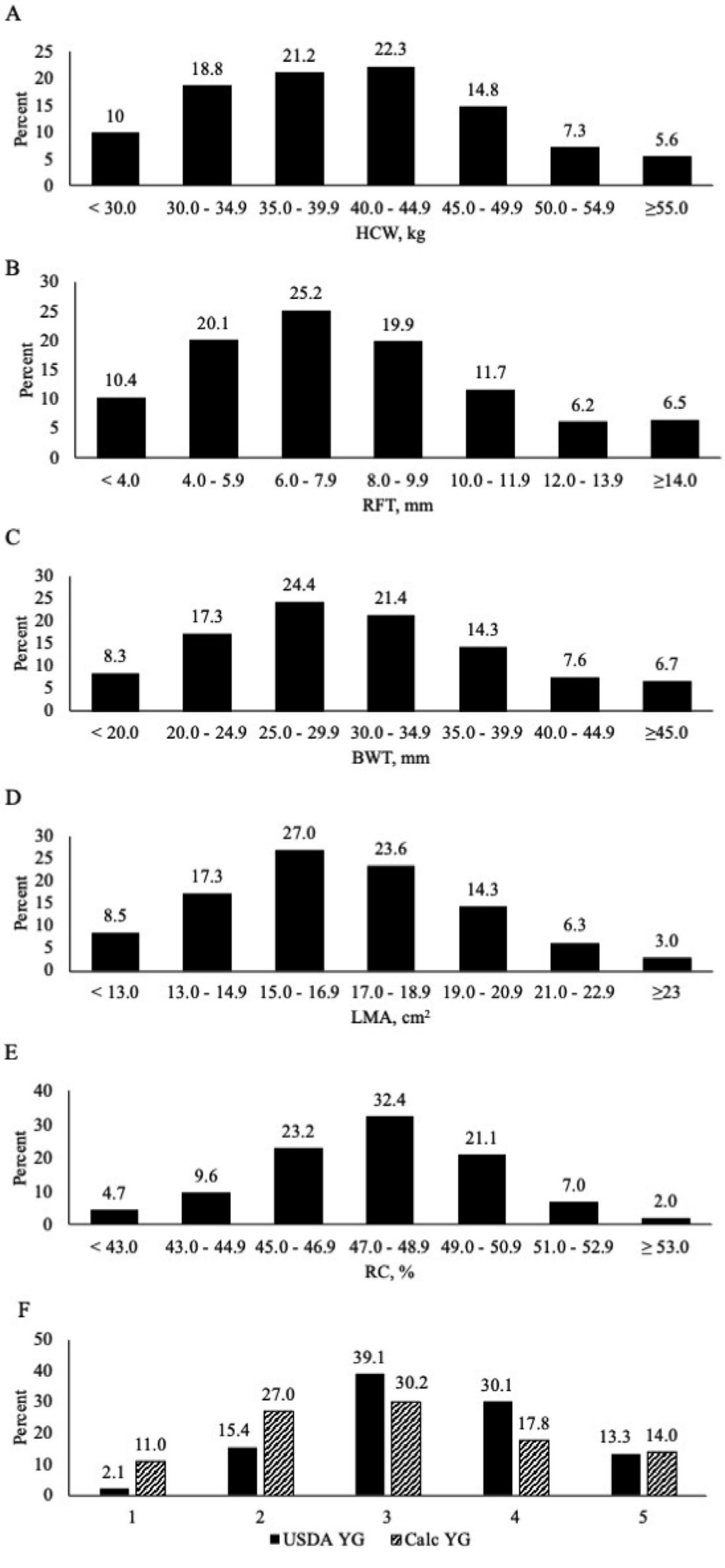

Figure 1. Frequency distributions of hot carcass weight (HCW, A), 12th rib fat thickness (RFT, B), body-wall thickness (BWT, C), longissimus muscle area (LMA, D), percentage closely trimmed retail cuts (RC, E), and USDA yield grade (USDA YG) compared with calculated yield grade (Calc YG, F) for lambs slaughtered from the US Intermountain West, 2018–2019.

Table 2. Least squares means (±SE) for the interactive effects of slaughter season and commercial processing plant on carcass traits of lambs slaughtered in the US Intermountain West, 2018–2019[1]

	Spring		Summer	
Trait[2]	Commercial processing plant 1	Commercial processing plant 2	Commercial processing plant 1	Commercial processing plant 2
LMA, cm^2	17.6 ± 0.31	17.0 ± 0.40	16.7 ± 0.23	17.4 ± 0.21
RC, %	48.1 ± 0.40[a,b]	47.4 ± 0.50[a,b]	47.4 ± 0.29[b]	48.6 ± 0.26[a]

[a,b]Means within a trait with no common superscript are different ($P \leq 0.04$).

[1]Lambs were slaughtered at 1 of 2 commercial abattoirs in the Intermountain West during the course of one calendar year; Spring = December–April, Summer = May–August.

[2]LMA = longissimus muscle area, RC = percentage closely trimmed retail cuts.

plant interaction did not influence any other trait evaluated ($P \geq 0.06$), and least squares means for their main effects are displayed in Table 3.

There was an effect of season on HCW, as carcasses from lambs slaughtered in the spring (December–April) were 3.4 kg heavier than those slaughtered in the summer ($P = 0.04$). However, commercial processing plant location did not affect HCW ($P = 0.15$). From 2010 to 2020, American lamb carcasses weighed 31.3 kg on average, with heaviest dressed weights occurring in May (32.2 kg) and lightest occurring in September (30.1 kg; USDA ERS, 2021d). During the timeframe of this study, the average dressed weight of federally inspected lamb carcasses was 31.1 kg (USDA ERS, 2021d). Differences between the current results and USDA data may be attributable to the inclusion of smaller federally inspected plants and lamb carcass differences across the country. From USDA data, slaughter season also appears to exert a minor influence on carcass weights, with a 1.1-kg difference between the highest and lowest average monthly carcass weights (USDA ERS, 2021d).

To investigate the effects of slaughter season on the remaining traits, independent of seasonal HCW differences, HCW was fit as a linear covariate in their analyses and was highly significant and positive ($P < 0.001$; Table 3) for all traits. The main effects of commercial processing plant and slaughter season influenced USDA YG and were greater ($P = 0.01$) for carcasses processed at commercial processing plant 1 than 2 and greater for lambs slaughtered in the spring than summer ($P < 0.001$). Although RFT ($P = 0.06$) and Calc YG ($P = 0.09$) tended to be greater in spring than in summer, no other traits were

Table 3. Least squares means (± SE) for the main effects of slaughter season and commercial processing plant and solution for the linear covariate of hot carcass weight $\left(\hat{b}_{y,HCW}\right)$ on carcass traits of lambs slaughtered in the US Intermountain West, 2018–2019

		Trait[2]					
Effect[1]	Level	HCW, kg	RFT, mm	BWT, mm	LMA, cm^2	USDA YG	Calc YG
Commercial processing plant	1	40.5 ± 1.09	8.08 ± 0.20	30.9 ± 0.46	17.1 ± 0.19	3.53 ± 0.07[a]	3.02 ± 0.06
	2	38.1 ± 1.21	8.11 ± 0.24	31.1 ± 0.54	17.2 ± 0.23	3.26 ± 0.08[b]	2.87 ± 0.08
Season	Spring	41.0 ± 1.38[a]	8.38 ± 0.26	30.9 ± 0.61	17.3 ± 0.25	3.54 ± 0.09[a]	3.03 ± 0.08
	Summer	37.6 ± 0.86[b]	7.80 ± 0.16	31.2 ± 0.54	17.0 ± 0.15	3.25 ± 0.06[b]	2.86 ± 0.05
Hot carcass weight, linear covariate	$\hat{b}_{y,HCW}$	—	0.21 ± 0.01*	0.70 ± 0.01*	0.24 ± 0.004*	0.06 ± 0.001*	0.06 ± 0.002*

[a,b]Means within a trait and effect with no common superscript are different ($P \leq 0.04$).

[1]Lambs were slaughtered at 1 of 2 commercial processing plants in the Intermountain West during the course of one calendar year; Spring = December–April, Summer = May–August.

[2]HCW = hot carcass weight, RFT = 12th rib fat thickness, BWT = body-wall thickness, LMA = longissimus muscle area, USDA YG = yield grade assigned by a USDA-certified lamb carcass grader, Calc YG = calculated yield grade rounded down to the nearest whole number.

*$\hat{b}_{y,HCW}$ is different from zero ($P < 0.001$).

Table 4. Estimated Pearson correlation coefficients between carcass traits of lambs slaughtered in the US Intermountain West, 2018–2019[1]

Trait	HCW	RFT	BWT	LMA
HCW	—	0.57*	0.73*	0.58*
RFT	—	—	0.66*	0.22*
BWT	—	—	—	0.48*
LMA	—	—	—	—

[1]HCW = hot carcass weight, RFT = 12th rib fat thickness, BWT = body-wall thickness, LMA = longissimus muscle area.

*Correlation coefficient is different from zero ($P < 0.001$).

Table 5. Least squares means (±SE) for the main effect hot carcass weight (HCW) class on carcass characteristics of lambs slaughtered in the US Intermountain West, 2018–2019

	HCW class[2]		
Trait[1]	Light	Moderate	Heavy
RFT, mm	5.46 ± 0.21[c]	6.93 ± 0.19[b]	8.81 ± 0.19[a]
BWT, mm	22.1 ± 0.52[c]	27.5 ± 0.46[b]	34.3 ± 0.46[a]
LMA, cm^2	13.6 ± 0.16[c]	16.0 ± 0.13[b]	18.4 ± 0.13[a]
USDA YG	2.45 ± 0.06[c]	3.07 ± 0.06[b]	3.61 ± 0.06[a]
Calc YG	2.10 ± 0.07[c]	2.58 ± 0.06[b]	3.22 ± 0.06[a]
RC, %	48.7 ± 0.17[a]	48.3 ± 0.15[b]	47.4 ± 0.15[c]

[a–c]Means within a trait with no common superscript are different ($P < 0.001$).

[1]RFT = 12th rib fat thickness, BWT = body-wall thickness, LMA = longissimus muscle area, USDA YG = yield grade assigned by a USDA-certified lamb carcass grader, Calc YG = calculated yield grade rounded down to the nearest whole number, RC = percentage closely trimmed retail cuts.

[2]Light: <29.5 kg; moderate: 29.5–38.6 kg; heavy: >38.6 kg.

significantly influenced by slaughter season or commercial processing plant ($P \geq 0.06$). The previous industry audit also found that RFT, USDA YG, and USDA QG increased with HCW (Tatum et al., 1989).

Interrelationships Among Carcass Characteristics

Estimated correlation coefficients between HCW, RFT, BWT, and LMA are displayed in Table 4. All correlation coefficients were significantly different from zero and positive ($P < 0.001$) but varied in magnitude. The strongest correlations were between BWT and HCW (0.73) and BWT and RFT (0.66). Longissimus muscle area and RFT were correlated to a low degree (0.22), and all other correlation coefficients were moderate (0.48–0.58). Snowder et al. (1994) also found strong positive correlations between HCW and fat thickness measurements (RFT, 0.66; BWT, 0.84). The strongest correlation among carcass traits measured by LeValley et al. (1991) was between HCW and RFT (0.42).

Least squares means for the effect of HCW class on other carcass characteristics are displayed in Table 5. As expected from previous models that fit a linear covariate of HCW (Table 3) as well as correlation analyses (Table 4), all traits were significantly affected by HCW class ($P < 0.001$), with a negative relationship for RC and positive relationship for all others. Differences between HCW classes for each trait were additive for LMA and USDA YG but numerically greater between heavy and moderate compared with moderate and light carcasses for other traits.

Least squares means for the effects of USDA YG on other carcass characteristics are displayed in Table 6. All traits were significantly influenced by USDA YG ($P < 0.001$), with a negative relationship for RC and positive relationships for all others. Differences between USDA YG_A within a trait were generally additive from 1 to 4 but greater between 4 and 5. This is likely due to the upper boundary of USDA YG being 5 and having a greater average and variation in carcass fatness than other classes.

Kosulwat et al. (2003) reported a 40% increase in overall fat content when GR measurement increased from 5 mm (fat score 1) to 15 to 20 mm (fat score 4). Fat deposition can be reduced by identifying accurate target end-point weights across genetically diverse breed types, selecting within breed for lean muscle growth (Snowder et al., 1994; Karamichou et al., 2007; Kvame and Vangen, 2007), strategic use of terminal sire breeds (Mousel et al., 2012; Shackelford et al., 2012), and greater inclusion of NDF feedstuffs in the diet to reduce feed intake and rate of gain (Blackburn et al., 1991; Beermann et al., 1995). Lamb and feedstuff price volatility, restricted lamb abattoir capacity, and feedlot backlogs in heavy "old crop" lambs continue to create challenges in mitigating excessive fat deposition.

Results suggest that increased HCW is, on average, associated with greater LMA as well as, unfortunately, greater subcutaneous fat content. Disincentivizing heavy carcasses may indirectly decrease subcutaneous fat levels and overall proportion of excessively fat lambs entering the supply chain. Price signals within the industry for slaughter lambs have taken precedence over biological efficiency, promoting feeding to greater carcass weights at the expense of optimal lean composition (Blackburn et al., 1991; Field and Whipple, 1998).

Differences between subjective and objective yield grading methods (i.e., USDA YG − Calc YG) by USDA YG class are also shown in Table 6. Here, a positive (negative) value for USDA YG − Calc YG indicates that USDA graders estimated a greater (lesser) carcass fat content than suggested solely based on RFT. Carcasses assigned

Table 6. Least squares means (±SE) for the main effect of USDA yield grade (USDA YG) on carcass characteristics of lambs slaughtered in the US Intermountain West, 2018–2019

	USDA YG				
Trait[1]	1	2	3	4	5
HCW, kg	29.9 ± 0.64[e]	32.7 ± 0.52[d]	37.3 ± 0.51[c]	42.1 ± 0.51[b]	47.4 ± 0.54[a]
RFT, mm	3.70 ± 0.26[e]	5.45 ± 0.15[d]	6.98 ± 0.13[c]	8.76 ± 0.14[b]	11.7 ± 0.16[a]
BWT, mm	19.2 ± 0.63[e]	23.5 ± 0.44[d]	28.3 ± 0.41[c]	33.3 ± 0.42[b]	39.9 ± 0.46[a]
LMA, cm^2	14.6 ± 0.26[e]	15.5 ± 0.17[d]	16.4 ± 0.16[c]	17.4 ± 0.16[b]	18.7 ± 0.18[a]
RC, %	49.9 ± 0.21[a]	49.2 ± 0.14[b]	48.2 ± 0.13[c]	47.2 ± 0.13[d]	45.9 ± 0.15[e]
YG USDA – YG Calc	−0.53 ± 0.08*	−0.05 ± 0.05	0.37 ± 0.04*	0.74 ± 0.04*	0.99 ± 0.05*

[a–e]Means within a trait with no common superscript are different ($P < 0.001$).

[1]HCW = hot carcass weight, RFT = 12th rib fat thickness, BWT = body-wall thickness, LMA = longissimus muscle area, RC = percentage closely trimmed retail cuts, Calc YG = calculated yield grade rounded down to the nearest whole number.

*Estimate for USDA YG − Calc YG is different from zero ($P < 0.001$).

USDA YG 1 were, on average, 0.5 Calc YG fatter ($P < 0.001$). There was general agreement between yield grading methods at USDA YG 2, as USDA YG − Calc YG was not different from zero ($P = 0.34$). However, USDA YG − Calc YG became larger at USDA YG 3 and greater ($P < 0.001$), indicating that carcasses were leaner based on RFT alone. Overall, USDA YG and Calc YG methods were in agreement for 37% of lamb carcasses in the current study. DeWalt et al. (1992) and Heaton et al. (1993) verified the accuracy of objective, visual appraisal for assigning USDA YG. When compared with probe measurements, visual estimates of RFT were variable between 3 evaluators, and USDA YG was accurately assigned between 54% and 66% of the time. Correct assignment of USDA YG has a relatively small margin of error, with only 0.1 in fat thickness ranges, so even a small over- or underestimation of fat thickness can lead to incorrect classification of yield grades (DeWalt et al., 1992). Vision-based grading may provide more precise indication of carcass composition and could be used to improve value-based pricing of lamb carcasses but lacks widespread adoption across the lamb industry (Brady et al., 2003)

APPLICATIONS

Based on current findings, season of slaughter influenced HCW and USDA YG but no other carcass characteristics of lambs slaughtered in the Intermountain West. In the current study, over 43% of the 10,027 carcasses surveyed were assigned USDA YG 4 or 5, indicating industry-wide room for improvement. Efforts to reduce the production of excessively fat lambs will require cross-sector strategies that involve all segments of the industry. Currently this challenge is being mitigated by the lamb processor by trimming fat and routing heavier carcasses to alternative market outlets. Additionally, industry-wide efforts that agree on acceptable standards regarding trimness are warranted.

Prospective audits need to be conducted on an industry-defined routine basis and should include monthly sampling to provide a complete picture of carcass characteristics across the calendar year. Regular audits will promote accountability, with the end goal of improving the quality of American lamb and its differentiation from imported product. These audits need to be integrated into educational efforts, to ensure transparency and industry-wide communication for improvement across all segments (consumers, producers, feeders, and packers). Results from this study can provide lamb industry insights into areas of improvement as they relate to fat composition and current production trends.

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