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Impact of Changes in Weight, Fat Depth, and Loin Muscle Depth on Carcass Yield and Value and Implications for Selection and Pricing of Rams from Terminal-Sire Sheep Breeds

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Summary

Breeding objectives and selection indexes are necessary to support comprehensive genetic-improvement programs. This study used off-test body weights (OTBW) or chilled-carcass weights (CCW), ultrasonic measurements of fat depth (USFD, mm), and predicted-ultrasound, loin-muscle depths (USLMD, mm) from 456 wether lambs to predict carcass value and link predictions to estimated breeding values (EBV) of terminal sires. Carcasses were processed by closely trimming high-value cuts (rack, loin, leg, and sirloin), and carcass value (TrCVal) was determined for each carcass. Increasing OTBW had positive effects on carcass value but did not affect dressing percentage (DP). Increasing USFD increased CCW and DP but decreased TrCVal. Increasing USLMD had positive effects on CCW, DP, and TCVal. The EBV for postweaning weight (PWWT), USFD, and USLMD of average and elite Suffolk rams were compared to develop breeding objectives for lambs harvested at a constant time on feed, harvest weight, or harvest fatness, and for a scenario with larger-than-current-price premiums for leanness and muscling. At constant harvest weights, the breeding objective was $I_2 = 1.2\ EBV_{PWWT} - EBV_{USFD} + 0.8\ EBV_{USLMD}$, but changed to $I_4 = 0.3\ EBV_{PWWT} - EBV_{USFD} + 0.4\ EBV_{USLMD}$ if carcass price was strongly influenced by leanness and muscling. Genetic correlations among indexes exceeded 0.85. Index I_4 was strongly correlated with the Australian LAMBPLAN Carcass Plus index, indicating that selection on Carcass Plus would be effective under U.S. conditions. All indexes were dominated by PWWT EBV. Effects of increasing muscling were substantial, but changing USFD EBV had only modest effects.

Key Words: Breeding Objectives, Carcass Value, Genetic Evaluation, Sheep

Introduction

The development of breeding objectives and associated selection indexes is critical to implementation of comprehensive, integrated programs of genetic improvement (Hazel, 1943; Schneeberger et al., 1992). In particular, linkages between breeding objectives in seedstock flocks and profitability in commercial production are essential to ensure the relevance of the seedstock sector. Adoption of value-based marketing procedures in the sheep industry has lagged behind that in other livestock species (NRC, 2008), but recent initiatives in image-based instrument grading of lamb carcasses (Cunha et al., 2004) have provided new opportunities to improve leanness and consumer acceptance of American lamb.

This study utilized data from a comprehensive evaluation of terminal-sire sheep breeds conducted at the U.S. Sheep Experiment Station (Leeds et al., 2012) to develop procedures to link genetic improvement of terminal-sire sheep types to carcass yield, value, and cost of production in crossbred market lambs. Specific objectives of the study were to: 1) describe the relationship between ultrasonic measurements of loin muscle area and depth in lambs; 2) develop equations to predict yield and value of carcasses of crossbred lambs sired by terminal-sire sheep breeds from body or chilled-carcass weights, ultrasonic measurements of fat depth, and predicted ultrasonic measurements of loin-muscle depth; and 3) link these prediction equations to EBVs for post-weaning weights and ultrasonic fat and loin-muscle depths to develop indexes for selection and pricing of rams that are to be used as terminal sires.

Materials and Methods

The U.S. Sheep Experiment Station Institutional Animal Care and Use Committee approved all husbandry practices and experimental, transportation, and harvest procedures used in this study.

Animals and Data

This study used carcasses from 456 crossbred wether lambs produced over 3 yr by mating Columbia, U.S. Meat Animal Research Center Composite, Suffolk, and Texel rams to Rambouillet ewes at the U.S. Sheep Experiment Station in Dubois, Idaho. Sire selection, animal management, diets, ultrasonography, transportation and harvest procedures, and carcass fabrication were described in detail by Leeds et al. (2008, 2012), Notter et al. (2012), Mousel et al. (2012, 2013), and Kirschten et al. (2013).

Lambs were born in March and early April, maintained outdoors in drylot for approximately 30 d, and then herded on sagebrush steppe and subalpine range until weaning at an average of 132 d of age. Within 8 d of weaning, one of three replicated feedlot pens was assigned randomly, within sire breed and sex, to each lamb, and lambs were moved to these pens for the duration of the feeding period. Wether lambs were assigned randomly to one of three harvest groups and scheduled for harvest when mean BW of wethers remaining in the feedlot reached targets of 54.4 kg, 61.2 kg, or 68.0 kg. Lambs were weighed weekly and scanned using ultrasound every 2 wk on the left side between the 12th and 13th ribs to estimate USFD (mm) and loin-muscle area (**USLMA**, cm^2). When wether lambs reached their designated harvest endpoint, off-test BW were taken, and lambs were scanned twice on the left side on the morning before shipment to The Ohio State University Meat Laboratory, Columbus, Ohio for processing. Both USLMA and ultrasonic-loin-muscle depth (**USLMD**, mm) were determined for wethers born in the first year of the study (Leeds et al., 2008), but USLMD was not determined for lambs born in years 2 and 3. Animals remained on feed before determination of off-test weight. Transport to Columbus required approximately 48 hr. Lambs received water and hay during transport, and were provided water and allowed to rest overnight after arrival at the abattoir. A harvest weight was obtained the next morning before slaughter and hot-carcass weights were recorded.

After harvest and chilling for approximately 24 hr, chilled-carcass weight (**CCW**) was recorded, and backfat thickness and loin-muscle area were measured on the left and right side of each carcass. Carcasses were then fabricated (Mousel et al., 2013) and individual cuts were weighed. Weights of high-value cuts (rack, loin, leg, and sirloin) were determined before (**HVW**) and after (**TrHVW**) trimming and removal of bone from leg and sirloin. Weights of boneless sirloin were determined only in 2007 and 2008, but estimated for 2006 from weights of untrimmed, bone-in leg and sirloin (Notter et al., 2014a). Carcass value was determined before (**CVal**) and after trimming of high-value cuts (**TrCVal**) by summing products of weights and average prices for each cut. Prices were derived from daily price reports for lamb cuts in U.S. markets between wk 42 and wk 50 of 2006 through 2009 (Notter et al., 2014a). The TrHVW also was expressed as a percentage of CCW (**TrHV%**) for comparisons with previous studies.

Development of Prediction Equations

Editing of data to identify the 456 carcasses that were used for this study was described by Notter et al. (2014a). Development of equations to predict carcass yield and value followed procedures described by Notter et al. (2014b), but were modified to replace measurements of USLMA with estimates of USLMD, thereby allowing interpretation of prediction equations in the context of measurements of USLMD used in the U.S. National Sheep Improvement Program (**NSIP**). The model used to derive prediction equations included effects of year of measurement, harvest group, sire breed, and year × harvest group and year × breed interactions; a measure of weight (the off-test body weight or chilled-carcass weight); and values for USFD and USLMD derived from ultrasonic measurements taken on the morning of shipment to the abattoir.

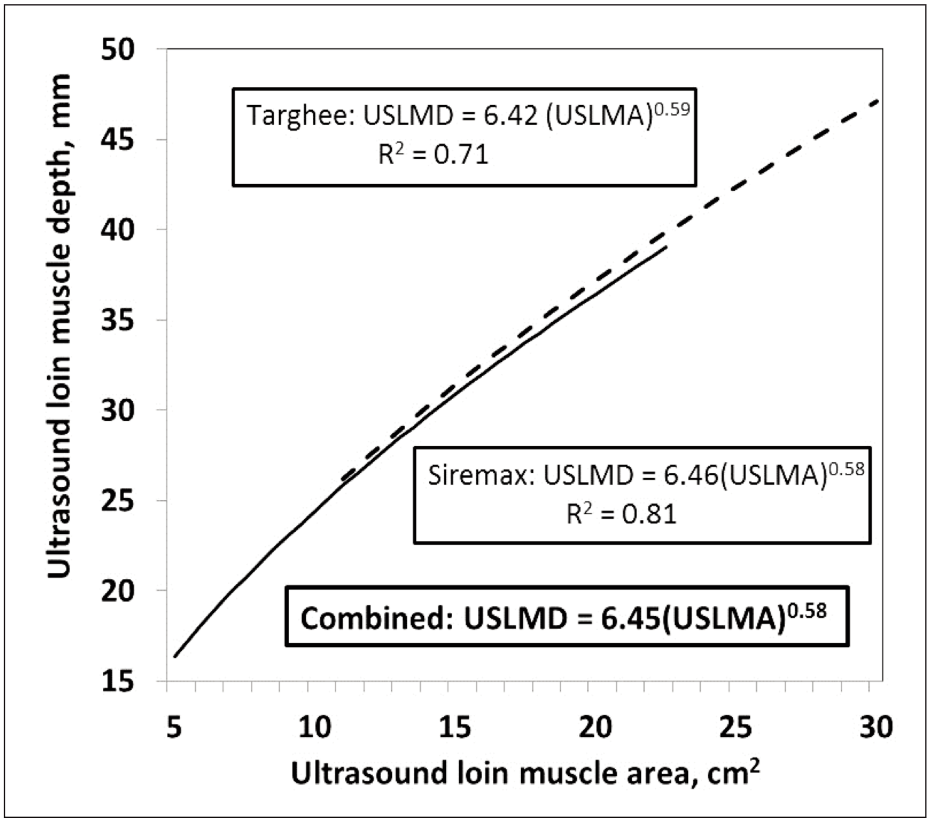
Two data sets were available to predict USLMD from USLMA. The first contained measurements of USLMD and USLMA for 2,607 yearling Targhee rams scanned at an average age of approximately 12 mo over 5 yr in 13 Montana flocks. The second data set contained records on 2,769 Siremax Composite lambs from a single flock scanned over 10 yr at approximately 7 mo of age. Records from each data set were analyzed to predict USLMD using models that included effects of measurement year, flock (for Targhee records), lamb sex (for Siremax lambs), and a continuous effect of USLMA. Measurements of USLMD and USLMA were converted to natural logarithms before analysis, and prediction equations were derived as USLMD = $\alpha(\text{USLMA})^{\beta}$ where β is the power function relating USLMD to USLMA and α is the antilog of the intercept of the prediction equation (Notter et al., 2012).

Predicted USLMD were combined with weights and USFD to predict: 1) harvest BW from off-test BW as an indicator of weight loss during shipping; 2) CCW from off-test body weight and expressed either directly (in kilograms) or as a percentage of BW (i.e., as dressing percentage); and 3) HVW, TrHVW, TrHV%, CVal, and TrCVal from CCW to evaluate effects on carcass yield and value at comparable CCW, or from OTBW to evaluate combined effects of shipping shrink, dressing percentage, and carcass fabrication on carcass yield and value.

Development of Breeding Objectives

Prediction equations were used to assess opportunities for selection and pricing of terminal sires by comparing predictions of TrCVal for NSIP Suffolk rams with EBV in the 50th vs 10th percentiles for 120-d postweaning weights (**PWWT**), postweaning fat (**PFAT**) and postweaning eye-muscle depth (**PEMD**) (June, 2014 Suffolk Percentile Report; nsip.org). The NSIP PEMD EBV is a direct predictor of the EBV for USLMD at the 12th rib. By contrast, the NSIP PFAT EBV is based on measurements of USFD over the 12th rib, but is then multiplied by a factor of three to predict genetic differences in the GR-fat measurement. The GR measurement is taken over the 12th rib and 110 mm ventral to the dorsal midline (AWI and MLA, 2013) and is analogous to the body wall measurement recorded in the United States at the 12th rib and approximately 127 mm from the dorsal midline (Leeds et al., 2008). The PFAT EBV is thus equal to three times the USFD EBV. Alternative harvest and pricing scenarios (e.g., harvest at constant days on test, constant harvest BW, or constant fat depth; direct effects of fatness and loin-muscle size on price per kilogram of trimmed and untrimmed cuts) were subsequently compared with regard to their impact on the breeding objectives.

Figure 1. Relationship between ultrasonic measurements of loin muscle depth (USLMD) and loin muscle area (USLMA) in yearling Targhee rams (dashed line) and Siremax ram and ewe lambs (solid line).



Results and Discussion

Prediction of USLMD from USLMA

Equations to predict USLMD from USLMA in Targhee and Siremax lambs are shown in Figure 1. For Targhee yearling rams, the mean BW at scanning was 84 kg, with a range of 43 kg to 125 kg. Means for LMA and LMD were 19.8 cm^2 (with a range of 11.1 cm^2 to 30.5 cm^2) and 33.7 mm (with a range of 21 mm to 47 mm), respectively. For Siremax lambs, the mean BW at scanning was 46 kg, with a range of 19 kg to 79 kg. Means for LMA and LMD were 12.9 cm^2 (with a range of 4.7 cm^2 to 22.8 cm^2) and 28.5 mm (with a range of 15 mm to 41 mm), respectively. The R^2 for prediction of LMD from LMA was 0.71 for Targhee rams and 0.81 for Siremax lambs. Despite differences in breed type and animal age and the presence of both ewe and ram lambs in Siremax data, resulting prediction equations were remarkably consistent and were combined to yield a common predictor: USLMD = $6.45(\text{USLMA})^{0.58}$. Associations between USLMA and USLMD in these data were consistent with the residual correlation of 0.87 (equivalent to an R^2 of 0.76) reported by Leeds et al. (2008) for 172 wethers born in the first year of the current study.

Prediction of Carcass Yield and Value

Notter et al. (2014b) discussed accuracies of ultrasonic measures of backfat thickness and loin-muscle area for these lambs. Correlations between ultrasonic measurements and actual-carcass measurements were 0.69 for backfat thickness and 0.65 for loin-muscle area and were generally consistent with results of previous studies (e.g., Emenheiser et al., 2010). Prediction equations (Tables 1 and Table 2) differ from those of Notter et al. (2014b) only in use of predicted values of USLMD instead of observed values of USLMA in the prediction equations. Average harvest weight was approximately 89 percent of off-test weight (i.e., 11 percent shrink), with a small favorable effect of increas-

Table 1. Prediction equations, R^2, and residual SD (RSD) for estimation of harvest BW, chilled carcass weight (CCW), and dressing percentage from off-test body weights (OTBW; kg), ultrasonic measurements of fat depth (USFD) and predicted ultrasonic loin muscle depths (USLMD).

	Regression coefficients ± SE				
Prediction[a]	Weight, kg	USFD, mm	USLMD, mm[b]	R^2	RSD
Harvest BW, kg × OTBW	0.885 ± 0.010***	0.005 ± 0.032	0.041 ± 0.020*	0.986	1.038
CCW, kg × OTBW	0.473 ± 0.010***	0.153 ± 0.029***	0.161 ± 0.019***	0.961	1.026
Dressing % x OTBW	-0.022 ± 0.016	0.245 ± 0.047***	0.269 ± 0.031***	0.412	1.656

[a] Predictand × weight predictor.
[b] Predicted from ultrasonic loin muscle area (USLMA; cm^2) as USLMD = $6.45(\text{USLMA})^{0.58}$.
*, **, ***: $P < 0.05$, 0.01, and 0.001, respectively.

Table 2. Prediction equations, R^2, and residual SD (RSD) for estimation of carcass yield and value from weights (kg), ultrasonic measurements of fat depth and predicted ultrasonic loin muscle depth[a]

		Regression coefficients ± SE				
Predictor	Prediction[b]	Weight, kg	USFD, mm	USLMD, mm[c]	R^2	RSD
CCWT +						
ultrasound measures	HVW, kg × CCW	0.494 ± 0.007***	0.021 ± 0.011*	0.038 ± 0.007***	0.980	0.375
	TrHVW, kg × CCW	0.302 ± 0.006***	-0.093 ± 0.009***	0.051 ± 0.006***	0.956	0.325
	TrHV% × CCW	-0.075 ± 0.019***	-0.304 ± 0.031***	0.154 ± 0.020***	0.608	1.053
	CVal, $ × CCW	5.226 ± 0.047***	0.230 ± 0.075**	0.206 ± 0.050***	0.992	2.567
	TrCVal, $ × CCW	5.304 ± 0.066***	-1.125 ± 0.106***	0.499 ± 0.070***	0.982	3.641
Off-test BW +						
ultrasound measures	HVW, kg × OTBW	0.230 ± 0.006***	0.102 ± 0.019***	0.122 ± 0.012***	0.940	0.658
	TrHVW, kg × OTBW	0.141 ± 0.004***	-0.044 ± 0.013***	0.102 ± 0.009***	0.911	0.460
	CVal, $ × OTBW	2.459 ± 0.057***	1.052 ± 0.174***	1.067 ± 0.114***	0.952	6.082
	TrCVal, $ × OTBW	2.505 ± 0.062***	-0.308 ± 0.189†	1.361 ± 0.123***	0.942	6.587

[a] OTBW = off-test BW, HW = harvest weight, CCW = chilled carcass weight, HVW = weight of high-value cuts, TrHVW = weight of trimmed high-value cuts, CVal = carcass value, TrCVal = carcass value after trimming of high-value cuts, USFD = ultrasonic fat depth, USLMD = predicted ultrasonic loin muscle depth.
[b] Predictand × weight predictor.
[c] Predicted from ultrasonic loin muscle area (USLMA; cm^2) as USLMD = $6.45(\text{USLMA})^{0.58}$.
†, *, **, ***: P < 0.10, 0.05, 0.01, and 0.001, respectively.

ing USLMD. Effects of USLMD were positive and strongly significant for dressing percentage and all measures of carcass yield and value. After adjusting for off-test body weight, residual standard deviations (RSD) were 1.18 mm for USFD and 1.80 mm for USLMD. At comparable off-test weight, a decrease of 1 RSD in USFD thus reduced TrCVal by $0.36 [1.18 x (-0.308) from Table 2] and an increase of 1 RSD in USLMD increased TrCVal by $2.45 (1.80 x 1.361).

Breeding Objectives for Terminal-Sire Sheep Breeds

Differences in EBV between elite (preferred 10th percentile) and average (50th percentile) lambs (Table 3) were 4.68 kg for PWWT, 0.33 mm for USFD (equivalent to 0.99 mm in PFAT EBV), and 1.43 mm for USLMD and corresponded to predicted differences in lamb performance for PWWT, USFD, and USLMD of 2.34 kg, 0.165 mm, and 0.715 mm, respectively. Based on equations in Table 2, and assuming that differences in EBV for PWWT, USFD, and USLMD in purebred lambs were directly predictive of differences in OTBW, USFD, and USLMD in crossbred market wethers, observed differences in EBV between rams in the 10th versus 50th percentiles were expected to generate differences in TrCVal for 100 market lambs of $586 for 120-d postweaning weight, $5 for fat depth, and $97 for loin-muscle depth. Dividing these expected differences by observed differences in EBV between rams in the difference percentiles and scaling of coefficients relative to a value of 1.0 for the USFD EBV provided a lamb-value index (I0) for terminal-sire rams of:

$$I_0 = 8.1\ EBV_{PWWT} - EBV_{USFD} + 4.4\ EBV_{USLMD}.$$

This equation can be used to relate differences in ram EBV to anticipated differences in lamb carcass value. However, in terms of the relative importance of the different traits in breeding programs, the most appropriate scalar is the additive genetic SD for each trait in the population. For NSIP Suffolks, these val-

Table 3. EBV for average (50% percentile) and elite (preferred 10% percentile) Suffolk lambs and additive SD for 120-d postweaning weight (kg), ultrasonic fat depth (mm), and ultrasonic loin muscle depth (mm).[a]

	Mean EBV by percentile			
EBV	**10th**	**50th**	**Difference**	**Additive SD**
120-day Post-weaning Weight	7.62	2.94	4.68	4.17
Ultrasonic fat depth[b]	-0.67	-0.34	0.33	0.57
Ultrasonic loin muscle depth[b]	2.48	1.05	1.43	1.30

[a] Based on NSIP June 2014 Suffolk Percentiles.

[b] The ultrasonic fat depth EBV is equal to one third the reported LAMBPLAN postweaning fat EBV. The ultrasound loin muscle depth EBV is the same as the reported LAMBPLAN postweaning eye muscle depth EBV.

ues are 4.17 kg for PWWT, 0.57 mm for USFD, and 1.30 mm for USLMD. On this scale, rams in the upper 10th percentile for PWWT, lower 10th percentile for USFD, and upper 10th percentile for USLMD were superior to average Suffolk rams by 1.12, 0.58, and 1.10 additive SD, respectively. Predicted changes in the value of 100 market lambs associated with changes of one additive SD in sire EBV for each trait were therefore $523 for PWWT, $9 for USFD, and $88 for USLMD. These values provide estimates of the relative importance of these three traits in defining carcass value in crossbred lambs.

Index I_0 does not consider changes in feed costs associated with differences in postweaning performance, so predicted-energy requirements of lambs sired by average and elite rams were compared. Performance of lambs sired by average rams was assumed equal to that reported by Notter et al. (2012), Mousel et al. (2012), and Kirschten et al. (2013). We assumed that lambs were weaned into a feedlot at a mean age of approximately 130 d, a mean-weight of 39 kg, and a mean-fat depth of 2 mm. Lambs were assumed to gain at an average rate in the feedlot of 278 g/d and be harvested after 90 d on feed at a mean weight of 64 kg and mean-fat depth of 6.5 mm. Postweaning ME requirements were estimated (NRC, 2006) to be 468.9 Mcal: 41.2 percent of ME was predicted to be associated with maintenance requirements and 58.8 percent was required for gain. Maintenance requirements were based on averages of metabolic body weights ($kg^{0.75}$) at weaning and harvest. Equations from Notter et al. (1983) were used to predict body energy density (ED, Mcal/kg) from USBF as ED = $32.18e^{0.464\ USFD^{0.386}}\ USFD^{0.390}$. This equation was then used to predict energy density of postweaning gains from USBF at weaning and harvest and combined with NRC (2006) equations to predict energy requirements for gain. The predicted-energy density of postweaning gains by progeny of average rams harvested at 90 d after weaning was 5.51 Mcal/kg. The predicted efficiency of ME use (i.e., predicted lamb gain per unit of ME consumed) was 0.533 kg/Mcal, which was within 5 percent of the value observed for these lambs at 90 d postweaning (Kirschten et al., 2013). The average-energy density of the diet was assumed to be 2.92 Mcal/kg DM with a dry matter content of 89 percent. The predicted feed:gain ratio at 90 d postweaning was 7.22 kg feed/kg gain.

Rams in the upper 10th percentile for PWWT had EBV that were 4.68 kg larger than those of average rams, indicating that, at comparable ages, lambs from high-growth rams were expected to be 2.34 kg heavier than lambs from average rams. This difference was expected to evolve throughout the postnatal period, and we arbitrarily assumed that 50 percent of the difference (1.17 kg) was present at weaning and 50 percent was associated with differences in postweaning growth. Progeny of high-growth rams were correspondingly predicted to be 3 percent heavier at weaning, grow 4.7 percent faster during the postweaning period, be 3.7 percent heavier at 90 d postweaning, and have 2.0 percent greater cumulative maintenance requirements from weaning to 90 d. Economic weightings in breeding objectives are partial regression coefficients representing the effect of a 1-unit change in genetic merit (i.e., EBV) for each trait, holding EBV for all other traits in the breeding objective constant at their mean. Effects of changing PWWT EBV were therefore modeled assuming no changes in EBV for ultrasonic fat or muscle depths at comparable-scanning weights (i.e., at 64 kg). Because progeny of high-growth sires were assumed harvested at heavier weights and to not differ in leanness from progeny of average sires at comparable harvest weights, progeny of high-growth sires were anticipated to be fatter at harvest, with 0.3 mm more fat depth at a projected harvest weight of 66.4 kg, 1.9 percent greater energy density of postweaning gains, 7 percent greater feed requirements for growth, and 4.9 percent greater total postweaning feed requirements.

Rams in the lower 10th percentile for USFD had EBV that were 0.33 mm less than those of average rams, corresponding to an expected reduction in fat depth in their crossbred progeny of 0.165 mm (i.e., from 6.5 mm to 6.335 mm at 90 d postweaning). Based on relationships from Notter et al. (1983), this change in fat depth was predicted to correspond to a decrease of 0.7 percent in energy density of gains in progeny of low-fat sires and a reduction of 0.4 percent in total-feed requirements to a weight of 64 kg at 90 d postweaning. For loin-muscle depth, rams in the upper 10th percentile had EBV that were 1.4 mm greater than average rams, corresponding to a predicted difference of 0.7 mm in progeny of the two groups of rams. Effects of muscling per se in the breeding objective were assessed at comparable EBV for PWWT and USFD. Given this assumption, no effect on feed requirements was associated with changes in USLMD EBV. After adding effects of predicted changes in feed intake to predictions of carcass yield and value in Table 2 at a cost of $0.24/kg of diet (Kirschten et al., 2011), differences in returns-minus-feed costs for 100 lambs sired by rams in the preferred 10th percentile and average rams and marketed after comparable numbers of days on feed was $372 for PWWT, $22 for FD, and $95 for USLMD. Scaling these differences for differences in EBV and expressing them relative to a coefficient of 1.0 for USFD EBV resulted in a postweaning net-value index (I_1) of:

$$I_1 = 1.2\ EBV_{PWWT} - EBV_{USFD} + EBV_{USLMD}.$$

In most feedlot-production systems, lambs are more likely to be marketed at comparable BW or degrees of fatness instead of after comparable numbers of days on feed. Marketing of lambs at comparable BW appears to remove effects of differences in PWWT EBV but, in fact, merely shifts the impact of differences in growth rate away from effects on weight of lamb marketed per se to effects on costs (i.e., time and feed) required to reach the target-harvest weight. If lambs were marketed at a weight of 64 kg, then lambs from rams in the upper 10th percentile for PWWT would be expected to reach this weight approximately 8.1 d sooner than progeny of an average ram and have 2.5 percent higher daily maintenance requirements but 9.0 percent lower total maintenance requirements and 7.5 percent lower total postweaning feed requirements. Progeny of high- and low-growth sires were assumed to not differ in FD or USLMD at comparable harvest weights, so the energy density and partial efficiency of gain did not differ between the two groups.

For lambs harvested at a fixed weight of 64 kg, costs of time on feed (i.e., yardage in the lamb feedlot) were set at \$0.17/d (Cornell University Sheep Program, 2013). Postweaning feedlot costs to a constant-harvest-weight endpoint were therefore predicted to be \$4.65/head less, and net returns for 100 progeny were predicted to be \$465 more, for sires in the 10th versus 50th percentile for PWWT. Differences associated with sire differences in USFD and USLMD at comparable PWWT EBV were identical to those estimated for time-constant harvest at a mean weight of 64 kg. This change in marketing policy thus resulted in a small change in the relative importance of PWWT compared to ultrasound EBVs and yielded a postweaning, net-value index for weight-constant harvest of:

$$I_2 = 1.5\ EBV_{PWWT} - EBV_{USFD} + EBV_{USLMD}.$$

If lambs were harvested at a fixed fat depth of 6.5 mm, effects of changing PWWT EBV were the same as those predicted for weight-constant harvest because the target-harvest weight of 64 kg for progeny of average sires corresponded to a fat depth at harvest of 6.5 mm. Effects of changing sire EBV for loin-muscle depth were likewise unchanged from previous scenarios. However, reducing sire EBV for fat depth by 0.33 mm allowed lambs to be harvested at heavier weights. Mousel et al. (2012) predicted that carcass-fat depth in these lambs was proportional to the 1.28 power of BW. Thus lambs with a fat depth of 6.5 mm at 64 kg were predicted to have 6.335 mm of fat depth at 65.3 kg and, at an average daily gain of 278 g/d, to require 5 more days on feed and 5.5 percent more postweaning feed to gain an additional 1.3 kg. The value of the additional harvest weight (Table 2) was \$3.26, and combined effects of yardage and increased feed costs were \$3.15, resulting in an increase of only \$0.11/head in net returns. The value of extending the feeding period and increasing harvest weight by reducing fatness without corresponding increases in growth rate was thus almost completely taken up by increased production costs. The resulting postweaning, net-value index with harvest at a fixed-fat depth (i.e., at a fixed Yield Grade) was:

$$I_3 = 3.0\ EBV_{PWWT} - EBV_{USFD} + 2.0\ EBV_{USLMD}.$$

The reduced impact of changes in USFD EBV assumed no time trends in carcass price. However, under seasonal-production conditions, price premiums could be available for lambs that could be harvested later in the year without becoming excessively fat and would increase the value of reducing USFD EBV. Index I_3 became essentially equivalent to I_2 if the extra time to reach 6.5 mm of USFD was accompanied by weekly lamb price increases for properly finished lambs that approached \$0.01/kg.

Effects of reducing fatness in I_1 through I_3 were based only on differences in weights of trimmed and untrimmed cuts. However, as discussed by Notter et al. (2014b), these predicted effects of increasing leanness may be conservative, because no price penalty was assessed for effects of fatness on yield and value of less valuable cuts such as the shoulder and breast. Also, differences in fat content of the leg and loin after trimming were expected to be small, but trimming of racks from fatter lambs almost certainly did not remove all differences in fat content. Results in Table 2 do not consider possible changes in value (\$/kg) for carcasses with larger loin-muscle areas beyond that associated with changes in the yield of trimmed, high-value cuts. These assumptions are largely justified for terminal-sire sheep types harvested with fat depths of < 9.1 mm (i.e., at Yield Grade 3 or less) and for markets that do not provide premiums for larger loin-muscle areas. However, to provide for sensitivity analysis and accommodate possible future increases in emphasis on leanness and loin-muscle size, weightings for EBV for USFD and USLMD in I_2 were arbitrarily increased by 4-fold and 2-fold, respectively, resulting in a net value index of:

$$I_4 = 0.4\ EBV_{PWWT} - EBV_{USFD} + 0.5\ EBV_{USLMD}.$$

Index coefficients in I_4 assumed corresponding substantial price premiums (\$/kg) for leaner and more muscular carcasses. For USFD, a 4-fold increase in value associated with reductions in fatness compared to I_2 required an increase in carcass price of \$0.204/kg for each 1 mm reduction in fat depth (equivalent, in imperial units, to a carcass price discount of \$23.55/cwt for each increase of 0.10 inches in carcass fat depth). Price discounts for fatness of this magnitude exist in the U.S. sheep industry, but usually only at boundaries between Yield Grades 3 and 4 or Yield Grades 4 and 5. Index I_4 might therefore be appropriate for markets in which frequencies of lambs in Yield Grades 4 and 5 are high, due either to use of small-framed, early-maturing breeds or marketing of very heavy carcasses, but is unlikely to be optimal for relatively lean lambs produced in the current study using typical, and readily available, terminal sires.

An increase in emphasis on USFD may be justified if differences in EBV for USFD in purebred rams have multiplicative rather than additive effects on FD in crossbred market lambs. Measurements of USFD in growing rams of terminal-sire breeds reported to NSIP seldom exceed 7 mm. In contrast, the boundary between Yield Grade 3 and 4 corresponds to a fat depth of 9.1 mm. We assumed that a change of 1 mm in USFD EBV (corresponding to an approximate mean change of from 5 mm to 6 mm, or 20 percent) in terminal-sire rams would correspond to a change of 0.5 mm in their progeny. However, at a mean FD in the progeny of 8 mm, a 20 percent change in EBV could be hypothesized to

Table 4. Index coefficients, impact of a one-unit change in sire EBV on net value of 100 market lambs (shown in parentheses), and genetic correlations of indexes with 120-d postweaning body weight for alternative terminal-sire breeding objectives.

		EBV coefficient and impact on lamb value for:[a,b]				Genetic correlation
Index	Description	WWT	PWWT	USFD	USLMD	with PWWT
I_1	Harvest at constant time on feed	-	1.2 ($79)	-1.0 ($67)	1.0 ($66)	0.96
I_2	Harvest at constant body weight	-	1.5 ($100)	-1.0 ($67)	1.0 ($66)	0.97
I_3	Harvest at constant fat depth	-	3.0 ($100)	-1.0 ($33)	2.0 ($66)	0.98
I_4	Increase coefficients in I2 for EBVUSFD (4X) and EBVUSLMD (2X)	-	0.4 ($100)	-1.0 ($267)	0.5 ($133)	0.88
I_{CP}	LAMBPLAN Carcass Plus Index	0.2	0.3	-1.0	0.9	0.73

[a] WWT = weaning weight, PWWT = 120-d postweaning weight, USFD = ultrasonic postweaning fat depth, USLMD = ultrasonic postweaning loin muscle depth.

[b] Published LAMBPLAN EBV for postweaning fat (PFAT) are equal to 3 times the USFD EBV. Indexes using PFAT EBV should therefore have coefficients for PWWT and USLMD multiplied by 3.0 and the impact of a one-unit change in PFAT EBV would be one-third that listed for a one-unit change in USFD EBV. The USLMD EBV is equal to the published LAMBPLAN postweaning eye muscle depth (PEMD) EBV; no additional changes are required to use the PEMD EBV.

result in a realized change of 10 percent, or 0.8 mm, in the progeny. Such a change would result in a 30 percent increase in the coefficient for EBV_{USFD} in indexes I_1, I_2, and I_3.

Doubling of emphasis on USLMD in I_4 compared with I_2 would require an increase in carcass price of $0.114/kg for each 1 mm increase in USLMD. In practice, such a relationship between carcass price and USLMD would correspond to an increase in carcass price at constant CCW of $0.41/kg ($18.65/cwt) in association with an increase in loin-muscle area from 16.10 cm2 to 19.35 cm^2 (i.e., from 2.5 in^2 to 3.0 in^2). While perhaps not unreasonable, premiums of this magnitude for increases in loin-muscle area are not generally available in U.S. markets.

Indexes I_1 through I_4 (Table 4) are potentially appropriate breeding objectives for terminal-sire sheep types in U.S. flocks, depending on assumptions about harvest endpoints and pricing of carcasses. The relative importance of PWWT, USFD, and USLMD appears to differ considerably among these indexes. However, genetic correlations among the indexes, derived using genetic parameters for NSIP terminal-sire breeds (Table 5), were very high, indicating that these indexes would result in selection of similar breeding animals. For I_1, I_2, and I_3, genetic correlations among indexes exceeded 0.98. The genetic correlation between I3 and I_4, despite an apparent strong difference in emphasis on leanness between the two indexes, was still 0.96. Genetic correlations were high because, despite differences in relative emphasis among indexes, the basic pattern of emphasis (positive for PWWT and USLMD and negative for USFD) was the same for all indexes and the higher additive genetic variance for PWWT relative to ultrasound EBV caused PWWT to dominate all indexes. Genetic correlations of PWWT with I_1 through I_3 exceeded 0.95, and the genetic correlation between PWWT and I_4, despite substantial emphasis on fatness and muscling in I_4, was 0.88.

The LAMBPLAN "Carcass Plus" index (Sheep Genetics, 2013) has been used as a terminal-sire index in NSIP flocks. Carcass Plus is a "desired gains" index (Gibson and Kennedy, 1990) with relative emphases of 30 percent, 35 percent, 5 percent, and 30 percent on LAMBPLAN EBV for weaning and postweaning weights, PFAT and PEMD.

Table 5. Genetic parameters for U.S. National Sheep Improvement Program terminal-sire sheep breeds.

		Additive variances and genetic correlation[b]			
Trait[a]	Heritability	WWT	PWWT	USFD	USLMD
WWT	0.15	4.5	8.0	-0.55	-0.83
PWWT	0.28	0.90	17.4	-1.21	-2.06
USFD	0.24	-0.45	-0.51	0.325	-0.12
USLMD	0.39	-0.30	-0.38	-0.16	1.69

[a] WWT = 60-d weaning weight, PWWT = 120-d postweaning weight, USFD = ultrasonic postweaning fat depth, USLMD = ultrasonic postweaning loin muscle depth.

[b] Additive genetic variances are shown on the diagonal. Additive genetic covariances and correlations are shown above and below the diagonal, respectively.

The EBV weightings in the index were 2.33, 3.50, -4.07, and 11.40, respectively. For comparison with the current study, the PFAT EBV in the Carcass Plus index can be replaced with (3 USFD EBV) and then scaled by the USFD EBV to give:

$$I_{CP} = 0.2\ EBV_{WWT} + 0.3\ EBV_{PWWT} - EBV_{USFD} + 0.9\ EBV_{USLMD}$$

Using genetic parameters for NSIP terminal-sire breeds (Table 5), I_{CP} had a genetic correlation with PWWT of 0.73 and a genetic correlation with I_4 of 0.96. Genetic correlations of ICP with I_1 through I_3 exceeded 0.85. Selection on Carcass Plus thus had essentially the same results as selection on indexes derived in this study.

Indexes derived in this study specifically addressed production of rams for use as terminal sires in commercial crossbreeding. Breeding objectives were based on differences in only crossbred-lamb value and postweaning costs. Differences in EBV for PWWT, USFD, and USLMD among terminal sires were assumed to not affect ewe productivity (i.e., fertility, prolificacy, and lamb survival). This assumption was supported by a lack of differences in ewe productivity among four diverse, terminal-sire sheep breeds under Western-range conditions (Leeds et al., 2012). However, breed effects on ram survival were reported under summer-breeding conditions in California (McInturff, 2001) and effects of sire breed on survival of crossbred lambs were reported by Leymaster and Jenkins (1993). Accurate estimates of genetic correlations between production traits and measures of reproduction and lamb survival in terminal-sire breeds are not available, but given the low heritabilities of reproduction and fitness traits (Safari et al., 2005), are unlikely to have a major impact on breeding objectives for terminal-sire breeds.

Effects of differences in EBV on preweaning-production costs were not explicitly considered. We assumed that these costs generally accrued on a per-ewe basis and were unlikely to be influenced in an important way by differences in preweaning-lamb-growth rate or composition. We likewise did not attempt to address the relative importance of differences in weaning weight versus PWWT EBV in selection of terminal sires. The genetic correlation between weaning and postweaning weights in U.S. Suffolk sheep was 0.90 (Table 5), so little opportunity exists to use selection within terminal sire breeds to genetically modify the growth curve (i.e., to change the proportion of the postweaning weight achieved at weaning). The relative importance of weaning weight and postweaning gain in defining lamb value will depend on the production and marketing system, with greater emphasis on weaning weight in feeder-lamb production and less discrimination between effects of weaning weight and postweaning gain if the producer retains ownership of the lambs until harvest. Genetic modification of the proportion of the final-harvest weight achieved by weaning mainly involves selection among maternal breeds and the relative importance assigned to direct and maternal effects on weaning weight in selection of sires of replacement ewes.

Costs of production in terminal-sire breeding flocks were not explicitly considered and not anticipated to have a major impact on breeding objectives. Terminal sires in this study were each assumed to produce 100 crossbred progeny. With favorable assumptions regarding production parameters in purebred flocks (i.e., 90 percent ewe fertility, an average of 1.7 lambs born per ewe lambing, 90 percent lamb survival, equal numbers of ram and ewe lambs, and culling of the bottom 25 percenr of ram lambs), approximately 1.9 purebred matings were required to produce a commercial ram. Under less favorable conditions (85 percent ewe fertility, 80 percent lamb survival, and culling of the bottom 50 percent of ram lambs), this number increased to 3.5 purebred matings per commercial ram. The impact of differences in cost of production associated with an average of perhaps 2.5 purebred ewes was expected to be small relative to differences in cost and value for 100 market lambs.

Conclusion and Implications

Results of this study confirmed that postweaning body weight was the primary determinant of terminal-sire value across a wide range of production systems and marketing scenarios. Effects of increasing loin-muscle depth and decreasing fatness were also positive, but smaller than effects of increasing postweaning growth. The LAMBPLAN Carcass Plus index was shown to be an effective, terminal-sire index for U.S. producers.

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