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Evaluation of Dorset, Finnsheep, Romanov, Texel, and Montadale breeds of sheep: IV. Survival, growth, and carcass traits of F₁ lambs^{1,2}

B. A. Freking³ and K. A. Leymaster

ARS, USDA, U.S. Meat Animal Research Center, Clay Center, NE 68933-0166

ABSTRACT: The objectives of this study were to estimate effects of sire breed (Dorset, Finnsheep, Romanov, Texel, and Montadale), and dam breed (Composite III and Northwestern whiteface) on survival, growth, carcass, and composition traits of F₁ lambs. Effects of mating season (August, October, and December) were estimated for survival and growth traits. Data were collected on 4,320 F₁ lambs sired by 102 purebred rams over 3 yr. Birth weight was recorded on all lambs, and subsequent BW were adjusted to 56 (weaning), 70, and 140 d of age (n = 3,713, 3,654, and 3,579 observations, respectively). Survival of dam-reared progeny (n = 4,065) to weaning was recorded. Each year, wethers from October matings were slaughtered in three groups at 25, 29, and 33 wk of age to obtain carcass data (n = 546). In addition to standard carcass traits, resistive impedance measurements were recorded on the warm carcass to predict lean mass. Dam breed ($P = 0.37$) did not influence lamb survival to weaning, but sire breed ($P < 0.05$) was important. Romanov-sired lambs excelled

in survival rate to weaning (94.1%), followed by Finnsheep (93.0%), Texel (90.7%), Dorset (90.0%), and Montadale (89.1%) sired progeny. Lower ($P < 0.01$) postweaning growth rate was observed for Texel (267 g/d) and Finnsheep (272 g/d) sired progeny than for Dorset (285 g/d), Montadale (282 g/d), and Romanov (278 g/d) sired progeny. Sire breed and dam breed were generally significant for most carcass traits. Breed differences in distribution of carcass fat and carcass shape were detected; however, carcass composition was similar for all sire breeds when compared at a constant carcass weight. When evaluated at a constant 12th-rib fat depth, carcasses of lambs from Finnsheep, Romanov, and Texel sires produced 1 to 1.5 kg less ($P < 0.001$) predicted lean mass per lamb than carcasses of lambs from Dorset and Montadale sires. These experimental results provide information about the direct breed effects for survival, growth, and carcass traits of these breeds and their potential use in crossbreeding systems.

Key Words: Breeds, Carcass Composition, Growth, Sheep, Survival

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Introduction

Commercial lamb production in the United States would benefit greatly by systematic use of the genetic diversity among breeds of sheep in structured crossbreeding systems (Leymaster, 2002). Comprehensive evaluation of breeds provides necessary information on use of breeds in crossing systems that exploit effects of

heterosis and complementarity to meet specific production and marketing objectives. Terminal crossbreeding systems use breeds in paternal roles to produce crossbred lambs that excel in traits associated with survival, lean growth rate, and carcass composition. A large comprehensive experiment was completed to evaluate Dorset, Finnsheep, Romanov, Texel, and Montadale breeds in both paternal and maternal crossbreeding roles. The extensively studied dual-purpose Dorset and prolific Finnsheep breeds served as standards for comparison in this experiment (Fogarty et al., 1984; Young et al., 1996). Comparative data in the scientific literature to estimate breed effects for survival, growth, and carcass traits are less extensive for Romanov and Texel (Ricordeau et al., 1990; Gallivan et al., 1993; Leymaster and Jenkins, 1993), and nonexistent for Montadale. The Montadale breed was developed in the United States by crossing Cheviot rams with Columbia ewes.

The objective of this study was to estimate effects of sire breed (Dorset, Finnsheep, Romanov, Texel, and

¹L. Young (deceased) provided leadership for conceiving, designing, and conducting this experiment.

²Mention of trade names is necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the same by USDA implies no approval of the product to the exclusion of others that may also be suitable.

³Correspondence: P.O. Box 166 (phone: 402-762-4278; fax: 402-762-4173; e-mail: freking@email.marc.usda.gov).

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Montadale), and dam breed (Composite III [CIII] and Northwestern whiteface [WF]) on survival, growth, carcass, and compositional traits of F₁ lambs. Effects of mating season (August, October, and December) were estimated for survival and growth traits.

Experimental Procedures

General Information

A detailed description of the general design, germplasm sampling, and flock management for this experiment was presented by Freking et al. (2000). Dorset, Finnsheep, Romanov, Texel, and Montadale rams were mated to CIII (Leymaster, 1991) and WF ewes in an annual lambing system for 3 yr. Three separate 35-d fall mating seasons, beginning approximately August 5, October 15, and December 15, were used each year. Six rams sampled from each breed were used in all three mating seasons within a year unless rams became injured or sick, in which case the affected rams were replaced. This design avoided confounding between mating season and sampling of rams. During this study, 20, 21, 19, 23, and 19 rams were sampled from the Dorset, Finnsheep, Romanov, Texel, and Montadale breeds, respectively. Effects of these sire breeds on reproduction of CIII and WF ewes were reported by Freking et al. (2000). To evaluate these five breeds for use in crossbreeding systems, we report herein data regarding survival, growth, and carcass traits recorded on F₁ lambs produced from these matings. In total, 4,320 F₁ lambs were born during 1991, 1992, and 1993 at the U.S. Meat Animal Research Center (MARC).

Description of Traits

Traits were defined and analyzed as traits of individual lambs. It was our objective that estimates of sire breed effects on survival, growth, and carcass traits have inference to lambs reared by their own dam. Data collected on artificially reared or cross-fostered lambs subsequent to birth were not analyzed. This decision excluded data recorded on 255 lambs from further analyses. Survival (0, 1) to weaning was thus recorded on 4,065 dam-reared lambs. Weights were adjusted to 56 (n = 3,713), 70 (n = 3,654), and 140 (n = 3,579) d of age by use of individual growth rates during the previous adjacent interval. Preweaning ADG was calculated between birth and weaning. Postweaning ADG was calculated between 70 and 140 d of age.

First-cross wether lambs from the October mating season each year were slaughtered at the MARC abattoir (n = 546). Lambs were fed ad libitum a total mixed diet (2.96 Mcal of ME/kg of DM with 14.5% CP) during the finishing period. Ninety-one of the 102 sires sampled in the experiment produced progeny with carcass data. A group of wethers was slaughtered at each of three ages at approximately 25, 29, or 33 wk of age each year. Within each of the 10 combinations of sire

breed and dam breed, lambs were ranked within sire for 20-wk weight and assigned to each slaughter group to represent progeny of a sire over as many slaughter groups as possible. Weight at 20 wk was used to equalize genetic potential for growth among slaughter groups. Live weight of lambs was recorded just before slaughter. Kidney-pelvic fat was stripped from the carcass on the kill floor and weighed. Hot carcass weight was recorded after removal of kidney-pelvic fat. Carcass length was measured on the dorsal surface of the spine from approximately the fourth sacral vertebra to the midpoint of the shoulder blade. After a 24-h chill, each carcass was measured for s.c. fat depth at the midline on the fourth sacral vertebra, fat depth three-fourths of the distance over the LM at the 12th rib, and LM area between the 12th and 13th ribs.

Resistive impedance measurements were made on the warm carcass as a nondestructive technique to predict lean mass. For a detailed discussion of the measurement and physiological basis of resistive impedance, see Jenkins et al. (1988). Resistance exploits the differential conductivity between fat-free mass and fat to predict composition (Lukaski et al., 1986). The measurement of resistive impedance was recorded with a tetrapolar impedance plethysmograph (model BIA-101, RJL Systems, Inc, Detroit, MI). One source electrode was attached to the flexor muscle complex of a fore leg, and the second source electrode was attached to the extensor complex of a rear leg. A detector electrode was attached to each of the remaining legs at corresponding muscles. An equation to predict soft tissue fat-free mass (carcass protein + carcass water) was developed from complete carcass composition and impedance data collected on 45 Suffolk- and Texel-sired crossbred wethers (Jenkins and Leymaster, personal communication). This prediction equation included a linear coefficient for carcass weight, linear and quadratic coefficients for fourth sacral vertebra fat depth, and a linear coefficient for impedance ratio. Impedance ratio is the square of the distance between the source and detector electrodes divided by the resistance (Jenkins et al., 1988). This prediction equation was chosen over other models because it was the most parsimonious model with a high R² value (97%) and a minimized residual standard deviation of 0.291 kg.

Statistical Analyses

Data were analyzed with the mixed model ANOVA procedure of SAS (SAS Inst., Inc., Cary, NC). Survival to weaning was analyzed as a binary trait; therefore, significance levels should be interpreted with caution. Similar estimates of fixed effects can be expected for lamb mortality obtained using both survival and logistic analyses (binary trait), with the latter having a slightly larger standard error (Southey et al., 2001). The model for survival and growth traits included effects of year of lamb birth (1991, 1992 or 1993), sire breed (Dorset, Finnsheep, Romanov, Texel, or Montadale), dam

breed (CIII or WF), mating season (August, October, or December), sex of lamb (wether or ewe), all two-way interactions among these fixed effects, and the three-way interaction of sire breed \times dam breed \times season. The random effect of individual sires within year and sire breed was also fitted. Significance levels associated with effects of year, sire breed, and year \times sire breed were tested using the sire within year and sire breed mean square and were considered approximations due to unbalanced data. Remaining fixed effects were tested against the residual mean square. The Satterthwaite option was used to approximate denominator degrees of freedom associated with the random effect of sire within year and sire breed (approximately 75 df for each trait).

Carcass traits were collected only on wether lambs produced from the October mating season; thus, effects fitted were year of lamb birth, sire breed, dam breed, and complete two-way interactions. Carcass data were analyzed with age, carcass weight, or s.c. fat depth at the 12th rib fitted as single covariates. Preliminary analyses fitted linear and quadratic regressions within sire breed, dam breed, and sire breed \times dam breed; however, effects of subclass regressions were not significantly different and the final model fitted pooled linear and quadratic (when significant) covariates.

The estimated variance component for sires within year and sire breed was 0.0 for several traits when 12th-rib fat depth was included as the covariate. This value resulted in default to a model that included only fixed effects, testing all effects against the residual variance component. We chose to conduct a more conservative test, and thus calculated a sire variance component assuming a heritability of 0.15 and the phenotypic (residual) variance from the fixed model. The assumed variance components for sires and the residual were specified as parameters in the equations and solutions calculated without iteration. For these analyses only, the Contain option was used to compute the denominator degrees of freedom associated with the random effect. This approach resulted in all *F*-tests associated with the random effect being tested with 76 denominator degrees of freedom, a similar value to traits for which the sire variance component was estimable and the Satterthwaite option was used.

Pairwise comparisons of means (LSD method) were conducted for sire breed when *F*-tests of the two-way interactions (except for year) involving sire breed were not significant and main effects of sire breed were significant at the $P < 0.05$ level. Probability values are nominal and were not corrected for multiple testing.

Results

General

The primary objective of this study was to estimate the direct breed effects of the five sire breeds. Estimated differences between sire breed least squares means re-

sult primarily from differences in direct breed effects, whereas specific individual heterosis and paternal breed effects to the extent that they exist, may also contribute. Estimates of direct breed effects are a critical piece of information to predict performance of specific breed crosses or potential new composite populations. Direct effects are pertinent to breeds that perform in general purpose, paternal, or maternal roles of a crossbreeding system. Effects of year and its interaction with sire breed, dam breed, and mating season, although included in statistical models, are not presented or discussed because environmental conditions contributing to these effects could not be identified, effects could not be predicted to recur in the future, and it is likely that producers will choose breeds based on average year effects. However, effects of mating season and its interactions can affect decisions about use of breeds in specific seasons and will be presented.

Survival and Growth Traits

Results for survival and growth traits are presented in Table 1 for interactions of sire breed \times sex and dam breed \times mating season and in Table 2 for main effects of sire breed, dam breed, mating season, and sex. Significant interaction effects of sire breed \times dam breed, sire breed \times mating season, and dam breed \times sex were not detected for any trait. Mating season \times sex effects were detected only for postweaning ADG and 140-d weight, neither of which resulted in any change in rank of means. Results of nonsignificant interaction effects are neither tabulated nor discussed.

Survival rates of dam-reared lambs to weaning (56 d) were quite high for the entire experiment, with an overall rate exceeding 90%. High survival was likely achieved due to 100% heterosis expressed in crossbred lambs in addition to moderate prolificacy of mature CIII (1.7 lambs per ewe lambing) and WF ewes (1.4 lambs per ewe lambing). No interactions were important ($P > 0.05$) for survival rate. Mating season and dam breed also were not significant sources of variation in survival rate. Ewe lambs had 2.4% greater survival rate to weaning than wethers ($P < 0.01$). Sire breed effects were important for survival rates ($P < 0.05$). Despite being born in the largest litters (Freking et al., 2000), Romanov-sired lambs excelled in survival to weaning (94.1%), followed by Finnsheep (93.0%), Texel (90.7%), Dorset (90.0%), and Montadale sired (89.1%) progeny.

The three-way interaction of sire breed \times dam breed \times mating season was significant ($P < 0.01$) for birth weight; however, there was no obvious systematic trend as several changes in rank and magnitude were present among the ten crossbred types and three seasons. A more systematic interaction of dam breed \times season was important ($P < 0.01$) for birth weight. Composite III ewes mated in August (lambs were born in December and January) produced lambs with heavier (0.2 kg) birth weights than in other seasons. Birth weight did not differ across seasons from lambs born to WF ewes.

Table 1. Levels of significance, least squares means, and average standard errors for the interaction effects of sire breed \times sex and dam breed \times mating season on survival and growth traits

Item	Survival from birth to weaning	Birth wt, kg	56-d wt, kg	70-d wt, kg	140-d wt, kg	ADG, g/d	
						0 to 56 d	70 to 140 d
Sire breed \times sex							
Level of significance	0.21	0.95	0.01	0.02	0.15	<0.01	0.75
Least squares mean							
Dorset \times wether	88.8	5.50	21.05	25.02	45.66	276	296
Dorset \times ewe	91.2	5.22	20.69	24.10	43.38	275	275
Finnsheep \times wether	92.3	5.09	20.97	24.94	45.01	283	285
Finnsheep \times ewe	93.7	4.78	20.23	23.83	41.88	274	258
Romanov \times wether	94.1	5.14	20.98	24.80	45.16	282	291
Romanov \times ewe	94.2	4.80	20.13	23.55	41.91	272	265
Texel \times wether	89.7	5.61	21.46	25.15	44.61	282	280
Texel \times ewe	91.7	5.29	20.16	23.58	41.42	264	255
Montadale \times wether	85.9	5.65	20.44	23.83	44.61	263	295
Montadale \times ewe	92.3	5.38	20.49	23.81	42.65	268	270
Average SEM	1.5	0.06	0.24	0.30	0.44	5	4
Dam breed \times mating season^a							
Level of significance	0.64	<0.01	0.01	<0.01	<0.01	0.07	0.23
Least squares mean							
CIII \times August	89.2	5.43	22.08	25.75	47.13	296	306
CIII \times October	91.4	5.18	20.23	23.95	41.70	267	253
CIII \times December	92.4	5.23	20.52	24.20	43.98	271	285
WF \times August	90.9	5.21	20.98	24.27	44.72	280	292
WF \times October	92.2	5.18	19.89	23.66	41.15	261	248
WF \times December	92.1	5.27	20.23	23.76	43.08	266	278
Average SEM	1.1	0.04	0.17	0.20	0.29	3	3

^aCIII = Composite III; WF = Northwestern whiteface.

Average litter sizes from CIII ewes mated during August were lower than litter size from October but similar to December (see Table 4, Freking et al., 2000); therefore, the influence of season on litter size of CIII ewes does not explain the interaction. Composite III ewes were older (mature ewes) than WF ewes (2 yr old) entering the experiment and also benefited from heterosis effects associated with composite populations. These factors could help explain the increased birth weight of lambs born to CIII ewes in response to cold stress during late gestation. Data in the literature show an increased birth weight of twin lambs compared with singles in response to shearing (Revell et al., 2000). Prolificacy of CIII ewes exceeds WF by 0.2 to 0.3 lambs per ewe lambing. Perhaps August-bred CIII ewes responded differently than WF ewes to the stimulus of cold temperatures after December shearing by increased feed intake and increased nutrient uptake by the developing fetus.

Birth weight was influenced ($P < 0.05$) by sire breed, dam breed, mating season, and sex (Table 2). Sire breed means were not separated statistically due to the interactions involved, however; it is apparent that Romanov (4.97 kg) and Finnsheep-sired (4.94 kg) lambs were on average 0.4 to 0.5 kg lighter at birth than Dorset-, Texel-, and Montadale-sired lambs.

Weights taken at weaning (56 d) and 70 d were influenced ($P < 0.05$) by sire breed \times sex and dam breed \times mating season interaction effects (Table 1). Interaction

of sire breed \times sex was the result of greater than average sex difference in Texel-sired progeny (1.3 kg at 56 d; 1.6 kg at 70 d) and virtually no weight difference between sexes of Montadale-sired progeny (0.05 kg at 56 d; 0.02 kg at 70 d). Perhaps the Texel-sired male progeny were better able to cope with stress at castration (14 d) than Montadale-sired male progeny because this interaction was not important for growth measurements after 70 d. The interaction effect of dam breed \times mating season on 56- and 70-d weight is a consequence of maintaining birth weight differences noted previously. In addition to the consistent dam breed \times mating season interaction already noted, the interaction of mating season \times sex was also significant ($P < 0.01$) for 140-d weight. This interaction was due to change in magnitude of effects rather than rank.

Prewaning ADG was influenced ($P < 0.05$) by the interaction of sire breed \times sex and the main effects of sire breed, dam breed, mating season, and sex. The interaction of dam breed \times season approached significance for preweaning ADG. Lambs born to CIII dams mated in August grew most rapidly, consistent with birth weight. The interaction of sire breed \times sex was primarily the result of a change in rank. In contrast to all other sire breeds, Montadale-sired female progeny grew at a faster rate to weaning than contemporary male progeny. A larger than average difference between sexes for Texel-sired progeny also contributed to the interaction.

Table 2. Levels of significance, least squares means, and average standard errors for the main effects of sire breed, dam breed, mating season, and lamb sex on survival and growth traits

Item	Survival from birth to weaning	Birth wt, kg	56-d wt, kg	70-d wt, kg	140-d wt, kg	ADG, g/d	
						0 to 56 d	70 to 140 d
Sire breed							
Level of significance	0.02	0.01	0.54	0.28	0.08	0.05	0.01
Least squares mean ^a							
Dorset	90.0 ^{de}	5.36	20.87	24.56	44.51	275	285 ^d
Finnsheep	93.0 ^{cd}	4.94	20.60	24.39	43.44	278	272 ^c
Romanov	94.1 ^c	4.97	20.55	24.17	43.53	277	278 ^d
Texel	90.7 ^{de}	5.45	20.81	24.37	43.01	273	267 ^c
Montadale	89.1 ^e	5.52	20.47	23.82	43.63	265	282 ^d
Average SEM	1.2	0.05	0.20	0.24	0.38	3	3
Dam breed^b							
Level of significance	0.37	0.04	<0.01	<0.01	<0.01	<0.01	<0.01
Least squares mean							
CIII	91.0	5.28	20.96	24.63	44.27	278	281
WF	91.8	5.22	20.37	23.89	42.98	269	273
Average SEM	0.7	0.03	0.11	0.13	0.20	2	2
Mating season							
Level of significance	0.13	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Least squares mean							
August	90.1	5.32	21.53	25.01	45.92	288	299
October	91.8	5.18	20.08	23.80	41.43	264	251
December	92.3	5.25	20.37	23.98	43.53	269	281
Average SEM	0.8	0.03	0.13	0.15	0.23	2	2
Sex of lamb							
Level of significance	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Least squares mean							
Wether	90.2	5.40	20.98	24.75	45.01	277	289
Ewe	92.6	5.09	20.34	23.78	42.25	270	265
Average SEM	0.7	0.03	0.11	0.13	0.20	2	2

^aWithin a trait, sire-breed means without a common superscript differ, $P < 0.05$.

^bCIII = Composite III; WF = Northwestern whiteface.

Dam breed and sire breed main effects significantly affected postweaning ADG. Lambs reared by CIII ewes had an 8-g/d advantage in postweaning growth rate compared with lambs reared by WF ewes. Texel- and Finnsheep-sired progeny grew more slowly during the postweaning phase than all other sire breeds. Dorset-, Romanov-, and Montadale-sired progeny grew at a similar rate.

Age-Constant Carcass Traits

Results for carcass traits are presented in Tables 3 to 5. Data were evaluated at constant age (Table 3, 205.6 d), carcass weight (Table 4, 28.75 kg), or 12th-rib fat depth (Table 5, 0.71 cm). Slaughter age was an experimentally controlled variable with three slaughter groups per year at approximately 25, 29, and 33 wk of age. Variation in age within a slaughter group (SD = 4.3 d) represented the typical variation in birth dates within a lambing season. The interaction of sire breed \times dam breed was not significant for any carcass trait on an age-constant basis; therefore, only main effect means are tabulated.

Dam breed influenced ($P < 0.001$) all carcass traits except s.c. fat depth measures. Composite III ewes pro-

duced lambs with heavier live weights at slaughter, heavier and longer carcasses with less kidney-pelvic fat, and greater LM area. On average, progeny of CIII ewes had a 0.9 kg advantage in carcass lean mass compared with progeny of WF ewes when compared at the same age.

Sire breed was significant for all carcass traits except fat depth at the fourth sacral vertebrae. Dorset-sired progeny were heaviest at the average slaughter age, followed by Montadale-, Finnsheep-, Romanov-, and Texel-sired progeny. Carcass weights ranged from 30.2 kg for Dorset-sired wethers to 27.7 kg for Romanov-sired wethers. Kidney-pelvic fat deposition was greatest for Romanov- and Finnsheep-sired lambs, whereas Dorset-, Montadale-, and Texel-sired wethers accumulated 0.5 kg less fat at this depot when compared at the same age. Subcutaneous fat depth measured at the 12th rib indicated that Montadale-sired progeny deposited the least amount of fat at this location while Finnsheep-sired progeny deposited the most. Texel-sired carcasses were the shortest in length, whereas Dorset- and Montadale-sired carcasses were the longest. When compared at the average slaughter age, Texel-sired progeny excelled in LM area. Montadale- and Dorset-sired progeny were intermediate, whereas the Finn-

Table 3. Levels of significance, least squares means, and average standard errors for the main effects of sire breed and dam breed on carcass traits adjusted for slaughter age and pooled regression coefficients

Item	Live wt at slaughter, kg	Carcass wt, kg	Kidney-pelvic fat, kg	Fat depth, cm			LM area, cm ²	Impedance predicted lean mass, kg
				12th rib	Fourth sacral vertebrae	Carcass length, cm		
Sire breed								
Level of significance	0.04	<0.001	<0.001	<0.01	0.18	<0.001	<0.001	<0.001
Least squares mean ^a								
Dorset	54.2 ^d	30.2 ^e	1.01 ^c	0.68 ^{cd}	1.89	61.7 ^e	15.64 ^d	18.51 ^f
Finnsheep	52.1 ^c	28.3 ^{cd}	1.50 ^d	0.78 ^e	1.76	60.3 ^d	13.53 ^c	17.50 ^{cd}
Romanov	51.6 ^c	27.7 ^c	1.54 ^d	0.70 ^{cd}	1.74	59.5 ^{cd}	14.08 ^c	17.14 ^c
Texel	51.3 ^c	28.6 ^{cd}	0.98 ^c	0.74 ^{de}	1.86	58.8 ^c	16.34 ^e	17.70 ^{de}
Montadale	52.5 ^{cd}	29.3 ^{de}	0.97 ^c	0.63 ^c	1.77	61.6 ^e	15.74 ^d	18.10 ^{ef}
Average SEM	0.65	0.41	0.045	0.030	0.052	0.34	0.227	0.204
Dam breed ^b								
Level of significance	<0.001	<0.001	<0.001	0.13	0.99	<0.001	<0.001	<0.001
Least squares mean								
CIII	53.4	29.6	1.13	0.72	1.80	60.8	15.38	18.25
WF	51.2	28.1	1.27	0.69	1.80	59.9	14.76	17.33
Average SEM	0.39	0.24	0.027	0.018	0.030	0.19	0.132	0.120
Pooled regression coefficients								
Linear	0.18933***	0.11423***	0.01224***	-0.2102**	0.04387**	0.07364***	0.04244***	0.05480***
Quadratic	—	—	—	-0.00004*	-0.00009**	—	—	—

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

^aWithin a trait, sire-breed means without a common superscript differ, $P < 0.05$.

^bCIII = Composite III; WF = Northwestern whiteface.

sheep- and Romanov-sired lambs were lowest. Sire breed differences were detected for lean mass in the carcass. Dorset progeny produced the greatest weight of lean tissue in the carcass, followed by Montadale progeny, Texel, Finnsheep, and Romanov.

Although sire breed differences in weight of lean tissue were detected, sire breeds exhibited a similar estimated lean tissue accretion rate of 55 g/d and a 114 g/d accretion of carcass weight from 25 to 33 wk of age. Kidney-pelvic fat was deposited at a rate of 12 g/d.

Table 4. Levels of significance, least squares means, and average standard errors for the main effects of sire breed and dam breed on carcass traits adjusted for carcass weight and pooled regression coefficients

Item	Slaughter age, d	Live wt at slaughter, kg	Kidney-pelvic fat, kg	Fat depth, cm			LM area, cm ²	Impedance predicted lean mass, kg
				12th rib	Fourth sacral vertebrae	Carcass length, cm		
Sire breed								
Level of significance	0.02	<0.001	<0.001	<0.001	0.35	<0.001	<0.001	<0.12
Least squares mean ^a								
Dorset	200.5 ^e	51.8 ^d	0.89 ^d	0.63 ^d	1.80	60.9 ^{cd}	15.15 ^d	17.80
Finnsheep	208.0 ^{cd}	52.8 ^c	1.54 ^c	0.80 ^c	1.78	60.5 ^{de}	13.68 ^f	17.70
Romanov	209.5 ^c	53.4 ^c	1.63 ^c	0.74 ^c	1.80	60.0 ^e	14.44 ^e	17.67
Texel	206.0 ^{cde}	51.5 ^d	0.99 ^d	0.74 ^c	1.87	58.9 ^f	16.38 ^c	17.77
Montadale	203.2 ^{de}	51.7 ^d	0.92 ^d	0.61 ^d	1.74	61.3 ^c	15.57 ^d	17.84
Average SEM	1.9	0.24	0.042	0.024	0.044	0.29	0.206	0.052
Dam breed ^b								
Level of significance	0.01	0.06	<0.001	0.23	<0.01	0.73	0.49	<0.001
Least squares mean								
CIII	203.2	52.1	1.06	0.69	1.75	60.4	15.09	17.84
WF	207.7	52.4	1.33	0.71	1.85	60.3	15.00	17.67
Average SEM	1.2	0.14	0.025	0.015	0.026	0.16	0.115	0.030
Pooled regression coefficients								
Linear	3.5449***	1.9384***	0.0831***	0.0375***	0.0632***	1.0169***	0.3375***	0.5769***
Quadratic	—	-0.0054*	—	—	—	-0.0075**	—	-0.0015*

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

^aWithin a trait, sire-breed means without a common superscript differ, $P < 0.05$.

^bCIII = Composite III; WF = Northwestern whiteface.

Table 5. Levels of significance, least squares means, and average standard errors for the main effects of sire breed and dam breed of carcass traits adjusted for 12th-rib fat depth and pooled regression coefficients

Item	Slaughter age, d	Live wt at slaughter, kg	Carcass wt, kg	Kidney-pelvic fat, kg	Fourth sacral vertebrae fat depth, cm	Carcass length, cm	LM area, cm ²	Impedance predicted lean mass, kg
Sire breed								
Level of significance	0.79	<0.001	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001
Least squares mean ^a								
Dorset	207.0	54.65 ^c	30.51 ^c	1.04 ^d	1.92 ^c	61.9 ^c	15.74 ^c	18.66 ^c
Finnsheep	203.8	50.98 ^d	27.61 ^d	1.44 ^c	1.69 ^e	60.0 ^d	13.34 ^e	17.17 ^d
Romanov	205.6	51.66 ^d	27.68 ^d	1.54 ^c	1.74 ^{de}	59.4 ^{de}	14.08 ^d	17.15 ^d
Texel	204.7	50.84 ^d	28.33 ^d	0.96 ^d	1.83 ^{cd}	58.7 ^e	16.28 ^c	17.58 ^d
Montadale	207.8	53.62 ^c	30.02 ^c	1.03 ^d	1.85 ^{cd}	61.9 ^c	15.94 ^c	18.43 ^c
Average SEM	2.50	0.670	0.383	0.049	0.044	0.36	0.235	0.200
Dam breed^b								
Level of significance	0.91	<0.001	<0.001	<0.001	0.39	<0.01	<0.01	<0.001
Least squares mean								
CIII	205.9	53.27	29.49	1.12	1.79	60.8	15.37	18.21
WF	205.7	51.43	28.18	1.28	1.82	60.0	14.79	17.39
Average SEM	1.50	0.403	0.230	0.030	0.027	0.21	0.138	0.120
Pooled regression coefficients								
Linear	75.9774***	28.5887***	17.3633***	1.7030***	1.3359***	10.5637***	0.2138***	8.5737***
Quadratic	-24.2509**	-8.1607***	-4.5166***	-0.5215***	-0.2375†	-3.7158***	-2.1293**	-2.4612***

† $P < 0.10$; ** $P < 0.01$; *** $P < 0.001$.

^aWithin a trait, sire-breed means without a common superscript differ, $P < 0.05$.

^bCIII = Composite III; WF = Northwestern whiteface.

Carcass length increased at a rate of 0.074 cm/d and LM area increased 0.042 cm²/d. Subcutaneous fat at the 12th rib and fourth sacral vertebrae was also increasing, but at a slightly decreasing rate as age increased.

Weight-Constant Carcass Traits

Breed effects on carcass traits adjusted for age are often associated with differences between breeds in carcass weight. It is therefore of interest to estimate effects of sire breeds on carcass traits independent of carcass weight (Table 4). The range in carcass weight was 16.7 to 43.1 kg. Sire breed and dam breed influenced age required to produce the mean carcass weight ($P < 0.05$). The largest difference among sire breeds was represented by Romanov-sired progeny, which were 9 d older than Dorset-sired progeny at the same carcass weight. To achieve the same carcass weight, Romanov- and Finnsheep-sired progeny needed to be slaughtered at 1 to 1.5 kg heavier live weights than Dorset-, Texel-, and Montadale-sired progeny. Current industry practice does not retain the internal fat depot with the carcass; therefore, much of this difference in live weight can be accounted for by the 0.5 to 0.6 kg greater weight of kidney-pelvic fat for Romanov- and Finnsheep-sired lambs. Dam breed was also significant for weight of kidney-pelvic fat, with WF ewe progeny producing 0.27 kg more fat at this depot than progeny of CIII ewes. Subcutaneous fat depth measured at the 12th rib was less for Dorset- and Montadale-sired progeny than the other sire breeds. Significant sire breed differences were not detected for fat depth at the fourth sacral

vertebrae independent of carcass weight; however, WF progeny exhibited 0.1 cm greater fat depth at this depot than did CIII ewe progeny. Texel-sired progeny had 1.1 to 2.4 cm shorter carcasses than other sire breeds. Montadale- and Dorset-sired progeny had the longest carcasses and Romanov- and Finnsheep-sired lambs were intermediate. Texel-sired progeny had the largest LM area, followed by Dorset- and Montadale-sired, Romanov-sired, and Finnsheep-sired lambs. Estimates of sire breed differences in predicted lean mass were not significant. Dam breed influenced predicted lean in the carcass with CIII progeny on average producing nearly 0.2 kg more lean tissue than WF progeny.

Pooled regression coefficients indicated that for all breeds, lean weight of the carcass was increasing but at a decreasing rate as carcass weight increased. A 1-kg increase in carcass weight from the average carcass weight of 28.75 kg, would be composed of 575 g of lean tissue. A similar 1-kg increase in carcass weight is associated with 83 g of increased kidney-pelvic fat, and increased s.c. fat depths of 0.04 cm at the 12th rib and 0.06 cm at the fourth sacral vertebrae. Carcass length increased by 1.0 cm, and LM area increased by 0.34 cm² for this incremental change in carcass weight.

Subcutaneous-Fat-Constant Carcass Traits

Subcutaneous fat depth at the 12th rib is the single subjective measure used to establish current USDA yield grades for lamb. Distribution of total carcass fat can differ substantially between breeds. Specific breeds may have an advantage or disadvantage under the current marketing system, which uses this single fat depot

to determine carcass value. Therefore, it is important to evaluate breed differences at this economically important marketing end point (Table 5). Fat depth measured at this depot varied from 0.0 to 2.0 cm.

Differences among sire breeds and differences among dam breeds for slaughter age adjusted for 12th-rib fat thickness were not significant. This does not imply that all breed types have similar levels of carcass lean and fat tissue distributions at this end point. Dam breed influenced all carcass traits except for s.c. fat depth measured at the fourth sacral vertebrae. Composite III ewes produced wether progeny with heavier live weights at slaughter, and heavier and longer carcasses with less kidney-pelvic fat and greater LM area. Progeny of CIII ewes had a 0.8 kg advantage in carcass lean weight compared with progeny of WF ewes.

Sire breed was significant for all carcass traits adjusted to this endpoint and did not interact with dam breed. Dorset- and Montadale-sired progeny exhibited significantly heavier live and carcass weights than other sire breeds. Finnsheep-, Romanov-, and Texel-sired progeny were similar to each other for live weight at slaughter and for carcass weight. Kidney-pelvic fat weight was about 0.5 kg greater for Finnsheep- and Romanov-sired progeny than the other sire breeds. Indicative of differences in patterns of subcutaneous fat deposition among breeds, the fourth sacral vertebrae depot was significantly different among these sire breeds when compared at the same 12th-rib fat depth. Dorset-sired progeny had the greatest fat depth at this depot, whereas Finnsheep-sired progeny had the least. Dorset- and Montadale-sired progeny produced longer carcasses than other sire breeds. Finnsheep- and Romanov-sired progeny were intermediate in length and Finnsheep-sired carcasses were significantly longer than those from Texel sires. When LM area was evaluated at the same 12th-rib fat depth, Texel-, Dorset-, and Montadale-sired progeny exceeded Romanov-sired progeny, whereas Finnsheep-sired lambs had significantly a smaller LM area than all other sire breeds. Dorset- and Montadale-sired progeny produced carcasses with 0.9 to 1.5 kg heavier predicted carcass lean mass than the other three sire breeds.

Linear and quadratic regression coefficients indicated that all traits increased significantly but at a decreasing rate with increased 12th-rib fat depth. Comparisons of breed means at a common 12th-rib fat depth clearly indicated that differences among these breed crosses existed for internal and subcutaneous fat deposition, weight of the carcass, and predicted lean mass. Under the current USDA yield grading system that classifies lamb carcasses based on 12th-rib fat depth, similar yield grade carcasses out of Finnsheep, Romanov, and Texel sires would be expected to produce 1 to 1.5 kg less lean mass than those from Dorset and Montadale sires. Because there are breed differences in fat distribution, carcass weight and yield grade (12th-rib fat depth) may not accurately reflect differences in lean mass.

Discussion

A comprehensive objective in breed use is efficient conversion of feed resources into animal products useful to man (Dickerson, 1969). No single breed of sheep excels for all economically important traits, highlighting the importance of heterosis and complementarity in crossbreeding systems to optimize economic performance (Leymaster, 2002). Breeds that excel in a paternal role of a crossbreeding system produce progeny that perform at nearly optimal levels for traits such as survival, growth rate, and composition of the carcass. In addition, estimating direct breed effects on these traits is useful to determine optimal contributions of breed resources in either maternal or paternal roles within crossbreeding systems.

Sire breed effects did not interact with dam breed for any carcass trait. Thus, inference of information presented here should be applicable beyond these specific ram and ewe breed crosses. For example, estimates of regression coefficients on age, carcass weight, or fat depth could be used in analyses of carcass trait breeding values by National Sheep Improvement Program (NSIP) because statistics were estimated from a broad range of germplasm resources. These results are mostly consistent with literature, suggesting that specific combining ability of sheep breeds is of minimal importance for growth and carcass composition traits (Vesely et al., 1977; Wolf et al., 1980).

Genetic improvement of lamb survival in a production system spreads fixed costs per ewe over more live lambs. A computer simulation model of life cycle efficiency indicated that the greatest proportional improvements were brought about by increased lamb viability to weaning, fertility rate, and prolificacy (Wang and Dickerson, 1991). Despite being born in larger litters and having lower birth weights, Romanov-sired progeny excelled in survival rate to weaning (94.1%). In addition to survival advantages, gains to be made in life cycle efficiency would warrant increased use of Romanov as maternal germplasm in crossbreeding systems due to high fertility, prolificacy, extended seasonality, and longevity (Casas et al., 2004). Direct breed effects of Romanov could be used to improve fitness and reproduction traits in a composite maternal population or as part of structured crossbreeding system. The advantage in reproductive traits for Romanov would be accentuated under management systems that use nursery facilities (Casas et al., 2004). Compared with other sire breeds, Finnsheep also excelled in survival from birth to weaning (93%), similar to the Romanov, in spite of low birth weights of crossbred progeny. Information in the literature about performance of purebred Finnsheep and Romanov for lamb survival suggested that survival was as good as nonprolific breeds despite the greater litter sizes (Young et al., 1996). When compared at similar litter size and independent of maternal breed effects, direct breed effects of the prolific breeds on sur-

vival were superior to the other sire breeds in this experiment.

Direct breed effects on growth traits were not as large as might be expected based on purebred differences for mature body weight. Weights of mature purebred ewes representing breeds in this experiment can range from 55 to 60 kg for Romanov and Finnsheep, 75 kg for Texel, to nearly 90 kg for Dorset. Significant interactions of sire breed \times sex of lamb and dam breed \times season for growth traits precluded direct statistical separation of sire and dam breed means for these traits. Other than birth weight, the average of Finnsheep- and Romanov-sired lambs was similar to lambs of the other sire breeds for body weights and gains. Reproductive rate and/or maternal effects of prolific breeds do not allow lambs to reach their genetic potential for growth. Gallivan et al. (1993) directly compared Finnsheep- and Romanov-sired progeny, reporting similar estimates of BW as the current experiment. Finnsheep- and Romanov-sired progeny were similar to each other in body weights from birth to slaughter. Several studies in the United Kingdom have included Texel and Dorset breeds in direct comparisons as sires of crossbred progeny (Wolf et al., 1980; Croston et al., 1987; Kempster et al., 1987). However, comparisons of literature to the current study are difficult due to different production environments (grass fed vs. high concentrate diets) and samples of the breeds involved. It is doubtful that the current samples of U.S. Dorset and Texel breeds have been under similar genetic selection pressure for growth to those in the United Kingdom. There are no previously published experimental data to compare growth of Montadale.

When compared at the same slaughter age, the primary direct breed effects were for slaughter weight, carcass weights, fat deposition, carcass shape, and predicted lean mass. At this age-constant endpoint, Dorset and Montadale sires produced the heaviest and longest carcasses with the greatest mass of predicted carcass lean. Finnsheep and Romanov sires produced progeny with greater weight of kidney-pelvic fat and smaller LM area than other breeds. Texel sires produced carcasses that had the greatest LM area, associated with decreased carcass length, although carcass weight and predicted lean mass were intermediate relative to other sire breeds.

It is perhaps more relevant to compare these breeds at constant carcass weight or s.c. fat depth to reflect how lambs are marketed. When compared at constant carcass weight, these sire breeds exhibited differences in age, live weight, fat deposition, and carcass shape. The propensity of Romanov- and Finnsheep-sired progeny to accumulate kidney-pelvic fat, which is not included as part of carcass weight, is a primary difference in the age and live weight necessary to achieve carcass weights of other sire breeds. Subcutaneous fat deposition is similar for all sire breeds at the fourth sacral vertebrae but differs between breeds by as much as 0.17 cm at the 12th-rib depot. Differences at this industry standard location for estimating carcass yield grades

are not reflected by differences in predicted lean mass of the carcass. Progeny from Finnsheep, Romanov, and Texel accumulate s.c. fat at the 12th rib to a greater extent than Dorset and Montadale progeny, without changing carcass composition. Therefore, Finnsheep, Romanov, and Texel sires produce carcasses that could fall into a separate cell in the carcass weight and yield grade grid, despite having equivalent lean mass to lamb carcasses produced by Dorset and Montadale.

When sire breeds were compared at constant 12th-rib fat depth, differences among breeds were detected for carcass weight, carcass shape, s.c. and internal fat depots, as well as predicted lean mass. Dorset- and Montadale-sired progeny were heavier, longer, and produced more predicted carcass lean than other breeds. Texel-, Romanov-, and Finnsheep-sired progeny were similar to each other in carcass weight and predicted carcass lean, despite large differences in fat tissue distribution and carcass shape.

As part of the comprehensive evaluation of these five breeds, reproduction of F₁ ewes during fall breeding seasons has been reported by Casas et al. (2004). Total productivity through 3 yr of age for each ewe entering the breeding flock was calculated as the sum of 20-wk weights for dam-reared lambs. Least squares means of sire breeds for total productivity were 98.5, 103.5, 106.9, 124.6, and 154.9 kg for Texel, Dorset, Montadale, Finnsheep, and Romanov, respectively (Casas et al., 2004). Romanov-sired ewes outperformed other sire breeds due to greater conception rates and litter sizes for each mating season and ewe age, in addition to greater ewe longevity. Wool characteristics of these same F₁ breed types were also reported by Lupton et al. (2004), documenting the lower percentage of white fleeces and decreased clean wool output of Romanov-sired ewes. However, from this comprehensive evaluation of these five breeds, it is evident that the Romanov breed warrants consideration for a increased role in crossbreeding systems. Productivity of Romanov crossbred ewes is greater than that of ewes produced by Finnsheep sires. Direct effects of Romanov for growth and carcass traits do not indicate a distinct disadvantage compared with Dorset, Finnsheep, Texel, and Montadale.

Implications

Direct breed effects of Dorset, Finnsheep, Romanov, Texel, and Montadale sheep were estimated for survival, growth, and carcass traits. This study provides comparative information necessary to evaluate potential contributions of these breeds in crossbreeding systems to target specific levels of performance. Romanov- and Finnsheep-sired progeny excelled for survival and were comparable to other breeds in growth. Breed differences in distribution of carcass fat, most notably differences in internal fat deposition, as well as carcass shape were detected; however, predicted carcass lean weight was similar for all sire breeds when compared at a similar carcass weight. Increased use of Romanov

as a maternal contributor to crossbreeding systems can be implemented with minimal consequences in growth or carcass characteristics, while increasing reproduction and fitness.

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