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ABSTRACT: This experiment was conducted to compare meat quality and carcass composition of a diverse sampling of sheep breeds. Finnsheep, Romanov, Dorper, White Dorper, Katahdin, Rambouillet, Suffolk, Texel, Dorset, and Composite (½ Columbia rams to ¼ Hampshire × ¼ Suffolk) rams were mated to mature Composite ewes. Lambs (n = 804) were reared intensively, grain finished, and serially harvested over a 63-d period. Average harvest age was 216 d and average HCW was 30.7 kg. At a common harvest age, progeny of Suffolk sires were heavier than progeny of all other breeds ($P < 0.05$) and their carcasses were heavier ($P < 0.05$) than progeny of all other breeds, except White Dorper and Dorper. Progeny of Finnsheep and Romanov sires had lighter ($P < 0.05$) carcasses than progeny of all other breeds. Progeny of Texel, Suffolk, White Dorper, and Dorper sires had larger ($P < 0.05$) LM area than all other breeds. Progeny of Finnsheep and Romanov sires had smaller ($P < 0.05$) LM area than all other breeds. Fat thickness at the 12th rib was greater ($P < 0.05$) for progeny of Dorper sires than those of all other breeds, except White Dorper and Katahdin. Fat thickness at the 4th sacral vertebrae was greater ($P < 0.05$) for progeny of White Dorper and Dorper sires than those of all other breeds. On a carcass weight-constant basis, progeny of Suffolk sires had a lesser ($P < 0.05$) percentage of ether-extractable carcass fat than progeny of all other breeds, except Texel. Regardless of harvest endpoint (age-constant or HCW-constant), LM of progeny of Finnsheep and Romanov sires contained a greater ($P < 0.05$) percentage of intramuscular fat and received greater ($P < 0.05$) marbling scores than Rambouillet, Suffolk, Texel, Dorset, or Composite. Regardless of harvest endpoint, progeny of Finnsheep, Romanov, and Katahdin sires had smaller LM slice shear force values and greater trained sensory panel tenderness ratings at 7 d postmortem than did progeny of Composite, Suffolk, and Dorset sires ($P < 0.05$). At an age-constant basis, small differences ($P < 0.05$) were observed among breeds for lamb flavor intensity scores; however, when means were adjusted to a carcass weight-constant basis, breed of sire did not affect flavor intensity or off-flavor scores. These results document that each breed has relative strengths and weaknesses across traits, and that no single breed excels for all growth, carcass, and sensory traits.

Key words: breeds, carcass, flavor, lamb, slice shear force, tenderness

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INTRODUCTION

Breed evaluation experiments provide information that is essential for effective development and use of genetic resources. Experiments have been conducted in many countries to evaluate sheep breeds for growth and carcass traits (e.g., Carter and Kirton, 1975; Croston et al., 1987; Freking and Leymaster, 2004). Comprehensive characterization of breeds also should include sensory traits to provide relevant information for highly competitive markets, as attributes of lamb meat affect whether consumers choose lamb instead of beef, pork, poultry, or fish, or perhaps discourage consumption of lamb (Rhee and Yiprin, 1996). Although interest in attributes that affect palatability of lamb is increasing (Johnson et al., 2005), limited research has been directed toward evaluating breed effects on sensory traits of sheep (Clarke et al., 1996; Duckett and

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Kuber, 2001). Nonetheless, a consumer-responsive goal of sheep industries must be consistent production of uniform, safe, nutritious, lean lamb that results in an enjoyable and pleasant eating experience.

Therefore, the primary objective of this experiment was to estimate direct breed effects of Composite, Dorper, Dorset, Finnsheep, Katahdin, Rambouillet, Romanov, Suffolk, Texel, and White Dorper on carcass and sensory traits. These 10 breeds were chosen to provide substantial genetic diversity associated with wide levels of performance for economically important traits. Comparative information on several of these breeds was limited or nonexistent when the experiment was initiated, particularly for sensory traits.

MATERIALS AND METHODS

Animal procedures were reviewed and approved by the Animal Care and Use Committee of the U.S. Meat Animal Research Center (**USMARC**).

Mating Design

When the experiment was designed, our intent was to evaluate 9 breeds, using White Dorper rather than Dorper. However, due to the limited availability of genetically diverse White Dorper rams, we decided to also include Dorper in the experiment. White Doper and Dorper were treated as a single breed during the experiment because of common origin and lack of evidence that these breeds differed in performance. This assumption was subsequently tested by fitting separate effects for these 2 breeds during analysis of the data.

Several of the breeds evaluated have major roles in commercial sheep production in the United States (Dorset, Finnsheep, Katahdin, Rambouillet, Romanov, and Suffolk). Texel sheep were imported from Denmark and Finland into the United States in 1985, but comparisons with prominent U.S. breeds for sensory traits were lacking. Dorper and White Dorper were imported from South Africa into North America in 1995. Interest in hair breeds of sheep (Dorper/White Dorper and Katahdin) was increasing in the United States at this time due to perceived "easy care" attributes that potentially could be exploited in low-input production systems. Therefore, contemporary evaluation of these hair breeds was an important feature of the experiment. Composite sheep were developed at USMARC by mating Columbia rams to Hampshire × Suffolk crossbred ewes (Leymaster, 1991) and were included in the experiment as requested by a review team representing the American Sheep Industry Association.

Rams were single-sire mated with about 8 mature Composite ewes during 28-d breeding seasons, beginning in mid-September of 2001, 2002, and 2003. Composite ewes were at least 3 yr of age at lambing. Five rams per breed were used each year and then replaced by a new set of rams the next year. Six rams observed to have low libido (rams were equipped with marking harnesses and failed to mark any ewes) early in the breeding season were replaced. A total of 130 rams produced progeny that contributed carcass and sensory data to the experiment. Of those rams, 82 were purchased from 46 seedstock producers to either supplement existing breeds at USMARC (Dorset, Finnsheep, Romanov, Suffolk, and Texel) or establish additional breeds (Dorper/White Dorper, Katahdin, and Rambouillet). Breed associations were contacted to request information relevant to the experiment and seek advice on sources of rams. The objective was to buy rams out of influential flocks. After receiving information about experimental plans, producers selected rams for the experiment with the restriction that rams were less related than half-sibs. The number of rams and number of purchased rams per breed is shown in Table 1. The combined number of Dorper and White Dorper rams (n = 15) was similar to other breeds, and rams of both types were used each year.

Experimental Procedure

Over a 3-yr period, 1,664 lambs were born in 871 litters, averaging 1.9 lambs per litter. Ewes judged capable of rearing triplets were allowed to do so; however, 14% of lambs were reared artificially and excluded from the project. Naturally reared lambs of all sire breeds were raised from birth until harvest in a single production facility with 6 pens (penned by birth date and without regard to whether the ewes were rearing single, twin, or triplet lambs). All male lambs were castrated at 2 to 3 d of age. Lambs were weighed at 0 (birth), 8 (weaning), 10, and 20 wk of age. At weaning, dams were removed from the production facility and lambs remained in their original pens until 20 wk of age. From 1 wk of age until harvest, lambs were given unrestricted access to total-mixed diets that contained 88% DM and 11.6 MJ of ME per kilogram DM. Crude protein content of diets from 1 to 10 wk of age, 10 to 20 wk of age, and 20 wk of age to harvest were 18.0%, 14.5%, and 11.5%, respectively. Lambs had unrestricted access to long-stem alfalfa hay and were not shorn.

Carcass and sensory data were collected on ~270 lambs each year (~30 lambs of each sire breed) for 3 years (n = 804). To the extent possible, sampling of lambs for evaluation was based on the goal of 6 progeny per sire, 3 wethers and 3 ewes. Only naturally reared lambs were sampled. A small number of lambs were excluded for conditions (e.g., rectal prolapse) that clearly impacted performance. Otherwise, selection of lambs

Table 1. Sampling of lambs for evaluation

	No. of progeny															
	Ram															
Breed	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Total
Finnsheep	8[1]	8	7[1]	7	7	6[1]	6[1]	6[1]	6[1]	6	6	6	6	6	5[1]	96
Romanov	9[1]	7[1]	7	7	7	6[1]	6[1]	6[1]	6	6	6	6	6	5	3	93
Dorper	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]									42
White Dorper	7[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	5[1]								48
Katahdin	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	90
Rambouillet	7[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	6[1]	5[1]	90
Suffolk	13	10	9[1]	8[1]	7[1]	7	6[1]	6[1]	5[1]	5	4	3[1]				83
Texel	8[1]	8[1]	7[1]	7[1]	7[1]	7	6[1]	6[1]	6[1]	6[1]	6	6	6	3[1]	1	90
Dorset	13[1]	11	6[1]	6[1]	6[1]	6[1]	6[1]	6	6	6	6	4[1]	3[1]	3		88
Composite	10	8	8	7	7	7	7	6	6	6	4	4	2	2		84

[1]Ram was purchased from the industry. Otherwise, rams were sourced from U.S. Meat Animal Research Center flocks.

was random within sire × sex subclass. Although all rams passed semen quality examinations before the breeding season, several rams (see Suffolk, Dorset, and Composite in Table 1) were infertile or sired <6 viable progeny. Thus, additional lambs were sampled from other sires within the respective breeds (Table 1). On average, 6.18 progeny per sire were sampled.

Each year, lambs were harvested at weekly intervals in 10 groups of ∼27 lambs. The serial harvest was initiated when the average age of the lambs was 186 d and was completed when the average age of the lambs was 249 d. Each harvest group consisted of 3 lambs of each sire breed. At least 1 ewe and at least 1 wether of each sire breed were included in each harvest group. No more than 1 progeny of any sire was assigned to a given harvest group. Otherwise, assignment of lambs to harvest groups was random.

Two weeks before the first harvest date, lambs were sorted and penned in groups of lambs assigned to 2 or 3 harvest dates. To minimize stress and any potential impacts that stress may have on meat quality, final BW was determined 2 d before harvest. At that time, lambs that were assigned to the upcoming harvest group were sorted into a separate pen. Thus, lambs did not have to be sorted on the morning of harvest. Lambs had unrestricted access to feed and water until the morning of harvest. Lambs were transported to the USMARC abattoir and harvested within 3 h of being removed from their pen.

Lambs were stunned mechanically with a captive-bolt pistol. After evisceration, kidney-pelvic fat was removed from the carcass and weighed. Carcasses underwent a series of antimicrobial washes and a 2-min-long postwash drip drying period before HCW was recorded. Carcasses were not electrically stimulated and were not spray chilled. After chilling (24 h at 0°C then 24 h at 1°C), subjective leg scores were assigned (10 = low choice, 13 = low prime), chilled carcass weights were recorded, and carcasses were split longitudinally using a band saw.

The right carcass side was weighed for subsequent calculation of chemical composition. Fat thickness was measured at the midline adjacent to the 4th sacral vertebrae. The right side of the carcass was ribbed between the 12th and 13th ribs, marbling score was subjectively evaluated, and 12th rib fat thickness and LM area were measured. A 10-cm-long section of denuded LM was obtained from the 12th rib region, weighed, ground, and ether extracted to determine the level of intramuscular fat. The remainder of the right side was frozen (–20°C for 3 d), tempered to –5°C (palletized boxes held at 25°C for 18 h), ground 3 times through a plate with 0.635-cm diam. openings, and sampled for determination of ether-extractable fat level. Subsequently, the ether-extractable fat level of the entire right side was calculated using the weights and proximate composition of the 2 components.

The entire LM was obtained from the left side of each carcass, vacuum packaged (3-mil vacuum bags, Prime Source, Kansas City, MO; oxygen transmission rate = 0 cc · 100 cm^{-2} · 24 h^{-1} and Ultravac 2100 double chamber vacuum machine with vacuum setting = 9 and seal setting = 6.5; Koch Supplies Inc, Kansas City, MO), cooler (1°C) aged until 7 d postmortem, and then frozen (–20°C). Subsequently, eleven 2.54-cm thick chops were obtained from the frozen muscles using a band saw. Two of the chops (obtained from the 12th rib region) were thawed (24 h at 5°C), belt grilled (details provided by Shackelford et al., 2004) to an internal temperature of 71°C, and slice shear force was measured according to Shackelford et al. (2004). After 5 to 7 d of frozen storage, the remaining chops were thawed (24 h at 5°C) and grilled for trained sensory panel evaluation.

Trained Sensory Evaluation. Chops were cooked as described above and then LM was cut into 1 cm × 1 cm cooked steak thickness pieces. Three pieces were served warm to each panel member. An 8-member descriptive attribute sensory panel, trained according to procedures described by Cross et al. (1978), evaluated cooked steak on 8-point scales for tenderness, juiciness, lamb flavor intensity, and off-flavor score, where 8 = extremely tender, extremely juicy, extremely intense, or no off flavor, and 1 = extremely tough, extremely dry, extremely bland, or extremely intense off flavor. A warm-up sample was served first and then 4 or 5 experimental samples were served in each of 2 sessions per day (5 min between sessions) and 3 evaluation days each week. That is, 1 sample of each sire breed was evaluated on a given day. Each year, excess lambs (same genetics and contemporary group) were harvested before the first group of experimental lambs was harvested to provide material for refresher training (6 d over the course of 2 wk) and warm-up samples. Panelists sat in booths in an isolated room free from distractions. Panelists were instructed to drink room temperature water and apple juice to cleanse the palate between samples. Panelists recorded their scores on laptop computers. The light from the laptop screens negated the effects of controlled lighting. Thus, booths were lit with ambient lighting.

Statistical Analysis

Using the GLIMMIX procedure (SAS Inst. Inc., Cary, NC), data were analyzed using models that included fixed effects of sire breed, sex of lamb, year, sire breed × sex interaction, and random effect of sire nested within sire breed and year, and either harvest age or HCW fitted as a pooled, linear, and quadratic (when significant) covariate. Effects of Dorper and White Dorper were fitted separately to test our initial assumption of equality between these two breeds. Standard errors of means for Dorper and White Dorper were greater than other breeds due to fewer sheep resources committed to these two South African hair breeds.

The primary objective was to estimate direct breed effects of the 10 sire breeds. Significant interactions of sire breed × sex were detected in several analyses and are tabulated herein. However, the application of these experimental results by the sheep industry will likely be based on effects of sire breeds averaged over both sexes. Therefore, comparisons of sire-breed means using the LSD method were reported if main effects of sire breed were significant at the $P < 0.05$ level, regardless of significance of sire breed × sex interactions. Probability values are nominal and not corrected for multiple testing. The significance of the sire variance component was computed using the covtest (covtest 0) statement in GLIMMIX.

RESULTS

Age-constant Basis

Breed means for growth and carcass composition traits, adjusted to the mean harvest age of 216 d, are presented in Tables 2 and 3. Progeny of Suffolk sires were 3 to 9 kg heavier than progeny of all other breeds ($P < 0.05$). The carcasses of progeny of Suffolk sires were heavier ($P < 0.05$) than those of the progeny of all other breeds, except White Dorper and Dorper. The carcasses of progeny of Finnsheep and Romanov sires were lighter ($P < 0.05$) than those of progeny of all other breeds.

Dressing percentage, which is HCW expressed as a percentage of BW, was greater ($P < 0.05$) for progeny of Dorper and White Dorper sires than those sired by all other breeds. Due to apparent variation in pelt weight and other dress-off items, there were substantial differences among breeds in dressing percentage.

Although breed of sire affected weight of kidney-pelvic fat, differences among breeds were proportionately greater when we expressed kidney-pelvic fat as a percentage of the sum of kidney-pelvic fat weight and HCW (as if kidney-pelvic fat had not been removed from the carcass). Progeny of Romanov sires had a greater ($P < 0.05$) kidney-pelvic fat percentage than progeny of all sire breeds, except Finnsheep. These results contributed to the decreased dressing percentage of progeny of Romanov and Finnsheep sires.

Leg score, which is a subjective evaluation of carcass muscularity in which greater scores indicate greater muscularity, was greater ($P < 0.05$) for progeny of Texel sires than those of all other breeds, except Dorper (Table 3). Leg scores were smaller ($P < 0.05$) for progeny of Romanov, Finnsheep, and Rambouillet sires than for progeny of all other breeds, except Katahdin. Area of LM was larger ($P < 0.05$) for progeny of Texel, Suffolk, White Dorper, and Dorper sires than those sired by all other breeds. Area of LM was smaller ($P < 0.05$) for progeny of Finnsheep and Romanov sires than progeny of all other breeds.

Fat thickness at the 12th rib was greater ($P < 0.05$) for progeny of Dorper sires than those of all other breeds, except White Dorper and Katahdin. Fat thickness at the 4th sacral vertebrae was greater ($P < 0.05$) for progeny of White Dorper and Dorper sires than those of all other breeds. This result is consistent with the lineage of Dorper, which descended from the "fat-rumped" Blackheaded Persian breed.

Among the 804 carcasses sampled, whole-carcass, ether-extractable fat percentage ranged from 15 to 44%, due primarily to the serial harvest design and variation in carcass weight. The range in breed-of-sire means for carcass ether-extractable fat percentage was 4.1%, from 27.7% for Texel to 31.8% for White Dorper.

Breed of sire affected both LM ether-extractable intramuscular fat percentage and marbling score ($P < 0.05$; Table 4). As expected, breed of sire means for ether-extractable intramuscular fat percentage and marbling score were highly correlated ($r = 0.92$). The LM of prog-

Table 2. Levels of significance, least-squares means, and average SE of sire breeds and sire variance component for growth and carcass traits

Item	Harvest age, d	BW, kg	HCW, kg	Dressing, %	Kidney-pelvic fat Weight, kg	Kidney-pelvic fat Percentage
Means adjusted to a constant harvest age of 216 d						
Level of significance	—	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Least squares means						
Finnsheep	—	56.0^{e}	28.2^{f}	50.2^{f}	1.07^{ab}	3.59^{ab}
Romanov	—	56.1^{de}	28.4^{f}	50.5^{ef}	1.17^{a}	3.83^{a}
Dorper	—	59.9^{bc}	32.3^{ab}	53.7^{a}	1.01^{abc}	2.92^{cde}
White Dorper	—	62.4^{b}	33.4^{a}	53.4^{a}	1.04^{abc}	2.95^{cd}
Katahdin	—	58.5^{c}	30.5^{cde}	52.1^{b}	1.10^{ab}	3.37^{bc}
Rambouillet	—	58.4^{cd}	29.7^{e}	50.8^{def}	0.97^{bcd}	3.10^{c}
Suffolk	—	65.4^{a}	33.8^{a}	51.6^{bc}	0.92^{cde}	2.58^{de}
Texel	—	61.2^{b}	31.8^{bc}	51.8^{bc}	0.88^{cde}	2.61^{de}
Dorset	—	58.8^{c}	30.2^{de}	51.3^{cd}	0.79^{e}	2.50^{e}
Composite	—	61.6^{b}	31.6^{bcd}	51.1^{cde}	0.83^{de}	2.49^{e}
SEM	—	0.9	0.5	0.3	0.05	0.14
Sire variance[1]	—	3.8***	1.3***	0.3**	0.02***	0.16***
Residual variance	—	38.2	12.3	4.1	0.09	0.54
Pooled regression coefficients						
Linear	—	0.14***	0.11***	–0.090	0.010***	0.021***
Quadratic[2]	—	NS	NS	0.00035*	NS	NS
Means adjusted to a constant HCW of 30.7 kg						
Level of significance	<0.0001	<0.0001	—	<0.0001	<0.0001	<0.0001
Least squares means						
Finnsheep	224^{a}	59.9^{abc}	—	51.1^{def}	1.24^{a}	3.85^{a}
Romanov	223^{ab}	59.8^{bc}	—	51.3^{de}	1.32^{a}	4.08^{a}
Dorper	213^{cde}	57.5^{f}	—	53.2^{a}	0.91^{cd}	2.77^{cd}
White Dorper	210de	58.1^{ef}	—	52.6^{ab}	0.87^{d}	2.68^{d}
Katahdin	218^{c}	58.7^{de}	—	52.2^{bc}	1.12^{b}	3.40^{b}
Rambouillet	218^{bc}	60.0^{abc}	—	51.1^{def}	1.03^{bc}	3.19^{bc}
Suffolk	206^{e}	60.6^{a}	—	50.5^{f}	0.71^{e}	2.22^{e}
Texel	213^{cd}	59.5^{bc}	—	51.4^{de}	0.81^{de}	2.49^{de}
Dorset	219^{abc}	59.5^{cd}	—	51.5^{cd}	0.83^{de}	2.57^{de}
Composite	214^{d}	60.3^{ab}	—	50.8^{ef}	0.77^{de}	2.38^{de}
SEM	2	0.3	—	0.3	0.05	0.14
Sire variance[1]	0	0.2*	—	0.2**	0.01***	0.14***
Residual variance	332	5.2	—	3.8	0.07	0.57
Pooled regression coefficients						
Linear	2.7***	2.12***	—	0.33***	0.064***	0.23***
Quadratic[2]	NS	–0.0091***	—	NS	NS	–0.0020**

[a–f]Means within a column and harvest endpoint that do not share a common superscript letter differ significantly ($P < 0.05$).

[1]Superscripts indicate significance of the χ^2test of sire variance component.

[2]Nonsignificant (NS) quadratic terms were not included in the final model.

$^{*}P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$.

Table 3. Levels of significance, least-squares means, and average SE of sire breeds and sire variance component for carcass composition traits

Item	Leg score	LM area, cm^2	Fat thickness, mm 12th rib	Fat thickness, mm 4th sacral vertebrae	Carcass ether-extractable fat percentage
Means adjusted to a constant harvest age of 216 d					
Level of significance	<0.0001	<0.0001	<0.0002	<0.0001	<0.0001
Least squares means					
Finnsheep	11.2^{f}	14.7^{c}	6.6^{cde}	16.4^{de}	30.8^{ab}
Romanov	11.2^{f}	15.4^{c}	5.9^{e}	15.6^{e}	30.0^{bc}
Dorper	12.8^{ab}	18.3^{a}	8.8^{a}	24.4^{a}	29.8^{bcd}
White Dorper	12.5^{bc}	18.2^{a}	8.3^{ab}	26.6^{a}	31.8^{a}
Katahdin	11.5^{ef}	16.3^{b}	7.6^{abc}	20.4^{b}	31.2^{ab}
Rambouillet	11.4^{f}	16.3^{b}	6.2^{de}	16.7^{de}	28.3^{de}
Suffolk	12.6^{b}	18.2^{a}	6.4^{de}	17.5^{cde}	28.4^{de}
Texel	13.2^{a}	18.4^{a}	5.9^{e}	17.5^{de}	27.7^{e}
Dorset	11.9^{de}	16.4^{b}	6.7^{cde}	18.1^{cd}	28.5^{de}
Composite	12.1^{cd}	17.0^{b}	7.3^{bcd}	19.7^{bc}	28.8^{cde}
SEM	0.2	0.3	0.4	0.8	0.5
Sire variance[1]	0.1**	0.4***	1.3***	4.0***	2.1***
Residual variance	1.2	3.8	7.0	23.7	9.0
Pooled regression coefficients					
Linear	0.017***	0.036***	0.046***	0.010***	0.099***
Quadratic[2]	NS	NS	NS	NS	NS
Means adjusted to a constant HCW of 30.7 kg					
Level of significance	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Least squares means					
Finnsheep	11.5^{d}	15.6^{e}	7.5^{ab}	18.6^{c}	32.3^{a}
Romanov	11.5^{d}	16.2^{d}	6.8^{bc}	17.6^{cd}	31.4^{ab}
Dorper	12.5^{b}	17.7^{ab}	8.3^{a}	23.0^{a}	28.8^{cd}
White Dorper	12.1^{bc}	17.2^{abc}	7.4^{abc}	24.3^{a}	30.2^{bc}
Katahdin	11.5^{d}	16.4^{d}	7.7^{ab}	20.5^{b}	31.3^{ab}
Rambouillet	11.5^{d}	16.6^{cd}	6.5^{cd}	17.5^{cd}	28.8^{cd}
Suffolk	12.1^{bc}	17.1^{bc}	5.2^{e}	14.7^{e}	26.3^{f}
Texel	13.1^{a}	18.0^{a}	5.5^{de}	16.6^{d}	27.0^{ef}
Dorset	11.9^{c}	16.6^{cd}	6.9^{bc}	18.6^{c}	28.9^{cd}
Composite	11.9^{c}	16.7^{cd}	7.0^{abc}	18.9^{bc}	28.2^{de}
SEM	0.2	0.2	0.4	0.7	0.5
Sire variance[1]	0.1***	0.4***	1.1***	2.9***	1.6***
Residual variance	1.0	2.2	5.8	15.4	6.8
Pooled regression coefficients					
Linear	0.43***	0.58***	0.36***	0.86***	1.02***
Quadratic[2]	–0.0047***	–0.0037*	NS	NS	–0.0063*

[a–f]Means within a column and harvest endpoint that do not share a common superscript letter differ significantly ($P < 0.05$).

[1]Superscripts indicate significance of the χ^2 test of sire variance component.

[2]Nonsignificant (NS) quadratic terms were not included in the final model.

$^{*}P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$.

eny of Finnsheep and Romanov sires contained a greater ($P < 0.05$) percentage of intramuscular fat and received greater ($P < 0.05$) marbling scores than all breeds except Dorper, White Dorper, and Katahdin.

Progeny of Finnsheep sires had the numerically lowest slice shear force values and greatest trained sensory panel tenderness ratings (Table 5). Progeny of Composite sires had the numerically greatest slice shear values and numerically lowest trained sensory panel tenderness ratings. The correlation among sire-breed means for slice shear force and tenderness as scored by the descriptive attribute sensory panel was –0.92. Thus, it appears that there are breed differences in lamb tenderness that could affect consumer satisfaction as similar levels of slice shear force differences among beef LM samples have been associated with very significant differences in consumer satisfaction (Shackelford et al, 2001; Wheeler et al., 2004, 2010). Lamb flavor intensity scores were greater for progeny of Katahdin, Romanov, and Texel sires than progeny of Suffolk, Composite, and Rambouillet sires. Off-flavor scores were not affected by breed of sire ($P > 0.05$).

There was a sire breed × sex interaction ($P < 0.05$) for BW, HCW, 12th rib fat thickness, 4th sacral vertebrae fat thickness, and carcass ether extractable fat percentage when means were adjusted to a common harvest age (Table 6). Body weight and HCW means were numerically greater for wethers than ewe lambs for all breeds; however, the magnitude of the difference between sexes differed greatly among sire breeds.

For the fat traits, Dorset- and Texel-sired lambs did not follow the same pattern of differences between sexes as the other sire breeds. For 12th rib fat thickness, the interaction was due to changes in rank. For Dorset- and Texel-sired lambs, ewes had greater ($P < 0.05$) fat thickness than wethers. In contrast, Dorper-sired wethers had greater ($P < 0.05$) fat thickness than ewes. For 4th sacral vertebrae fat thickness, wethers had greater ($P < 0.05$) fat thickness than ewes for all sire breeds, except Dorset and Texel. For carcass ether-extractable fat percentage, the only sire breeds for which the sexes differed significantly were Dorset and Texel, with wethers having a smaller percentage ether-extractable fat than ewe lambs.

Variance among sires (nested within sire breed and year) accounted for a significant portion of the variance in all traits, when means were adjusted to a common harvest age, suggesting that there is exploitable within-breed genetic variation in these traits ($P < 0.01$; Tables 2, 3, 4, and 5).

Table 4. Levels of significance, least-squares means, and average SE of sire breeds and sire variance component for marbling

Item	Ether-extractable intramuscular fat percentage	Marbling score[1]
Means adjusted to a constant harvest age of 216 d		
Level of significance	<0.0001	<0.0001
Least squares means		
Finnsheep	4.18^{a}	574^{a}
Romanov	4.10^{a}	578^{a}
Dorper	3.74^{abc}	547^{abc}
White Dorper	4.04^{ab}	563^{ab}
Katahdin	4.06^{a}	545^{abc}
Rambouillet	3.41^{c}	498^{d}
Suffolk	3.59^{bc}	517^{cd}
Texel	3.51^{c}	523^{bcd}
Dorset	3.66^{bc}	522^{bcd}
Composite	3.64^{bc}	508^{cd}
SEM	0.14	14
Sire variance[2]	0.16^{***}	1113^{***}
Residual variance	0.59	6885
Pooled regression coefficients		
Linear	0.014^{***}	0.53^{***}
Quadratic[3]	NS	NS
Means adjusted to a constant HCW of 30.7 kg		
Level of significance	<0.0001	<0.0001
Least squares means		
Finnsheep	4.35^{a}	587^{ab}
Romanov	4.26^{ab}	590^{a}
Dorper	3.64^{cde}	538^{cd}
White Dorper	3.87^{bcd}	549^{bc}
Katahdin	4.08^{abc}	546^{c}
Rambouillet	3.46^{de}	503^{d}
Suffolk	3.36^{e}	500^{d}
Texel	3.44^{e}	517^{cd}
Dorset	3.70^{cde}	524^{cd}
Composite	3.58^{de}	506^{d}
SEM	0.14	13
Sire variance[2]	0.14^{***}	1063^{***}
Residual variance	0.62	6512
Pooled regression coefficients		
Linear	0.065^{***}	18.1^{***}
Quadratic[3]	NS	-0.20^{*}

[a–d]Means within a column and harvest endpoint that do not share a common superscript letter differ significantly (P < 0.05).

[1]500 = Small 00; 600 = Modest 00.

[2]Superscripts indicate significance of the χ^2 test of sire variance component.

[3]Nonsignificant (NS) quadratic terms were not included in the final model.

$^{*}P \le 0.05$; $^{***}P \le 0.001$.

HCW-constant Basis

Means of sire breeds adjusted to a HCW of 30.7 kg are given in Tables 2, 3, 4, and 5. For the most part, sire-breed means on a constant carcass-weight basis ranked similarly to means adjusted for variation in harvest age. To investigate these relationships, correlations were calculated using sire-breed means of a given trait adjusted for harvest age and the same trait adjusted for carcass weight. For example, the paired harvest age and carcass weight means of sire breeds for leg score (Table 3) were

Table 5. Levels of significance, least-squares means, and average SE of sire breeds and sire variance component for sensory traits of LM chops at 7 d postmortem

Item	Slice shear force, kg	Tenderness	Juiciness	Lamb flavor intensity	Off flavor
Means adjusted to a constant harvest age of 216 d					
Level of significance	<0.003	<0.0005	<0.03	<0.04	<0.13
Least squares means					
Finnsheep	19.8^{c}	5.98^{a}	5.63^{a}	4.69^{ab}	4.42
Romanov	21.6^{bc}	5.87^{ab}	5.60^{a}	4.79^{a}	4.48
Dorper	22.5^{abc}	5.75^{abc}	5.52^{ab}	4.66^{ab}	4.41
White Dorper	22.1^{abc}	5.63^{bc}	5.49^{b}	4.70^{ab}	4.43
Katahdin	20.9^{bc}	5.83^{ab}	5.61^{a}	4.80^{a}	4.49
Rambouillet	24.1^{ab}	5.64^{bc}	5.49^{b}	4.62^{b}	4.35
Suffolk	26.2^{a}	5.46^{c}	5.53^{ab}	4.55^{b}	4.27
Texel	21.4^{bc}	5.73^{abc}	5.54^{ab}	4.78^{a}	4.51
Dorset	25.2^{a}	5.44^{c}	5.53^{ab}	4.68^{ab}	4.40
Composite	26.3^{a}	5.41^{c}	5.55^{ab}	4.60^{b}	4.29
SEM	1.4	0.11	0.03	0.06	0.07
Sire variance[1]	8.4^{***}	0.07^{***}	0.004^{**}	0.01^{**}	0.02^{**}
Residual variance	95.3	0.44	0.06	0.20	0.25
Pooled regression coefficients					
Linear	0.012	-0.0043^{***}	-0.0012^{**}	-0.0036^{***}	−0.0013
Quadratic[2]	NS	NS	NS	NS	NS
Means adjusted to a constant HCW of 30.7 kg					
Level of significance	<0.0002	<0.002	<0.05	<0.10	<0.16
Least squares means					
Finnsheep	18.9^{d}	5.96^{a}	5.63^{a}	4.67	4.41
Romanov	20.8^{cd}	5.86^{a}	5.59^{ab}	4.77	4.48
Dorper	23.1^{abcd}	5.76^{ab}	5.52^{ab}	4.67	4.41
White Dorper	23.2^{abcd}	5.64^{ab}	5.49^{b}	4.72	4.43
Katahdin	20.9^{cd}	5.82^{a}	5.61^{a}	4.79	4.49
Rambouillet	23.7^{abc}	5.64^{ab}	5.49^{b}	4.62	4.35
Suffolk	27.2^{a}	5.49^{b}	5.54^{ab}	4.59	4.28
Texel	21.7^{bcd}	5.73^{ab}	5.55^{ab}	4.79	4.52
Dorset	25.2^{ab}	5.43^{b}	5.52^{ab}	4.67	4.40
Composite	26.6^{a}	5.42^{b}	5.55^{ab}	4.61	4.29
SEM	1.4	0.11	0.03	0.06	0.07
Sire variance[1]	7.3^{**}	0.07^{***}	0.004^{**}	0.01^{**}	0.02^{**}
Residual variance	93.6	0.45	0.06	0.21	0.25
Pooled regression coefficients					
Linear	-1.67^{**}	−0.0048	−0.00092	−0.0075	−0.0020
Quadratic[2]	0.021^{*}	NS	NS	NS	NS

[a-d]Means, within a column and harvest endpoint, that bear a superscript letter and that do not share a common superscript letter differ significantly ($P < 0.05$).

[1]Superscripts indicate significance of the χ^2 test of sire variance component.

[2]Nonsignificant (NS) quadratic terms were not included in the final model.

$^{*}P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$.

as follows: Finnsheep (11.2, 11.5), Romanov (11.2, 11.5), Dorper (12.7, 12.5), White Dorper (12.6, 12.3), Katahdin (11.5, 11.5), Rambouillet (11.4, 11.5), Suffolk (12.6, 12.1), Texel (13.2, 13.1), Dorset (11.8, 11.9), and Composite (12.1, 11.9). The correlation between these values is 0.95. Correlations for all sensory traits were at least 0.95, whereas correlations of carcass traits were generally >0.90. Two exceptions were 12th rib fat thickness (r = 0.78) and carcass ether-extractable fat percentage (r = 0.79). Means of sire breeds with the lightest (Finnsheep and Romanov) and heaviest (Suffolk and White Dorper) carcass weights at 216 d of age were affected most by fitting carcass weight as a covariate for these 2 traits. At a constant carcass-weight basis, progeny of Suffolk sires had significantly less 12th rib fat thickness and carcass ether-extractable fat percentage than progeny of all other sire breeds, except Texel (Table 3).

There was a sire breed × sex interaction ($P < 0.05$) for 4th sacral vertebrae fat thickness, when means were adjusted to a common HCW (Table 6). Wethers had greater ($P < 0.05$) 4th sacral vertebrae fat thickness for 6 of the 10 sire breeds. As with the age-constant interaction for 4th sacral vertebrae fat thickness, the sexes did not differ for Dorset- and Texel-sired lambs. Also, the sexes did not differ for Finnsheep- and Rambouillet-sired lambs.

DISCUSSION

The 10 breeds evaluated can be classified into 4 distinct roles based on industry use for commercial production: general purpose hair breeds (Dorper, Katahdin, and White Dorper), general purpose wool breeds (Dorset and Rambouillet), prolific breeds (Finnsheep and Romanov), and terminal sire breeds (Composite, Suffolk, and Texel). As expected, lambs sired by terminal sire breeds had significantly greater growth rates, greater leg scores, larger LM areas, and leaner carcasses than progeny of prolific breeds. However, with the exception of Texel, lambs by terminal sire breeds produced less tender LM chops relative to progeny of prolific breeds. Means of general purpose hair and wool breeds were generally intermediate to prolific and terminal sire breeds.

Significant differences were detected in performance of progeny sired by hair breeds. Katahdin-sired lambs grew less rapidly than lambs by White Dorper sires, had smaller LM area, and less fat depth at the 4th sacral vertebrae than Dorper- and White Dorper-sired lambs, and greater percentage of carcass fat than lambs sired by Dorper rams. There were no significant differences detected among progeny of Dorper- and White Dorper-sired lambs for any trait, except for carcass ether-extractable fat percentage. Standard errors of means for Dorper and White Dorper were estimated with less precision than other sire breeds, as noted previously.

Crossbred progeny of Dorset and Rambouillet sires, the 2 general purpose wool breeds, were very similar in performance. Significant differences were detected only for weight and percentage of kidney-pelvic fat and

Table 6. Sire breed × sex interaction ($P < 0.05$) for live weight, HCW, 12th rib fat thickness, 4th sacral vertebrae fat thickness, and carcass percentage ether-extractable fat adjusted to a common harvest age and for 4th sacral vertebrae fat thickness adjusted to a common HCW

		Means adjusted to a constant harvest age of 216 d					Means adjusted to a constant HCW of 30.7 kg
Breed of sire	Sex	BW, kg	HCW, kg	12th rib fat thickness, mm	4th sacral vertebrae fat thickness, mm	Carcass ether-extractable fat percentage	4th sacral vertebrae fat thickness, mm
Finnsheep	Ewe	55.2	27.7	6.6	15.2	31.3	17.8
Finnsheep	Wether	57.0	28.8	6.6	17.6	30.2	19.3
Romanov	Ewe	54.8	27.5	5.9	13.2	30.6	16.0
Romanov	Wether	57.6	29.2	6.0	18.0	29.4	19.3
Dorper	Ewe	54.8	29.3	7.6	20.2	29.3	21.4
Dorper	Wether	63.5	34.4	10.4	28.0	30.7	24.8
White Dorper	Ewe	60.5	31.9	7.8	23.7	31.4	22.7
White Dorper	Wether	63.9	34.7	9.2	29.5	32.2	26.1
Katahdin	Ewe	57.0	29.6	7.4	18.6	31.4	19.6
Katahdin	Wether	59.9	31.5	7.8	22.2	30.9	21.5
Rambouillet	Ewe	55.8	28.2	6.0	14.5	28.3	16.7
Rambouillet	Wether	61.1	31.3	6.3	18.9	28.3	18.3
Suffolk	Ewe	63.7	32.8	6.3	15.8	28.7	13.9
Suffolk	Wether	67.0	34.8	6.3	19.5	28.4	15.9
Texel	Ewe	60.9	31.6	6.5	17.3	28.9	16.6
Texel	Wether	61.6	32.1	5.3	17.8	26.5	16.6
Dorset	Ewe	58.0	29.7	7.4	18.2	29.1	19.1
Dorset	Wether	59.3	30.6	6.0	17.9	27.8	18.0
Composite	Ewe	58.7	30.0	6.9	17.4	28.4	18.0
Composite	Wether	64.7	33.3	7.9	22.1	29.2	19.7

leg scores, with Dorset-sired lambs having less fat and greater leg scores.

Progeny of the 2 prolific breeds, like the general purpose wool breeds, were comparable to one another. The only significant difference detected between Finnsheep- and Romanov-sired lambs was for LM area, favoring Romanov progeny.

Numerous differences among progeny of the terminal sire breeds were significant. Effects of sire breed favored Suffolk, Texel, or both, rather than Composite. Suffolk-sired lambs grew more rapidly than Texel- and Composite-sired lambs, and had less percentage carcass fat than progeny of Composite sires. Suffolk- and Texel-sired lambs had less 12th rib and 4th sacral vertebrae fat thickness than lambs by Composite sires. Progeny of Texel rams were superior for dressing percentage, leg score, LM area, slice shear force, and tenderness. The superior performance of Texel-sired lambs for carcass traits can be partially explained by existence of the myostatin mutation in this breed (Clop et al., 2006). Of the 15 Texel rams used in the experiment, 12 were homozygous for the mutation and 3 were heterozygous.

Snowder and Duckett (2003) contrasted tenderness and Warner-Bratzler shear force of a small (n = 10) sample of progeny of Dorper and Suffolk sires, and found a very large tenderness advantage for progeny of 4 Dorper sires. While the results of the present experiment tend to numerically agree with their results, we did not observe a significant difference in tenderness or slice shear force among progeny of Dorper and Suffolk sires. Examination of data from the present experiment (albeit on limited numbers of progeny per sire) revealed substantial variation among Suffolk sires in tenderness merit of progeny that might account for differing results across experiments.

Notter et al. (2004) contrasted progeny of Dorper and Dorset sires, and found that they had similar harvest weights, HCW, and dressing percentage. In the present experiment, we also observed that these breeds had similar harvest weights, but HCW and dressing percentage were greater for progeny of Dorper sires. The differing results for dressing percentage between the present study and Notter et al. (2004) could be due to preharvest animal handling. In Notter et al. (2004), lambs were shorn and shrunk before obtaining terminal weights. In the present study, lambs were neither shorn nor shrunk. The reason for the differing results for HCW between the present study and Notter et al. (2004) is unclear. Notter et al. (2004) included kidney-pelvic fat in HCW, whereas kidney-pelvic fat was removed for the present experiment. If kidney-pelvic fat had been included in HCW in the present study, the difference in HCW between these two sire breeds would have been even larger.

Sire breed affected tenderness to a greater extent than flavor. This was consistent with the results of large-scale breed evaluation studies in beef (Koch et al., 1976, 1979, 1982; Wheeler et al., 1996, 2001, 2005, 2010). While the differences in tenderness among breeds were significant and could be exploited through crossbreeding, they were very small relative to the impact of the callipyge mutation (Koohmaraie et al., 1995; Freking et al., 1998). Our results disagree with those of Burke et al. (2003), who conducted a small-scale, somewhat confounded experiment that showed purebred Katahdin lambs had much greater (50%) shear force than Dorper-crossbred lambs.

Although a limited number of studies have compared the effects of lamb breed on flavor (Crouse et al., 1981, 1983), a comprehensive evaluation of breeds has not been conducted. The present results dispel the perception that hair sheep breeds produce meat with a milder flavor, as progeny of Katahdin had the numerically greatest (most intense) flavor intensity scores.

Significant differences existed among breeds for growth, carcass, and tenderness traits, whereas breed effects on juiciness, flavor intensity, and off-flavor scores were relatively minor. If juiciness and flavor limit marketing opportunities, then it may be appropriate to investigate genetic regulation of these traits within a breed and evaluate selection strategies to improve lamb palatability within prominent breeds. The important variation among breeds for growth, carcass, and tenderness traits is justification for strategic use of breeds in terminal crossbreeding systems, allowing sire breeds to complement characteristics of crossbred ewes produced from general purpose and prolific breeds.

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