

Evaluation of Dorset, Finnsheep, Romanov, Texel, and Montadale breeds of sheep: III. Wool characteristics of F₁ ewes^{1,2}

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ABSTRACT: An experiment was designed to evaluate the effects of five sire breeds (Dorset, Finnsheep, Romanov, Texel, and Montadale), two dam breeds (Composite III [CIII] and northwestern whiteface [WF]), and three shearing seasons (December, February, and April, corresponding to August, October, and December breeding seasons) and their interactions on wool and other characteristics of F₁ ewes. Fleeces were collected and characterized from six 2-yr-old F₁ ewes representing each of the 90 sire breed × dam breed × shearing season × year (three) subclasses. Characteristics measured objectively were grease and clean fleece weights, clean yield, mean fiber diameter and SD, and mean staple length and SD. Visual assessments of fleece color were also made. Data collected on the F₁ ewes were analyzed using a mixed model analysis of variance procedure. The model included fixed effects of year of birth, sire breed, dam breed, shearing season, six two-way interactions, and the three-way interaction of sire breed × dam breed × shearing season. The random effect of individual sire within year of birth × sire breed was also fitted. Texel- and Montadale-sired ewes produced more clean wool ($P < 0.05$) (approximately

0.24 kg) than Dorset-, Finnsheep-, and Romanov-sired ewes. Texel-sired ewes produced the coarsest wool (28.7 μm) ($P < 0.05$), whereas Romanov-sired ewes produced the finest (24.9 μm) and longest (9.12 cm) fleeces ($P < 0.05$). Ewes from WF dams produced more and finer wool (0.15 kg and 2.7 μm) than ewes from CIII dams ($P < 0.001$). Ewes shorn in December produced more, coarser, and longer wool ($P < 0.05$) than those shorn in February and April. This trend in wool production is opposite to that in conception rate (reported previously). Romanov-sired ewes produced the lowest percentage of white fleeces (62.6%), whereas Dorset-sired ewes produced the most ($P < 0.001$) white fleeces (96.3%). Estimates of heritability were calculated for grease and clean fleece weights (0.36), percentage of clean yield (0.31), average fiber diameter and SD (0.86 and 0.42, respectively), and average staple length and SD (0.49 and 0.00, respectively). Although necessary for a thorough evaluation of these 10 types of crossbred ewes, it is estimated that wool income would only constitute a small portion (1 to 5%) of overall income from sheep of this type.

Key Words: Crossbred Sheep, Ram Breeds, Wool Production, Wool Characteristics

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Introduction

Many crossbreeding experiments have been conducted to estimate genetic effects of breeds of sheep. Typically (e.g., Wolf et al., 1980; Kempster et al., 1987),

but not always (e.g., Snowden et al., 1997), increased lamb production has been the primary objective of such experiments. Nevertheless, comprehensive evaluation requires that other factors, such as wool production and quality, also be considered. An experiment was designed to evaluate Dorset, Finnsheep, Romanov, Texel, and Montadale breeds of sheep at the U.S. Meat Animal Research Center, Clay Center, NE. Freking et al. (2000) reported effects of rams of these breeds when used for mating, whereas Casas et al. (2004) presented information on reproduction of resulting F₁ daughters. The objective of the current study was to evaluate effects of sire breed (Dorset, Finnsheep, Romanov, Texel, and Montadale), dam breed (Composite III and Northwestern Whiteface), shearing season (December, February, and April), and their interactions on wool characteristics of F₁ ewes.

¹L. D. 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.

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Experimental Procedures

General Experimental Design

The experimental design, ewe flocks, sampling of sire breeds, and flock management were described by Freking et al. (2000) and Casas et al. (2004). Briefly, Dorset, Finnsheep, Romanov, Texel, and Montadale rams were single-sire mated to Composite III (CIII) and Northwestern Whiteface (WF) ewes during 35-d breeding seasons beginning about August 5, October 15, and December 15 each year of 1990, 1991, and 1992. A sample of six rams from each sire breed was used across each breeding season within a year, with the exception that sick, injured, or infertile rams were replaced. A total of 102 rams (20 Dorset, 21 Finnsheep, 19 Romanov, 23 Texel, and 19 Montadale) produced F₁ progeny.

Approximately 20 F₁ ewe lambs were identified as replacements from each sire breed × dam breed × season × year subclass. Replacement ewe lambs went into the same 12-mo production system from which they were produced. Ewes from August, October, and December breeding seasons were shorn approximately on December 1, February 1, and April 1 of each year, respectively, 6 to 8 wk before lambing. The intent was to collect fleeces from a sample of six 2-yr-old ewes from each of the 90 sire breed × dam breed × shearing season × year subclasses. Within each subclass, one ewe was selected at random from daughters representing each of the six sires, irrespective of pregnancy status at the time of sampling. Wool data collected on 540 unskirted fleeces were well balanced with 5 subclasses of 5 observations, 5 subclasses of 7 observations, and 80 subclasses of 6 observations. Wool data were recorded on ewes sired by all rams used in the experiment with the exception of a single Romanov ram. Mean age of ewes at shearing was 680 d.

To provide baseline information about wool characteristics of breeds used in the experiment, wool data were also recorded on ewes of each dam breed and rams of each sire breed. Fleeces were collected from 20 4-yr-old CIII ewes, 20 4-yr-old WF ewes, and 10 3-yr-old WF ewes during each shearing season associated with lambing during 1993, for a total of 150 fleeces. Likewise, fleeces from rams of each sire breed (18 Dorset, 17 Finnsheep, 17 Romanov, 21 Texel, and 20 Montadale) were collected during May 1992 and 1993. Most of these rams were used in the experiment; however, 14 rams that did not produce experimental progeny were also shorn to provide wool data.

Wool Measurements

Fleeces from 540 F₁ ewes, 150 CIII and WF ewes, and 93 rams were sent to the Texas Agricultural Experiment Station Wool and Mohair Research Laboratory, San Angelo, where objective measurements of fleece and fiber traits were conducted. Each greasy fleece was weighed and subsampled for staple length. Five staples

removed from random positions in each fleece and measured using a standard method (American Society for Testing and Materials [ASTM, 1996b]) were obtained to calculate mean and SD values of staple length. Subsequently, fleeces were subsampled again using a mechanical coring device (Johnson and Larsen, 1978). Thirty-two 1.27-cm cores (total weight, >50 g) were removed from each fleece. These core samples were used for the measurement of clean yield (estimated clean wool fibers present; ASTM, 1996a). Clean samples from the yield test were minicored to produce snippets (short pieces of fiber, approximately 2 mm in length). These snippets (approximately 5,000 per fleece) were measured for mean fiber diameter and SD using an optical fiber diameter analyzer (BSC Electronics, Myaree, Western Australia; International Wool Textile Organisation [IWTO, 1995]). By observing cleaned subsamples, fleece color was subjectively described using the following convention: 1 = white, 2 = brown, 3 = black, 4 = predominantly white with brown fibers, 5 = predominantly white with black fibers, 6 = black and brown, and 7 = predominantly white with brown and black fibers. For statistical analysis, this system was simplified to white (Group 1) and nonwhite (Groups 2 to 7). Grease fleece weight, clean fleece weight, and staple length were adjusted to 365 d by use of multiplicative factors reflecting intervals between shearing dates; however, adjustments were slight because intervals ranged from 354 to 373 d.

Statistical Analysis

Data collected on F₁ ewes were analyzed using the mixed model analysis of variance procedure in SAS version 7.00 (SAS Inst. Inc., Cary, NC). The model included fixed effects of year of birth (1991, 1992, and 1993), sire breed (Dorset, Finnsheep, Romanov, Texel, and Montadale), dam breed (CIII and WF), shearing season (December, February, and April), six two-way interactions, and the three-way interaction of sire breed × dam breed × shearing season. The random effect of individual sire within year of birth × sire breed was also fitted. Effects of year of birth, sire breed, and year of birth × sire breed were tested with the mean square associated with the random effect of sire within year of birth × sire breed. Remaining fixed effects and their interactions were tested against the residual mean square. The Satterthwaite option was used in the analysis of variance to approximate degrees of freedom for sire within year of birth × sire breed, a value of approximately 78 for each trait. The estimate of the variance component for sires within year of birth × sire breed was 0.0 for staple length SD, resulting in default to a model that included only fixed effects. Examination of residuals indicated that the normality assumption was valid for all traits. Pairwise comparisons of means (LSD method) were tested for sire breed and shearing season when *F*-tests of two-way interactions were not significant and main effects of sire breed and shearing season

Table 1. Means of rams of the sire breeds for wool characteristics

Sire breed	No.	Clean yield, %	Fiber diameter, μm	
			Mean	SD
Dorset	18	48.4	31.5	6.45
Finnsheep	17	52.8	27.5	6.08
Romanov	17	58.5	27.7	17.46
Texel	21	55.8	34.1	7.32
Montadale	20	51.6	29.3	5.98

were significant at the $P < 0.05$ level. Heritabilities were estimated using the MTDFREML programs described by Boldman et al. (1995). The statistical model included all fixed effects described above and random effects of animal direct genetic and residual. Numerator relationships among F₁ ewes were based only on sire and dam information because further pedigree information was often missing.

After the description of fleece color had been simplified, χ^2 tests were used to examine the distribution of white and nonwhite fleeces among various breeds and types of crossbreeds.

Results and Discussion

Tables 1 and 2 summarize experimentally determined raw means of wool traits for sire and dam breeds used in this experiment. Significant interaction effects of year of birth \times shearing season on grease and clean fleece weights, clean yield, and fiber diameter SD and of year of birth \times sire breed on clean yield were detected. Significant main effects of year of birth on grease and clean fleece weights, clean yield, staple length, and staple length SD were also detected (Table 3). Statistical results for the main effect of year of birth are presented simply to document magnitudes of annual variation

for wool traits. Year-of-birth effects are not discussed further because conditions causing year differences are difficult to determine, future specific effects cannot be predicted, and it is appropriate for producers to make decisions about sire breeds, dam breeds, and shearing seasons based on information averaged over several years.

Levels of significance, least squares means, and average standard errors of means are reported for two-way interactions between sire breed, dam breed, and shearing season (Tables 4, 5, and 6) and for their main effects (Table 7). The three-way interaction among these main effects was not detected for any trait and results were not tabulated. The difference between least squares means of sire breeds estimates half the difference between direct breed effects, assuming that direct effects of specific heterosis, if indeed present, are not of relevant magnitude. The difference between least squares means of dam breeds estimates one-half of the difference between direct breed effects and the full difference between maternal breed effects, ignoring potential effects of specific heterosis.

Fleece Weights and Clean Yield

Interaction effects between sire breed, dam breed, and shearing season were not significant for grease and clean fleece weights or clean yield (Tables 4, 5, and 6); however, main effects of sire breed, dam breed, and shearing season were detected ($P < 0.001$) for these three traits (Table 7). Overall, Texel- and Montadale-sired ewes produced more clean wool than Dorset-, Finnsheep-, and Romanov-sired ewes. However, grease fleece weight was actually greater in Dorset- than in Finnsheep- or Romanov-sired ewes ($P < 0.05$), but a lower clean yield for ewes by Dorset sires caused clean fleece weights of these three sire breeds to be similar. All clean yields were relatively high (>60%) and similar

Table 2. Means of ewes of the dam breeds for wool characteristics by shearing season

Dam breed and shearing season ^a	No.	Fleece weight, kg		Clean yield, %	Fiber diameter, μm		Staple length, cm	
		Grease	Clean		Mean	SD	Mean	SD
CIII (4 yr old)								
December	20	4.02	2.58	64.3	29.0	5.8	7.47	0.69
February	20	3.66	2.31	64.6	28.2	5.6	6.86	0.66
April	20	3.78	2.40	63.0	29.1	6.3	7.68	0.74
Total	60	3.82	2.43	64.0	28.7	5.9	7.34	0.69
WF (4 yr old)								
December	20	4.60	2.70	58.5	23.7	4.4	7.65	0.71
February	20	3.86	2.35	61.8	23.0	4.5	6.88	0.71
April	20	3.69	2.19	58.8	22.0	4.1	7.54	0.74
Total	60	4.05	2.41	59.7	22.9	4.3	7.37	0.71
WF (3 yr old)								
December	10	4.97	2.88	58.0	22.7	4.2	7.80	0.76
February	10	3.70	2.20	60.9	22.1	4.2	6.96	0.63
April	10	3.74	2.23	58.8	21.5	4.4	7.32	0.84
Total	30	4.14	2.44	59.2	22.1	4.3	7.37	0.74

^aCIII = Composite III; WF = Northwestern Whiteface.

Table 3. Levels of significance, least squares means, and average standard errors of means for the main effect of year of birth

Item	Fleece weight, kg			Fiber diameter, μm		Staple length, cm	
	Grease	Clean	Clean yield, %	Mean	SD	Mean	SD
Significance	<0.001	0.01	<0.001	0.28	0.24	0.03	<0.001
Least squares means							
1991	3.50	2.26	64.8	26.4	6.0	8.32	0.88
1992	3.32	2.11	63.9	26.2	6.0	8.11	0.73
1993	3.63	2.21	60.9	26.7	6.2	8.57	0.93
Average SEM	0.052	0.034	0.39	0.22	0.08	0.119	0.025

Table 4. Levels of significance, least squares means, and average standard errors of means for sire breed \times dam breed interaction

Item	Fleece weight, kg			Fiber diameter, μm		Staple length, cm	
	Grease	Clean	Clean yield, %	Mean	SD	Mean	SD
Significance	0.24	0.10	0.11	0.06	0.22	0.24	<0.01
Least squares means ^a							
Dorset \times CIII	3.25	2.04	62.7	28.1	5.9	7.38	0.67
Dorset \times WF	3.65	2.23	61.3	26.1	5.4	7.48	0.76
Finnsheep \times CIII	3.04	2.02	66.4	26.6	5.7	9.11	1.13
Finnsheep \times WF	3.44	2.13	62.3	24.0	5.1	8.74	0.90
Romanov \times CIII	3.06	2.01	65.8	26.3	7.5	9.33	1.05
Romanov \times WF	3.37	2.14	63.6	23.6	6.6	8.92	0.88
Texel \times CIII	3.50	2.18	62.1	30.5	7.1	8.10	0.83
Texel \times WF	4.07	2.47	60.6	26.9	6.1	8.07	0.80
Montadale \times CIII	3.61	2.34	65.1	27.5	6.0	8.00	0.73
Montadale \times WF	3.84	2.37	61.7	24.8	5.2	8.18	0.74
Average SEM	0.087	0.057	0.67	0.33	0.13	0.191	0.046

^aSire breed listed first, dam breed second (CIII = Composite III; WF = Northwestern Whiteface).

Table 5. Levels of significance, least squares means, and average standard errors of means for sire breed \times shearing season interaction

Item	Fleece weight, kg			Fiber diameter, μm		Staple length, cm	
	Grease	Clean	Clean yield, %	Mean	SD	Mean	SD
Significance	0.92	0.93	0.69	0.22	0.02	0.20	0.55
Least squares means							
Dorset \times December	3.88	2.44	62.7	28.5	5.7	7.92	0.71
Dorset \times February	3.43	2.12	62.1	27.2	5.8	7.15	0.69
Dorset \times April	3.03	1.85	61.3	25.6	5.5	7.21	0.74
Finnsheep \times December	3.62	2.31	64.3	26.4	5.5	9.04	1.08
Finnsheep \times February	3.27	2.12	65.2	25.5	5.5	8.98	1.02
Finnsheep \times April	2.83	1.80	63.6	24.0	5.3	8.74	0.93
Romanov \times December	3.60	2.36	65.6	26.3	7.6	9.82	0.90
Romanov \times February	3.15	2.05	65.4	25.0	6.9	8.78	1.02
Romanov \times April	2.90	1.82	63.0	23.4	6.6	8.77	0.97
Texel \times December	4.17	2.60	62.1	29.6	6.6	8.20	0.82
Texel \times February	3.87	2.37	61.3	29.3	6.8	8.13	0.84
Texel \times April	3.32	2.01	60.7	27.2	6.4	7.94	0.78
Montadale \times December	4.12	2.64	64.2	26.7	5.7	8.28	0.75
Montadale \times February	3.76	2.41	64.6	26.5	5.6	8.01	0.71
Montadale \times April	3.29	2.01	61.5	25.3	5.6	7.98	0.74
Average SEM	0.100	0.067	0.80	0.37	0.16	0.223	0.057

Table 6. Levels of significance, least squares means, and average standard errors of means for dam breed × shearing season interaction

Item	Fleece weight, kg			Fiber diameter, μm		Staple length, cm	
	Grease	Clean	Clean yield, %	Mean	SD	Mean	SD
Significance	0.47	0.79	0.57	0.23	0.20	0.11	0.82
Least squares means ^a							
CIII × December	3.67	2.39	65.2	29.0	6.7	8.85	0.90
CIII × February	3.28	2.12	65.1	28.1	6.5	8.17	0.88
CIII × April	2.93	1.83	63.0	26.3	6.2	8.13	0.87
WF × December	4.09	2.55	62.3	26.0	5.8	8.45	0.81
WF × February	3.71	2.30	62.4	25.4	5.8	8.25	0.83
WF × April	3.22	1.96	61.0	23.9	5.6	8.13	0.80
Average SEM	0.062	0.041	0.49	0.22	0.09	0.133	0.036

^aCIII = Composite III; WF = Northwestern Whiteface.

in magnitude to those reported for the dam breeds used in this experiment (Table 2).

Crossbred ewes from WF dams produced more wool (0.38 kg of greasy and 0.15 kg of clean) than ewes from CIII dams ($P < 0.001$, Table 7). The magnitude of this difference in F₁ ewes was similar to that observed between the dam breeds themselves (Table 2). In contrast, clean yields of F₁ ewes from CIII dams were significantly greater (64.4 vs. 61.9%, Table 7) than F₁ ewes from WF dams, a situation similar to that observed for the CIII and WF ewes themselves.

Ewes shorn in December (bred in August and lambd in January) produced more clean wool (0.26 kg, $P < 0.05$; Table 7) than ewes shorn in February. February-

shorn ewes produced more clean wool (0.31 kg, $P < 0.05$; Table 7) than April-shorn ewes. The decrease in wool production with season is consistent with the corresponding seasonal increase in conception rate observed in this experiment (Casas et al., 2004). Negative correlations between wool production and reproductive traits were reported previously for Merino (Kennedy, 1967) and Rambouillet (Shelton and Menzies, 1968) breeds.

Fiber Diameter

The interaction of sire breed × dam breed approached significance ($P = 0.06$) for mean fiber diameter but was not important for SD of fiber diameter (Table 4). Con-

Table 7. Levels of significance, least squares means, and average standard errors of means for main effects of sire breed, dam breed, and shearing season

Item	Fleece weight, kg			Fiber diameter, μm		Staple length, cm	
	Grease	Clean	Clean yield, %	Mean	SD	Mean	SD
Sire breed							
Significance	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Least squares means							
Dorset	3.45 ^c	2.14 ^c	62.0 ^{c,d}	27.1 ^c	5.7	7.43 ^d	0.71
Finnsheep	3.24 ^d	2.08 ^c	64.3 ^b	25.3 ^e	5.4	8.92 ^b	1.01
Romanov	3.22 ^d	2.07 ^c	64.7 ^b	24.9 ^e	7.1	9.12 ^b	0.97
Texel	3.79 ^b	2.32 ^b	61.4 ^d	28.7 ^b	6.6	8.09 ^c	0.81
Montadale	3.72 ^b	2.35 ^b	63.4 ^{b,c}	26.2 ^d	5.6	8.09 ^c	0.73
Average SEM	0.067	0.044	0.50	0.28	0.10	0.153	0.033
Dam breed							
Significance	<0.001	<0.001	<0.001	<0.001	<0.001	0.29	0.02
Least squares means ^a							
CIII	3.29	2.12	64.4	27.8	6.5	8.38	0.88
WF	3.67	2.27	61.9	25.1	5.7	8.28	0.81
Average SEM	0.039	0.025	0.30	0.15	0.06	0.085	0.021
Shearing season							
Significance	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.81
Least squares means							
December	3.88 ^b	2.47 ^b	63.8 ^b	27.5 ^b	6.2	8.65 ^b	0.85
February	3.49 ^c	2.21 ^c	63.7 ^b	26.7 ^c	6.1	8.21 ^c	0.86
April	3.08 ^d	1.90 ^d	62.0 ^c	25.1 ^d	5.9	8.13 ^c	0.83
Average SEM	0.046	0.030	0.36	0.17	0.07	0.099	0.025

^aCIII = Composite III; WF = Northwestern Whiteface.

^{b,c,d,e}Within a column, sire breed or shearing season means without a common superscript letter differ ($P < 0.05$).

versely, the interaction of sire breed \times shearing season was not detected for mean fiber diameter but was significant for SD ($P = 0.02$, Table 5). The cause of this interaction was the greater SD in fleeces of Romanov-sired ewes when shorn in December compared with February- and April-shorn fleeces. This may be due to progressive shedding of some coarse guard hairs before shearing by the Romanov-sired ewes. This possibility is supported by a corresponding decline in mean fiber diameter from December to April. Effects of shearing season on SD of fiber diameter for all other sire breeds were negligible. The interaction of dam breed \times shearing season was not detected for mean fiber diameter or SD (Table 6).

Main effects of sire breed on mean fiber diameter and SD were highly significant (Table 7). Romanov and Finnsheep produced offspring having the finest wool followed by Montadale, Dorset, and Texel. This order of increasing fiber diameter in F_1 ewes was the same as for purebred rams of the sire breeds (Table 1). Predicted mean fiber diameters of the 2-yr-old F_1 ewes (average of ram breed and mean of 4-yr-old dam breeds (Table 2) were consistently 1.3 μm greater than actual means. This discrepancy is likely an age effect because fleeces of F_1 ewes, like their dams, would be expected to coarsen with age (see Table 2). Among wool breeds of sheep, SD and mean fiber diameter are highly and positively correlated (Lupton, 1995). This relationship appears to be true for most of the F_1 breed types, with Romanov crosses being the exception. The bicomponent-like nature of the Romanov fleece (coarse hair and relatively fine wool fibers) produces exceptionally high SD (Table 1). This high SD, though diluted considerably, is obviously a characteristic of crossbred daughters of Romanov sires. Although slightly lower in magnitude than the SD of Romanov-sired fleeces (6.6 vs. 7.1 μm), fleeces of Texel-sired ewes were associated with a higher mean fiber diameter. The CV of fiber diameter for Romanov- and Texel-sired ewes were 28.3 and 23.0%, respectively, indicating distinctly higher variability in fleeces of Romanov-sired ewes.

The influence of dam breed was quite predictable, with fleeces of crossbred ewes from WF dams being 2.7 μm finer than their counterparts from CIII dams (Table 7). Again, actual values of mean fiber diameter were smaller ($\geq 1.4 \mu\text{m}$) than predicted values, probably an age effect.

Main effects of shearing season were detected ($P < 0.001$, Table 7) for mean fiber diameter and SD. Mean and SD values decreased with a later shearing season. These effects are consistent with the same trend in fleece weights caused by progressively increasing conception rates of ewes exposed to rams later in the year and shorn later (Kennedy, 1967; Shelton and Menzies, 1968). It will be recalled that fleece data were measured on samples of six 2-yr-old F_1 ewes from each sire breed \times dam breed \times shearing season \times year subclass.

Staple Length

The interaction of sire breed \times dam breed was not detected for mean staple length but was highly significant for SD of staple length (Table 4). Dam breed had little effect on SD of staple length for F_1 ewes by Texel, Dorset, and Montadale sires. In contrast, the difference between Finnsheep-sired ewes out of CIII dams vs. WF dams and the difference between Romanov-sired ewes out of CIII dams vs. WF dams were quite large. Neither the sire breed \times shearing season nor the dam breed \times shearing season interactions were significant for mean staple length or SD (Tables 5 and 6).

Main effects of sire breed influenced mean staple length and SD ($P < 0.001$, Table 7). Romanov and Finnsheep offspring had the longest wool, Texel- and Montadale-sired ewes were intermediate, and Dorset offspring had the shortest wool. Although staple lengths of most rams used in this experiment were measured, means were not reported in Table 1 because intervals between shearing dates were generally unknown for purchased rams. Thus, the ranking of sire breeds for staple length of their offspring was not predictable from the data generated in this experiment. Sire breeds producing the longest mean staple length also had the most variability in staple length (CV = 11.3 and 10.6% for Finnsheep and Romanov, respectively; Table 7). The CV for staple length of Texel-, Dorset-, and Montadale-sired ewes were 10.0, 9.6, and 9.0%, respectively.

The main effect of dam breed did not affect mean staple length ($P = 0.29$, Table 7). The SD value for offspring of WF dams (0.81 cm) was less than ($P = 0.02$) the corresponding value for offspring of CIII dams (0.88 cm).

Fleeces of ewes shorn in December were longer than those shorn in February and April ($P < 0.05$). April-shorn fleeces (8.13 cm) were shorter than February-shorn fleeces (8.21 cm), but the difference was not significant. Nevertheless, this trend was consistent with decreased fleece weight and fiber diameter previously discussed. The suggested cause of these effects is the seasonal increase in conception rate associated with 2-yr-old ewes exposed in August, October, or December (83.6, 93.1, and 95.3%, respectively; Casas et al., 2004).

Fleece Color

Without mechanical blending (e.g., carding) of the washed fibers in a fleece, objective measurement of small proportions of colored fibers in white fleeces is imprecise. Typical industry practice is to count the number of colored fibers in a 28.5-g sample. This exacting and time-consuming method was not used in the current study. Rather, as described in the Experimental Procedures section, subjective assessments were made on the scoured, homogenized samples (1.27-cm cores) of each fleece.

Data summarized in Table 8 indicate that the distribution of white and nonwhite fleeces was different be-

Table 8. Frequency of white and nonwhite fleeces from ewes of dam breeds and rams of sire breeds

Item	White	Nonwhite	Total	% White
Dam breed ^a				
CIII	34	26	60	56.7
WF	80	10	90	88.9
$\chi^2 = 20.492, 1 \text{ df}, P < 0.005$				
Sire breed				
Dorset	3	15	18	16.7
Finnsheep	5	12	17	29.4
Texel	9	12	21	42.9
Romanov	0	17	17	0
Montadale	2	18	20	10
$\chi^2 = 13.202, 4 \text{ df}, P < 0.025$				

^aCIII = Composite III; WF = Northwestern Whiteface.

tween dam breeds and among sire breeds. Approximately 57% of CIII fleeces were white, whereas 89% of WF fleeces were white. For CIII ewes, 25 of the 26 nonwhite fleeces were predominantly white, with some black (14), brown (8), or black and brown (3) fibers, whereas the remaining fleece was brown and black. For WF ewes, the 10 nonwhite fleeces were all predominantly white with some black (7), brown (2), and black and brown (1) fibers. The percentage of white fleeces for sire breeds ranged from 0% for Romanov rams to 43% for Texel rams. For Dorset, Finnsheep, Texel, and Montadale rams, nonwhite fleeces were predominately white with black, brown, or black and brown fibers. This description was also true for 12 Romanov fleeces, but the remaining 5 fleeces were composed entirely of brown and black fibers.

The distributions of white and nonwhite fleeces from 540 F₁ ewes were investigated. A χ^2 test with 9 df detected differences among crossbred types for distribution of white and nonwhite fleeces ($P < 0.001$, Table 9). All 73 of the nonwhite fleeces were predominantly white with brown, black, or brown and black fibers. None of the F₁ fleeces were predominantly brown or black. Additional χ^2 tests were done to partition the 9 df into dam breed (1 df), sire breed (4 df), and the dam breed \times sire breed interaction (4 df). Results presented in Table 9 document that fleece color (white, nonwhite) was dependent on dam breed ($P < 0.025$) as well as sire breed ($P < 0.001$). Furthermore, dam and sire breeds interacted to affect color distribution ($P < 0.001$). The interaction was calculated as the difference between the χ^2 value for the 10 crossbred types (110.537) and χ^2 values for dam and sire breeds, 5.882 and 69.456, respectively (Table 9). The interaction was due to a larger difference (41.8%) in percentage of white fleeces between Romanov-sired ewes out of CIII ewes and Romanov-sired ewes out of WF ewes than each of the differences between dam breeds within the other four sire breeds. The percentage of white fleeces for the remaining eight crossbred types ranged from 83.3 to 98.2%.

Table 9. Frequency of white and nonwhite fleeces from F₁ ewes by dam and sire breeds and crossbred type

Item	White	Nonwhite	Total	% White
Dam breeds ^a				
CIII	223	46	269	82.9
WF	244	27	271	90.0
$\chi^2 = 5.882, 1 \text{ df}, P < 0.025$				
Sire breeds				
Dorset	105	4	109	96.3
Finnsheep	102	6	108	94.4
Texel	95	14	109	87.2
Romanov	67	40	107	62.6
Montadale	98	9	107	91.6
$\chi^2 = 69.456, 4 \text{ df}, P < 0.001$				
Crossbred type ^a				
CIII \times Dorset	54	1	55	98.2
CIII \times Finnsheep	52	2	54	96.3
CIII \times Texel	46	8	54	85.2
CIII \times Romanov	22	31	53	41.5
CIII \times Montadale	49	4	53	92.5
WF \times Dorset	51	3	54	94.4
WF \times Finnsheep	50	4	54	92.6
WF \times Texel	49	6	55	89.1
WF \times Romanov	45	9	54	83.3
WF \times Montadale	49	5	54	90.7
Total	467	73	540	
$\chi^2 = 110.537, 9 \text{ df}, P < 0.001$				

^aCIII = Composite III; WF = Northwestern Whiteface.

Heritability Estimates

Estimates of heritability were 0.36 ± 0.14 for grease and clean fleece weights, 0.86 ± 0.16 for fiber diameter, 0.42 ± 0.15 for diameter SD, 0.31 ± 0.13 for percentage clean yield, 0.49 ± 0.15 for staple length, and 0.00 ± 0.12 for staple length SD.

Fogarty (1995) summarized the literature to report means of heritabilities for wool traits, based primarily on wool and dual-purpose breeds, rather than meat breeds. Our heritability estimates for grease and clean fleece weights are very similar to the mean of heritabilities reported by Fogarty (1995), 0.35 and 0.36, respectively. Fogarty (1995) reported three estimates for greasy fleece weight of meat breeds and these values tended to be lower than the overall mean (0.16, 0.17, and 0.38). The mean heritability for average fiber diameter was 0.51 (Fogarty, 1995), based entirely on estimates within wool and dual-purpose breeds (range 0.17 to 0.84). Only one value (0.84, Watson et al., 1977) with Merino sheep approached the estimate reported herein; however, standard errors in the present experiment were relatively large. Although clean yield can be affected by the production environment, the heritability of yield within a flock is typically greater (0.5; Atkins, 1997) than our value of 0.31. Estimates of Atkins were based on Australian Merino strains under research and production conditions in Australia. The heritability of 0.40 for staple length reported by Atkins is similar to the value (0.49) estimated in our experiment.

Implications

Wool production, fiber diameter, and staple length have been estimated for 10 types of crossbred ewes that were bred, shorn, and lambled in three different production systems. Generally, wool production, fiber diameter, and staple length decreased as dates of exposure, shearing (December, February, and April), and lambing advanced later into the year. In the current wool market, the micrometer range (23 to 30 μm) of the wool produced by the F₁ ewes ensures that income from wool will be only a small portion (1 to 5%) of overall income from sheep production. Wool value from these crossbred types is further undermined by the presence of nonwhite wool in some of the predominantly white fleeces. In this respect, Romanov crosses produced the least percentage of white fleeces (62.6%) in contrast to Dorset crosses, which produced the greatest (96.3%).

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