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Sex of Littermate Twin Affects Lifetime Ewe Productivity[3]

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Summary

Ewe productivity is synonymous with annual litter-weight weaned (LWW) per ewe exposed to rams for breeding, and LWW is largely a function of number of lambs born (NLB) and weaned (NLW). Selecting for LWW should increase litter size and numbers of ewe-ram co-twins. Thus, we used historical records to determine whether sex of co-twin affected lifetime productivity of twinborn ewes. United States Sheep Experiment Station (USSES) lambing records (n = 8,650) from 1991 through 1997 were queried to identify twinborn ewes that were reared with their biological dams and retained in the breeding flock (n = 1,628; Columbia, 383; Polypay, 536; Rambouillet, 383; and Targhee, 326). Corresponding records for lifetime-cumulative counts of lambs born (stillborn and live-born) with recorded birth weights and weaned with recorded-weaning weights, cumulative weight of lambs weaned, lifetime count of lambing events, and age at first lambing (1 yr, 2 yr, or 3 yr) were evaluated using PROC GLM and PROC MIXED methods. Alpha was set at 0.10. Only the main effects of sex of co-twin, ewe-weaning weight, ewe breed, and ewe-birth year were significant. Per-ewe exposed to rams, but not per-ewe lambing, cumulative-lifetime weaning weight (*P* = 0.03) and numbers of lambs born (*P* = 0.07) and weaned (*P* = 0.04) were greater for ewes with a ram co-twin than for ewes with a ewe co-twin. Sex of co-twin did not affect number of lifetime-lambing events or age at first lambing for ewes exposed (*P* = 0.14 and *P* = 0.59, respectively) or ewes lambing (*P* = 0.67 and *P* = 0.27, respectively). Ewe-weaning weight affected cumulative-lifetime weaning weights (*P* = 0.0003), lifetime numbers of lambs born (*P* = 0.001) and weaned (*P* = 0.02), and lifetime-lambing events (*P* = 0.001), but not age at first lambing (*P* = 0.44) per-ewe exposed. Productivity of Polypay and Rambouillet ewes generally exceeded that of Columbia and Targhee ewes, although breed ranking was not constant among productivity traits of twinborn ewes. Based on the data, we concluded that ewes born co-twin to a ram had an advantage over ewes born co-twin to a ewe. This advantage amounted to 15.55 kg in lifetime litter-weight weaned per-ewe exposed. We believe that sex of co-twin should be evaluated further to determine whether it is a useful environmental adjustment, beyond lamb sex and type of birth and rearing, for lamb weights and traits related to ewe productivity.

Key Words: Sheep, Production, Efficiency, Reproduction

Introduction

Ewe productivity, typically synonymous with annual litter-weight weaned (LWW) per ewe exposed to breeding, is a key determinant of net-economic return per ewe (Ercanbrack and Knight, 1998; Snowder, 2002; Snowder and Fogarty, 2009). Ewe prolificacy (i.e., number of lambs born; NLB) accounted for approximately 37 percent of the genetic improvement in LWW (Ercanbrack and Knight, 1998). The weighted mean genetic correlation between LWW and NLB was 0.60 and between LWW and number of lambs weaned (NLW) was 0.80 (Snowder and Fogarty, 2009). Also, the genetic correlation between the NSIP Maternal Wool Breeds Index was 0.40 for NLB and 0.94 for NLW (Notter, 2014). Thus, selecting for LWW should increase litter size (Ercanbrack and Knight, 1998) and, as a consequence, "competition in utero between twin lambs" (Donald and Purser, 1956) and endocrinological disparities between ewe-ram fetal twins (Padula, 2005). However, the effect of competition in utero on reproductive performance and overall productivity of ewes has received little attention. The few reports in refereed journals indicated that sex of co-twin had little effect on subsequent reproductive performance of the ewes (Meredith and Keisling, 1996; Avdi and Driancourt, 1997; Casellas and Caja, 2014), although first-year survival, and thus breeding success, was less for unmanaged Soay ewes born co-twin to a ram (Korsten et al., 2009). By contrast, rodent and swine studies indicate that in utero proximity of a female to a male fetus can, for example, affect that female's age at first estrus (von Saal, 1981) and reproductive capacity (vom Saal and Finch, 1988; Drickamer et al., 1997). Because of the economic importance of ewe productivity, and its relationship to NLB and NLW, we used historic United States Sheep Experiment Station (USSES) records to test the null hypothesis that sex of co-twin does not affect ewe productivity.

Materials and Methods

Animals

This research was conducted with records extracted from a database and did not involve animal experimentation. Thus, Institutional Animal Care and Use Committee approval was not required. Lambing records (n = 8,650) from the United States Sheep Experiment Station were queried to identify twin-born ewes, which were born from 1991 through 1997 and with production years from 1992 to 2008, reared with their biological dams, and retained in the breeding flock (n = 1,628; Columbia, 383; Polypay, 536; Rambouillet, 383; and Targhee, 326). These ewes represented the most recent set of lifetime records, based on a typical, 8-yr-flock lifespan, at the time the data were queried. Single-born-single-reared ewes were not included in the dataset because the objective focused on the relationship only between co-twins. The dataset contained approximately twice as many records for ewes from ewe-ewe co-twin pairs than for ewes from ewe-ram co-twins because each ewe was considered a record and ram-ram co-twin data were not used. Corresponding lifetime-production records were extracted from the database for analyses.

Ewes were managed in a rangeland production system and mated annually with Columbia, Polypay, Rambouillet, and Targhee rams respective to breed. Lambs were born in mid-March through late April and reared with their biological dams on spring and summer ranges until weaning in August, when ram lambs were separated from ewe lambs. Flock sizes ranged from 600 to 1,100 mature ewes. Independent culling criteria for ewe lambs at weaning were based on body weights, wool blindness, fleece characteristics, jaw malformations, and various health issues. From the time of separation at weaning until breeding, ewes and ewe lambs grazed separate pastures. In mid-October, ewes and ewe lambs were moved to drylot pens for a 35-d breeding period. Ewes were single-sire mated, and ewe lambs were bred to either purebred or crossbred rams. Age of ewe and mating experience of rams varied across years. After breeding, ewes were returned to range until approximately February 1 each year and then placed in drylots through lambing. Ewe lambs remained in drylots throughout the winter and lambing. Generally, ewes were culled for debilitating disease, poor udder score, poor lambing history, or at greater than 8 yr of age. Even though rams had passed breeding soundness examinations, some rams had poor breeding success during the breeding period. Thus, only data from ewes that were exposed to fertile rams were considered.

Measurements and Statistical Methods

To determine the effect of co-twin sex on ewe productivity, lifetime-cumulative counts of lambs born (stillborn and live-born) with recorded birth weights and weaned with recorded weaning weights, cumulative weight of lambs weaned, lifetime count of lambing events, and age at first lambing (1, 2, or 3 yr) were evaluated. To include or exclude differences in fertility, cumulative weaning weight, lifetime counts of lambs born and weaned, lifetime count of lambing events, and age at first lambing were expressed as ewes exposed to rams for breeding and ewes that lambed. Records for ewes that did not lamb were excluded from calculations on a per-ewe-lambing basis. Lifetime-ewe productivity was measured as cumulative-weaning weight per ewe exposed to rams for breeding. Cumulative weights were determined using a calculated 120-d weaning weight (birth weight + [120 d × preweaning ADG]). The PROC GLM procedure in SAS (SAS Inst., Inc., Cary, N.C.) was used and included co-twin sex, age of dam in years (1 to 8), offspring sex (i.e., ewe or ram), sire breed, lambing year, birth-litter count (1, 2, or 3 lambs), and method of rearing (dam-reared or nursery-reared).

Ten ewes produced stillborn lambs and were given a value of 0 for birth weight and weaning weight. Ewes that were missing either birth-weight or weaning-weight data were excluded from the analyses. The effects of sex of co-twin on defined traits were analyzed using mixed models (PROC MIXED; SAS Inst., Inc.). The model included breed (Columbia, Polypay, Rambouillet, and Targhee), co-twin sex (male or female), breed × co-twin sex, ewe birth year (1991 to 1997), ewe-recorded-birth weight, and ewe-recorded-weaning weight, as fixed effects, and sire of the ewe as the random effect. The PROC GLM, Type III sums of squares were used to calculate percentage of the total sums of squares for each source of variation in the model to explain differences in ewe productivity, and we interpreted this as the relative importance of each effect. Quantitative data are shown as least-squares means and SEM. Alpha was set at 0.10.

Results

Only the main effects of sex of co-twin, ewe breed, ewe-weaning weight, and ewe-birth year were significant. The breed × co-twin sex interaction was not significant for any trait. Ewe weaning weight and ewe-birth weight, with one exception, accounted for the greatest proportions of the total variability, and sex of littermate always accounted for the smallest proportion; ewe-birth year and ewe breed, with one exception, were intermediate (Table 1). However, even when all main effects were taken into account in the analysis, co-twin differences were still apparent for most production traits.

Co-twin Effects

Cumulative-lifetime weaning weight was greater ($P = 0.03$) per ewe exposed from ewe-ram twins than for ewes from ewe-ewe twins, but the trait was not significant on a per-ewe-lambing basis ($P = 0.20$; Table 2). The ewe-ram advantage in cumulative-lifetime weaning weight for ewes exposed was 15.55 kg, averaging 1.94 kg/yr over a typical 8-yr flock lifespan. Per-ewe exposed, lifetime counts of lambs born and lambs weaned were greater for ewes born co-twin to a ram ($P = 0.07$ and $P = 0.04$, respectively) than for ewes born co-twin to a ewe (Table 3). However, per-ewe lambing, sex of co-twin did not affect the number of lambs born or weaned ($P > 0.20$). Ewes with a ram co-twin gave birth to an average of 1.57 lambs/yr and weaned an average of 1.44 lambs/yr, whereas ewes with a ewe co-twin gave birth to an average of 1.52 lambs/yr and weaned 1.38 lambs/yr. Sex of co-twin did not affect lifetime counts of lambing events or age at first lambing for ewes exposed ($P = 0.14$ and $P = 0.59$, respectively) or ewes lambing ($P = 0.67$ and $P = 0.27$, respectively; Table 3).

Effects of Birth Weight and Weaning Weight

On a per-ewe-exposed basis and a per-ewe-lambing basis, ewe birth weight was not a significant source of variation for any trait evaluated. However, ewe weaning weight was significant for cumulative lifetime weaning weights ($P = 0.0003$), lifetime numbers of lambs born ($P = 0.001$) and weaned ($P = 0.02$), and lifetime lambing events ($P = 0.001$), but not for age at first lambing ($P = 0.44$) per ewe exposed. Weaning weight per ewe lambing affected ($P < 0.09$) all traits, except lifetime counts of lambs weaned ($P = 0.22$).

Breed Effects

Cumulative-lifetime weaning weights (Table 2), on a per-ewe-exposed and on a per-ewe-lambing basis, were greater for Polypay than for Columbia ($P < 0.001$ and 0.0001, respectively), Rambouillet ($P = 0.01$ and 0.006, respectively), and Targhee ewes ($P = 0.003$ and 0.004, respectively). Rambouillet did not differ from Targhee ewes ($P = 0.30$), but both Rambouillet ($P = 0.003$ and 0.002, respectively) and Targhee exceeded ($P = 0.02$ and 0.007, respectively) Columbia ewes, which averaged 46.0 kg/yr less than the other three breeds.

Per-ewe exposed and per-ewe lambing, lifetime number of lambs born (Table 4) was greater for Polypay ($P = 0.0001$ and 0.0001, respectively),

Table 1. Type III sums of squares for main effects to show the relative importance of each source of variation for explaining differences in lifetime ewe productivity.

Source of variation	Cumulative lifetime weaning weight[a]	Lifetime born[a]	Lifetime weaned[a]	Lifetime counts of lambing events[a]	Age at first lambing[a]
Per ewe exposed (n = 1,628)					
Sex of littermate	67,907.24	53.05	50.31	11.91	0.34
Ewe birth year	327,692.47	424.61	322.66	122.06	12.38
Ewe breed	520,464.66	435.43	203.27	30.59	28.82
Ewe weaning weight	1,958,823.37	2,291.95	1,426.20	621.79	45.47
Ewe birth weight	1,294,931.41	1,575.31	1,070.34	477.75	60.39
Total sums of squares	24,131,731.40	30,249.46	22,159.38	8,703.94	1,059.44
Per ewe lambing (n = 1,277)					
Sex of littermate	14,066.11	3.20	9.99	0.21	0.75
Ewe birth year	337,223.57	397.54	267.35	83.87	8.65
Ewe breed	343,302.59	252.54	76.80	20.77	21.39
Ewe weaning weight	1,213,041.55	1,374.95	828.40	293.85	54.02
Ewe birth weight	910,981.44	1,156.90	791.30	301.67	16.02
Total sums of squares	15,971,570.45	20,295.62	14,312.07	4,884.97	422.70

[a] Cumulative lifetime weaning weight = cumulative weight of lambs weaned in kilograms; Lifetime born = cumulative count of recorded birth weights; Lifetime weaned = cumulative count of recorded weaning weight; Lifetime counts of lambing events = cumulative count of lambing events; Age at first lambing = age ewe first lambed (1, 2, or 3 yr of age). Ewes were produced in an autumn-breeding management system.

Table 2. Effect of sex of co-twin or breed on lifetime productivity of all ewes exposed and lambing[a].

	n	Cumulative lifetime weaning weight, kg
Per ewe exposed		
Co-twin[b]		
Ewe	1,090	113.20 ± 7.20
Ram	538	128.75 ± 8.74
Breed[c]		
Columbia	383	86.79 ± 10.30
Polypay	536	152.92 ± 8.90
Rambouillet	383	127.87 ± 9.95
Targhee	326	116.32 ± 10.24
Per ewe lambing		
Co-twin[d]		
Ewe	826	150.59 ± 7.00
Ram	451	160.24 ± 8.69
Breed[c]		
Columbia	309	121.06 ± 10.21
Polypay	433	186.11 ± 8.59
Rambouillet	297	158.15 ± 10.18
Targhee	238	156.33 ± 10.42

[a] Values are least-squares means ± SEM from SAS, PROC MIXED analyses.
[b] Cumulative lifetime weaning weight for ewes from ewe-ram co-twin births was greater ($P = 0.03$) than that of ewes from ewe-ewe co-twin births.
[c] On per-ewe-exposed and per-ewe-lambing basis, cumulative lifetime weaning weights were greater for Polypay than for Columbia ($P < 0.001$ and 0.0001, respectively), Rambouillet ($P = 0.01$ and 0.006, respectively), and Targhee ($P = 0.003$ and 0.004, respectively) ewes. Per ewe exposed and per ewe lambing, cumulative lifetime weaning weights for Rambouillet ($P = 0.003$ and 0.002, respectively) and Targhee ($P = 0.02$ and 0.007, respectively) were greater than those for Columbia ewes, but the values did not differ ($P > 0.30$) between Rambouillet and Targhee ewes.
[d] Sex of littermate did not affect ($P = 0.20$) cumulative lifetime weaning weights.

Rambouillet ($P = 0.0001$ and 0.0006, respectively), and Targhee ($P = 0.03$ and 0.01, respectively) than for Columbia ewes. The number was greater ($P = 0.006$) for Polypay than for Targhee, but not greater ($P > 0.20$) than for Rambouillet. Rambouillet and Targhee did not differ ($P > 0.10$).

Lifetime numbers of lambs weaned (Table 4), on per-ewe-exposed and per-ewe-lambing bases, were greater for Polypay ($P = 0.0002$ and 0.005, respectively) and Rambouillet ($P = 0.0003$ and 0.01, respectively) than for Columbia ewes. Polypay ewes exposed and lambing weaned more lambs in a lifetime than did Targhee ($P = 0.0007$ and 0.03, respectively), but not more than Rambouillet ewes ($P = 0.90$ and 0.60, respectively). On both bases, lifetime numbers of lambs weaned did not differ between Columbia and Targhee ewes ($P = 0.20$ and 0.44, respectively). Rambouillet ewes exposed weaned a greater number of lambs than did Targhee ewes exposed ($P = 0.02$), but Rambouillet and Targhee ewes lambing did not differ ($P = 0.10$).

For lifetime counts of lambing events per ewe exposed (Table 4), Rambouillet exceeded Columbia ($P = 0.01$) and Targhee ($P = 0.07$), but not Polypay ewes ($P = 0.54$). Counts were greater for Polypay than Columbia ($P = 0.04$), and counts for Targhee did not differ from Columbia ($P = 0.49$) or Polypay ($P = 0.15$). Per-ewe lambing, lifetime counts of lambing events for Rambouillet exceeded Columbia ($P = 0.07$) and Polypay ($P = 0.09$), but not Targhee ewes ($P = 0.17$). Counts did not differ

Table 3. Effect of sex of co-twin on prolificacy, lifetime number of lambs weaned, cumulative years lambing, and age at first lambing for ewes exposed and ewes lambing[a].

	n	Lifetime born[b]	Lifetime weaned[b]	Lifetime counts of lambing events	Age at first lambing
Per ewe exposed					
Ewe co-twin	1,090	4.06 ± 0.25	3.64 ± 0.21	2.64 ± 0.13	1.20 ± 0.05
Ram co-twin	538	4.49 ± 0.29	4.10 ± 0.26	2.83 ± 0.16	1.23 ± 0.06
Per ewe lambing[c]					
Ewe co-twin	826	5.24 ± 0.25	4.81 ± 0.21	3.49 ± 0.12	1.63 ± 0.04
Ram co-twin	451	5.43 ± 0.30	5.06 ± 0.26	3.55 ± 0.15	1.60 ± 0.04

[a] Values are least-squares means ± SEM from SAS, PROC MIXED analyses.
[b] Per ewe exposed, lifetime born and lifetime weaned were greater ($P < 0.08$) for ewes from ewe-ram co-twin births than for ewes from ewe-ewe co-twin births.
[c] Per ewe lambing, sex of co-twin did not affect ($P > .70$) any of the traits.

Table 4. Effect of breed on prolificacy, total number of lambs weaned, lifetime counts of lambing events, and age of first lambing for ewes exposed and ewes lambing[a].

	n	Lifetime born[b]	Lifetime weaned[c]	Lifetime counts of lambing events[d]	Age of first lambing[e]
Per Ewe Exposed					
Breed					
Columbia	383	3.18 ± 0.35	3.09 ± 0.31	2.46 ± 0.19	1.34 ± 0.07
Polypay	536	5.10 ± 0.31	4.42 ± 0.27	2.88 ± 0.18	1.34 ± 0.06
Rambouillet	383	4.71 ± 0.34	4.38 ± 0.31	2.99 ± 0.19	1.11 ± 0.07
Targhee	326	4.13 ± 0.35	3.57 ± 0.31	2.62 ± 0.19	1.06 ± 0.07
Per Ewe Lambing					
Breed					
Columbia	309	4.28 ± 0.35	4.42 ± 0.30	3.40 ± 0.17	1.86 ± 0.05
Polypay	433	6.04 ± 0.30	5.37 ± 0.26	3.46 ± 0.15	1.63 ± 0.04
Rambouillet	297	5.64 ± 0.34	5.25 ± 0.30	3.74 ± 0.17	1.52 ± 0.05
Targhee	238	5.38 ± 0.36	4.71 ± 0.31	3.48 ± 0.18	1.46 ± 0.05

[a] Values are least-squares means ± SEM from SAS, PROC MIXED analyses. Lifetime born = cumulative count of recorded birth weights; Lifetime weaned = cumulative count of recorded weaning weights; Lifetime counts of lambing events = cumulative count of lambing events; Age of first lambing = age ewe first lambed (1, 2, or 3 yr of age). Ewes were produced in an autumn-breeding management system.

[b] Per ewe exposed: Polypay, Rambouillet, and Targhee > Columbia (P = 0.0001, P = 0.001, P = 0.03, respectively); Polypay > Targhee (P = 0.006) but not different from Rambouillet (P > 0.20); and Rambouillet not different from Targhee (P > 0.10). Per ewe lambing: Polypay, Rambouillet, and Targhee > Columbia (P = 0.0001, P = 0.0006, P = 0.01, respectively); Polypay > Targhee (P = 0.07) but not different from Rambouillet (P > 0.20); and Rambouillet not different from Targhee (P > 0.50).

[c] Per ewe exposed: Polypay and Rambouillet > Columbia (P = 0.0002 and P = 0.0003, respectively); Columbia not different from Targhee (P = 0.20); Polypay > Targhee (P = 0.007) but not different from Rambouillet (P > .90); and Rambouillet > Targhee (P = 0.02). Per ewe lambing: Polypay and Rambouillet > Columbia (P = 0.005 and P = 0.01, respectively); Columbia not different from Targhee (P = 0.44); Polypay > Targhee (P = 0.03) but not different from Rambouillet (P > .60); and Rambouillet not different from Targhee (P = 0.10).

[d] Per ewe exposed: Rambouillet > Columbia (P = 0.01) and Targhee (P = 0.07) but not different from Polypay (P = 0.54); Polypay > Columbia (P = 0.04) but not different from Targhee (P = 0.15); and Columbia not different from Targhee (P = 0.49). Per ewe lambing: Rambouillet > Columbia (P = 0.07) and Polypay (P = 0.09) but not different from Targhee (P = 0.17); Columbia not different from Targhee (P = 0.72) and Polypay (P = 0.75); and Targhee not different from Polypay (P = 0.92).

[e] Per ewe exposed: Rambouillet and Targhee < Columbia (P = 0.001 and 0.0005, respectively) and Polypay (P = 0.0001 and 0.003, respectively); Rambouillet not different from Targhee (P > 0.30); and Columbia not different from Polypay (P = 0.99). Per ewe lambing: Rambouillet and Targhee < Columbia (P = 0.001 for both) and Polypay (P = 0.003 and 0.04, respectively); and Polypay < Columbia (P = 0.0001).

between Columbia and Targhee (P = 0.72), Columbia and Polypay (P = 0.75), or Targhee and Polypay ewes (P = 0.92).

On per-ewe-exposed and per-ewe-lambing bases, age at first lambing (Table 4) was less (P < 0.004) for Rambouillet and Targhee than for Columbia and Polypay ewes. Per ewe exposed, age at first lambing did not differ between Columbia and Polypay (P = 0.99) or between Rambouillet and Targhee ewes (P > 0.40). Per ewe lambing, Polypay were younger (P = 0.0001) at first lambing than Columbia ewes. Seventy percent of the Rambouillet and 60.5 percent of the Targhee ewes lambed as yearlings, whereas 54.4 percent and 52.7 percent, respectively, of the Columbia and Polypay ewes lambed for the first time as 2 yr olds.

Discussion

Sex of co-twin affected lifetime productivity of twinborn ewes. We used litter weight weaned per-ewe exposed to rams for breeding as the definition of ewe productivity because this is the typical expression of ewe productivity and consistent with management practices in extensive sheep production systems (Ercanbrack and Knight, 1998; Snowder, 2002; Snowder and Fogarty, 2009). Data were also expressed on a per-ewe-lambing basis to determine whether sex of co-twin affected that subset of ewes. The environmental effect of sex of co-twin was primarily limited to measures that were calculated on a per-ewe-exposed, rather than on a per-ewe-lambing, basis. There is no clear explanation for this difference, but we speculate that sex of co-twin could have affected the ability of ewes to become pregnant and lamb and to wean more lambs over a lifetime of exposures to rams for breeding. In rodents and swine, sex of adjacent littermate(s) in utero was associated with differences in timing of puberty (vom Saal and Finch, 1988), duration of estrous cycles (vom Saal and Bronson, 1980b), age at first estrus (vom Saal, 1981), and reproductive capacity (vom Saal and Finch, 1988; Drickamer et al., 1997). In the present study, marking harnesses were not used to identify ewes as bred and ultrasonography for pregnancy determination was not used as management tool, so it is possible that a greater percentage of ewes with a female co-twin did not become pregnant or had greater rates of fertilization failure or embryonic or fetal mortality than those with a male co-twin. Co-twin effects on embryonic loss in sheep has been assessed (Avdi and Driancourt, 1997), but loss was determined between ovulation and lambing, not taking into account potential fertilization failure in ewes exposed to rams for mating or late embryonic or fetal loss. In rodents and swine, sex of adjacent littermate(s) in utero was associated with differences in sexual behavior (vom Saal and Bronson, 1978; Kinsley et al., 1986a; Rohde Parfet et al., 1990) and attractiveness to males (vom Saal, 1989), so it may be possible that ewes with a male co-twin were more sexually attractive to rams or had more proceptive behavior than ewes with a female co-twin and became pregnant at a greater rate.

Per-ewe exposed, the cumulative-lifetime-weaning weight advantage for ewes born co-twin to a ram was substantial and considerably greater than the expected-annual-genetic increase in litter weight weaned of 0.69 kg/yr (Ercanbrach and Knight, 1998) for Columbia, Polypay, Rambouillet, and Targhee sheep and 0.61 kg/yr for Polypay sheep (Notter, 2014). Improvements in genetic merit for litter weight weaned were attributed to approximately 37 percent prolificacy, 27 percent to percentage of lambs weaned, 17 percent to lamb weaning weight, 12 percent to fertility, and 7 percent to ewe viability (Ercanbrack and Knight, 1998). Indeed, the weighted-mean genetic correlation between litter-weight weaned and number of lambs born was 0.60 and between litter-weight weaned and number of lambs weaned was 0.80 (Snowder and Fogarty, 2009).

In the present study, the environmental effect of ewes born co-twin to a ram improved, on a per-ewe-exposed basis, lifetime counts of lambs born (i.e., prolificacy) and lambs weaned. In addition, lifetime numbers of lambs born and weaned increased as ewe-weaning weight increased. Thus, the environmental "benefit" to a ewe born co-twin to a ram was perhaps due to a greater number of ewes born co-twin to a ram becoming pregnant and lambing, explaining the increased prolificacy, lambs weaned, and lifetime ewe-weaning weight in ewes exposed to rams for breeding and why effects of co-twin were not seen in these variables in ewes lambing. However, the benefit of having a male co-twin did not increase lifetime counts of lambing events or decrease the age at first lambing. This is somewhat surprising because ewe lambs with heavier weaning weights were more likely to lamb at 1 yr of age, and this relationship was primarily environmental, rather than genetic (Kirschten et al., 2015).

Data from the present study contrast with previous data in refereed journals. The data in those reports on sheep indicate that sex of co-twin did not have important effects on fertility (Slee, 1963), embryonic development (Avdi and Driancourt, 1997), timing of puberty (Meredith and Keisling, 1996), or number of lambs born per ewe (Casellas and Caja, 2014). However, first-year survival and breeding success were less for unmanaged Soay ewes born co-twin to a ram (Korsten et al., 2009).

Too little is known about the interaction of ewe-ram co-twins in utero and between birth and weaning to offer an unequivocal explanation for the effects of co-twin sex in the present study. Also, the events in utero and between birth and weaning were confounded and cannot be separated with the dataset used for this study. Nevertheless, a large percentage of ewe-ram co-twins may share chorioallantoic circulation, and the endocrine environment of ewes from ewe-ram co-twins should be expected to differ from that of ewes from ewe-ewe co-twins (Wilkes et al., 1978); this is possibly associated with variation in placental size, function (Alexander, 1964), and circulatory systems (Valdes Cruz et al., 1977). Shared chorioallantoic circulation between male and female fetuses leads to freemartinism in cattle (Parkinson et al., 2001). At least 90 percent of the female calves from female-male co-twins are freemartins, and freemartin females are anestrus and sterile (Parkinson et al., 2001). By contrast, only a small percentage, perhaps less than 5 percent (Brace et al., 2008; Martinez-Royo et al., 2009), of ewes from ewe-ram co-twins are freemartins, which are also anestrus and sterile.

In the present study, androgens and other biochemical factors from ram lambs were conceivably transferred to their ewe co-twins during critical periods of prenatal development, and this could have affected reproductive development and function after birth (Short, 1975; Clarke et al., 1976; Wood and Foster, 1998). Treating fetal sheep with large doses of testosterone will disrupt, but not enhance, reproductive functions of ewes in postnatal life (Padmanabhan and Veiga-Lopez, 2014), and neither fetal-testosterone treatment nor factors related to freemartinism can explain the response of ewes that were naturally born co-twin to rams in the present study.

Ewe-birth weight in the present study did not affect any of the traits that were evaluated. This is consistent with a recent report of a large study indicating that absolute-birth weight did not affect litter size of Ripollesa ewes from twin births, but in contrast to data from the same study indicating that relative-birth weight (i.e., weight difference between twins) affected litter size of ewes from twin births (Casellas and Caja, 2014). Reproductive ability, measured as litter size, of twinborn ewes that were >600 g lighter than their co-twins was less than that of ewes with smaller disparities in birth weights (Casellas and Caja, 2014).

However, in the present study, weaning weight of ewes exposed affected lifetime number of lambs born and weaned, lifetime-lambing events, and cumulative-weaning weights, but not age at first lambing. These results should be expected because the heritability estimate was 0.14 for 120-d weaning weight and 0.15 for probability of lambing as a yearling, and the phenotypic and genetic correlations between the two traits were 0.18 and 0.23, respectively (Kirschten et al., 2015). Also, the positive relationship between weaning weight and various reproductive traits has been recognized for many years (Burfening et al., 1971; Dickerson and Laster, 1975; Stobart et al., 1987). Moreover, the relationships between ewe-weaning weight, degree of maturity at weaning, number of lambs born, number of lambs weaned, and lamb weaning weight were all positive (Stobart et al., 1987).

Breed effects were expected in the present study, and most of the effects were consistent with various published studies of Columbia, Polypay, Rambouillet, and Targhee sheep and ewes with Finnsheep breeding (Dickerson, 1977; Ercanbrak and Knight, 1985; Lewis and Burfening, 1988; Notter and McClaughtery, 1991; Nawaz et al., 1992; Inman and Slyter, 1993; Ercanbrack and Knight, 1998; Leeds and Lewis, 2006; Taylor et al., 2009). In general, productivity of Polypay and Rambouillet ewes exceeded that of Columbia and Targhee ewes, although breed ranking was not constant among productivity traits. Particularly important were the Polypay and Rambouillet advantages, compared with Columbia and Targhee, in cumulative lifetime weaning weights, lifetime numbers of lambs born, and lifetime numbers of lambs weaned. For age at first lambing, breed ranking was not consistent with a previous study of United States Sheep Experiment Station Columbia, Polypay, Rambouillet, and Targhee sheep (Leeds and Lewis, 2006). Based on between 3,802 and 4,990 records per breed, 45.7 percent, 81.3 percent, 58.8 percent and 49.9 percent of the Columbia, Polypay, Rambouillet, and Targhee ewes, respectively, lambed at approximately 1 yr of age (Leeds and Lewis, 2006). The differences in age at first lambing between the present and previous reports may reflect how the data were sampled and the differences in sizes of the datasets: 1,628 records in the present study and 17,798 records in Leeds and Lewis (2006).

Conclusion

Ewe productivity, defined as litter-weight weaned per ewe exposed to rams for breeding, is considered the key determinant of net-economic-return per ewe. Based on the results of this study, ewes with a ram co-twin were more productive than ewes with a ewe co-twin, regardless of breed and birth weight. We do not have a mechanistic explanation for the environmental "benefit" to a ewe born co-twin to a ram and, thus, suggest that cause-and-effect studies are warranted to explore this phenomenon in depth. Also, we believe that sex of co-twin should be further evaluated to determine whether it is a useful environmental adjustment, beyond lamb sex and type of birth and rearing, for lamb weights and traits related to ewe productivity.

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Factors Affecting Price Differences Between Wool and Hair Lambs in San Angelo, Texas

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Summary

Transaction records of 286,764 lambs sold in 25,916 lots at the largest sheep and lamb auction in the United States were collected from 2010 through 2014, in order to estimate factors affecting lamb prices. The data set was restricted to those lots where the average weight per lamb was between 40 pounds and 100 pounds. Lots were classified according to type (hair or wool). Type is an indicator of breed that best represents the lot. Wool lambs were primarily Rambouillet. Hair lambs were primarily Dorper. A hedonic price model was used to estimate price differentials for lambs sold at auction in San Angelo, Texas. The fixed effects for type of lamb, year, month, weight class, lot size and 2-way interactions with type were significant sources of variation. The results indicate an overall discount of $3.42 ± $0.33 per hundredweight for hair lambs relative to wool lambs. The discount was largest in 2011 ($30.72 ± $0.51 per hundredweight). In 2012 the price paid for hair lambs was $9.62 ± $0.61 per hundredweight higher than the price paid for wool lambs. The discount relative to wool lambs increased as lamb weights increased. Hair lambs sold for $3.18±$0.83 per hundredweight more than wool lambs in the 40-pound to 50-pound weight class. Wool lambs sold for $9.09 ± $0.68 per hundredweight more than hair lambs in the 90-pound to 100-pound weight class. Prices increased as lot size increased. Wool lambs sold for a larger premium in the larger lot sizes. Wool lambs sold for $8.59 ± $0.39 per hundredweight more than hair lambs when there were 35 or more lambs in the lot. The difference in price between hair lambs and wool lambs varied across years, months, weight class, and lot size.

Key words: Hedonics, Hair Sheep, Price Differentials, Lamb Auction, Texas

Introduction

Ranchers, as land or resource managers, continually seek production systems that will provide the greatest return to resources, management and risk. The area around San Angelo, Texas is suited for sheep production, with Texas being the nation's leading state for lamb production (NASS, 2015). Rambouillet has historically been the predominant sheep breed in Texas and much of the western United States. In the mid-1990s the Dorper was imported into the United States from South Africa. Sheep producers were interested in Dorper sheep because of their reported performance (Cloete et al., 2000) in arid conditions. Additionally, low wool prices of the late 1990s made wool production less attractive. The Dorper breed has a mix of hair and wool. While not strictly a hair breed, Dorper is a shedding breed that does not require shearing. For the purpose of this paper, Dorper will be considered a hair breed. The Dorper breed has increased in popularity to become the 3rd largest breed in number of sheep registered in the United States (Banner, 2015). Performance of Dorpers has been compared to U.S. breeds (Snowder and Duckett, 2003; Yeaman et al., 2013).

Many sheep producers sell their lambs at livestock auctions at, or shortly after, weaning. The largest live sheep auction in the United States is located in San Angelo, Texas. Lamb buyers at auctions include traditional lamb feeders, who feed lambs for the traditional lamb market, as well as those buying lambs for the non-traditional market. The livestock auction is where producers collect their primary market information (Williams and Davis, 1998). Formal analysis of lamb prices is limited. Ward (1984) focused on the impact of buyer competition and buyer market share on slaughter lamb prices, while Ward and Hildebrand (1993) studied factors affecting prices of slaughter lambs. No reports were found with estimates of factors affecting lamb prices for lambs sold at weaning. If producers are more aware of what factors affect the prices paid for lambs, then it will help them to make more profitable production and marketing decisions.

The objectives of this study are to 1) estimate the factors affecting prices paid for lambs sold at, or shortly after, weaning in the San Angelo auction and 2) estimate the difference in value between hair sheep lambs and wool lambs. This information has the potential to strengthen the short-run decision making process of many sheep producers as they evaluate the production system best suited for their natural resources and management objectives.

Materials and Methods

Data

The transaction records from the weekly sales at Producers Livestock Auction Company years 2010 through 2014 were used for this study. The data included sales of 175,668 lots of sheep and goats. In a central market setting, sellers bring their animals to the sale facility. Auction staff typically sort a seller's animals into uniform groups according to type, weight and quality. If a seller delivers a group of 50 animals, they may sell as one lot if they are uniform, or be sorted into several lots to make each lot more uniform. The transaction records included number of head sold in the lot, price, total weight of the lot, and codes to describe the lot. Price was typically expressed as dollars per hundredweight ($/cwt). Because prices are reported in $/cwt, this paper uses pounds as the weight unit instead of kilograms. Some lots were priced by the head. Codes were used to distinguish among different classes of livestock. The data used in this study included only lots coded as lambs. Codes were also used to make a distinction among lambs of different types. The three types of lambs that made up the majority of the sales were 1) Rambouillet or other finewool breeds, which will be referred to as wool lambs, 2) Dorper or other hair sheep breeds which will be referred to as hair lambs, and 3) Suffolk or other blackface breeds, which will be referred to as blackface lambs. Because the goal of this study was to estimate factors affecting lamb prices received by typical range-flock lamb producers, and the majority of lambs produced in the area served by this auction are either Rambouillet (finewool) or hair breeds, transactions from lambs coded as blackface breeds were excluded. There were no codes for different breeds within those coded as hair sheep. The majority of lots coded as hair breeds were Dorper or Dorper-cross. A small proportion of the sheep coded as hair were Barbados Blackbelly or Katahdin, which are hair breeds. There was no code for a crossbred hair-wool lamb. The auction clerk chose a code that best represented the entire lot. There were 39,336 lots coded as lambs. Lots that were coded as blackface lambs (8 percent of the lots), shorn (6 percent of the lots) or had other codes indicating something unusual (approximately 5 percent of the lots) were excluded from further analysis.

Some of these lots (approximately 3.5 percent) were priced by the head instead of dollars per hundredweight. Lots that were typically priced by the head included those where the lambs were atypically small or young. The mean weight of lamb lots sold by the head was 33 pounds per head compared to the mean weight of 73 pounds for lambs sold by dollars per hundredweight. A small number of lots were sold by the head because of their value as potential breeding stock. All lots that were priced by the head were excluded from further analysis. After all edits, there remained 30,911 lots of lambs that were coded as either hair lambs or wool lambs and were sold by dollars per hundredweight. Table 1 shows number of lots, lambs, means of lot size, and weight, by year and type of lamb.

The wide range of lamb weights in the data set (Table 2) represents different segments of the lamb market. The light weight, young lambs were likely early weaned, or orphaned, or small for some other reason. The heavy weight lambs (> 100 pounds) have probably been on feed, rather than being recently weaned, and therefore were not representative of the target population for this study. The lambs with weights above 100 pounds were likely destined for the traditional lamb slaughter market. With the data available, there was no information to be used to divide the lots into the traditional categories of feeder and slaughter lambs. Therefore, to have a data set that is representative of the target for this study (lamb producers who sell lambs after weaning), all lots with an average weight less than 40 pounds or greater than 100 pounds were excluded.

After the weight restriction was applied, 25,916 lots with a total of 286,764 lambs remained in the data set. The average lamb weight was 70.8 pounds when each lot was weighted by

Table 1. Lots and lambs sold, number of head per lot, and average weight by year and type of lamb at San Angelo, TX.

	Hair				Wool			
Year	Lots	Lambs	Head/lot	Wt, lbs	Lots	Lambs	Head/lot	Wt, lbs
2010	2,939	31,798	10.8	66.2	3,410	45,358	13.3	76.8
2011	3,712	37,403	10.1	62.7	2,803	30,729	11.0	71.2
2012	3,087	26,641	8.6	72.8	2,006	22,005	11.0	84.3
2013	3,943	34,452	8.7	71.2	2,142	29,148	13.6	79.3
2014	4,915	41,298	8.4	70.4	1,954	21,794	11.2	79.2
All years	18,596	171,592	9.2	68.5	12,315	149,034	12.1	77.6

Table 2. Distribution of lots and lambs across weight classes within type of lamb sold at San Angelo, TX.

		Hair				Wool			
Weight Class	Pounds	Lots	Lambs	Lots, %	Lambs, %	Lots	Lambs	Lots, %	Lambs, %
1	< 20	1	8	0.01	< 0.00				
2	20 - <30	136	1,032	0.73	0.60	27	137	0.22	0.09
3	30 - <40	892	6,467	4.80	3.77	306	2,072	2.48	1.39
4	40 - <50	2,108	17,277	11.34	10.07	768	6,484	6.24	4.35
5	50 - <60	3,286	31,200	17.67	18.18	1,491	15,443	12.11	10.36
6	60 - <70	3,615	38,072	19.44	22.19	2,014	25,925	16.35	17.40
7	70 - <80	3,164	34,801	17.01	20.28	2,278	34,536	18.50	23.17
8	80 - <90	2,239	22,930	12.04	13.36	2,036	29,728	16.53	19.95
9	90 - <100	1,441	11,775	7.75	6.86	1,476	18,593	11.99	12.48
10	100 - <110	856	5,249	4.60	3.06	895	9,556	7.27	6.41
11	110 - <120	434	1,624	2.33	0.95	483	3,806	3.92	2.55
12	120 - <130	248	786	1.33	0.46	258	1,434	2.10	0.96
13	130 - <140	106	251	0.57	0.15	144	637	1.17	0.43
14	140 - <150	39	59	0.21	0.03	71	449	0.58	0.30
15	150 - <160	19	44	0.10	0.03	32	79	0.26	0.05
16	160 - <170	9	10	0.05	0.01	21	38	0.17	0.03
17	170 - <180	1	4	0.01	< 0.00	6	86	0.05	0.06
18	180 - <190	1	2	0.01	< 0.00	7	16	0.06	0.01
19	190 - <200	1	1	0.01	< 0.00	2	15	0.02	0.01
Total		18,596	171,592			12,315	149,034		

number of head in the lot. The distribution of lambs across 10 pound weight classes by type in this edited data set is shown in Table 3.

The number of head sold in each lot varied from 1 to 327. The mean number of head per lot was 9.2 head for hair lambs and 12.1 head for wool lambs (Table 1). The median of the distribution of lamb lots was 5 head. Number of head in each lot was assigned to lot-size categories as follows: A) 1 to 2 head, B) 3 to 5 head, C) 6 to 12 head, D) 13 to 34 head, and E) 35 or more head.

Table 3. Percent of lots (L=25,916) and lambs (N=286,764) by weight class within type of lamb in edited data set

	Hair		Wool	
Weight Class, lbs	Lots, %	Lambs, %	Lots, %	Lambs, %
40 - <50	13.30	11.07	7.63	4.96
50 - <60	20.73	19.99	14.82	11.81
60 - <70	22.80	24.40	20.01	19.83
70 - <80	19.96	22.30	22.64	26.42
80 - <90	14.12	14.69	20.23	22.74
90 - <100	9.09	7.55	14.67	14.22

Statistical Analysis

Lamb prices, in dollars per hundredweight, were analyzed with SAS PROC MIXED using a mixed linear model or hedonic price model (SAS, 2011) to estimate the price differences. The model included fixed effects for type (Hair or Wool), year (2010 to 2014), month, weight class (six 10 pound classes), lot size (A, B, C, D, E), and all 2-way interactions with type. The model also included a random effect for sale day. The weight statement of PROC

MIXED was used to adjust for number of head in a lot. The LSMEANS statement of PROC MIXED was used to produce estimates and standard errors of least squares means of main effects and interaction effects. The ESTIMATE statement of PROC MIXED was used to produce estimates and standard errors of differences between least squares means.

Results

The trend from 2010 to 2014 has been an increasing proportion of hair lambs (Table 1) in the 40-pound to 100-pound weight range. The last year that there were more wool lambs than hair lambs was 2010, when hair lambs were 41 percent of all lambs sold. In 2014, hair lambs were 65 percent of all lambs sold. In general, hair lambs came to the auction at lighter weights than wool lambs. The data in Table 2 shows that the percentage of lambs in the weight classes less than 70 pounds was greater for hair lambs, while the percentage of lambs in the weight classes greater than 70 pounds was greater for wool lambs.

The differences between the distributions of hair and wool lambs in the edited data set (Table 3) were similar to that shown in Table 2. Fifty-five percent of the hair lambs were in lots with an average weight of 70 pounds or less. Thirty-six percent of the wool lambs were in lots with an average weight of 70 pounds or less.

Because of the seasonal nature of sheep reproduction, there are substantial differences in numbers of lambs coming to market in different seasons of the year. The majority of lambs in the area from which the San Angelo auction draws are born in January, February, and March. Some flocks lamb earlier (October through December) or later (April and May). There are very few that lamb from June through September because of the high environmental temperatures and typically low quality of available pasture forage during those months. Lambs in the 40-pound to 100-pound weight range are generally 4 months to 6 months old in the typical management systems used in this area. Consequently, the months with the lowest number of lambs sold within the 40-pound to 100-pound range were January with an average of 2,857 lambs sold per year and February with 2,210 lamb sold per year. There were from 5,318 to 6,861 lambs sold per month from March through September. Number of lambs sold per month decreased substantially in October and November for both types (Table 4).

A greater percentage of hair lambs came to market early in the calendar year, relative to wool lambs. June was the month with the highest number of lambs sold for both hair and wool lambs. Forty-three percent of the hair lambs were sold prior to June, whereas only thirty-six percent of the wool lambs were sold prior to June. Hair sheep reproduction is not as seasonal as wool sheep reproduction. Therefore a producer of hair lambs has the option of having lambs born earlier, which can be brought to the auction earlier in the year. Hair lambs coming to market earlier than wool lambs is likely a result of Dorpers being less seasonal in their reproduction than wool sheep. However, the lower weights of the hair lambs may also indicate that the hair lambs were coming to the auction at younger ages than wool lambs.

Table 5 provides information about the distribution of number of head per lot sold. The lot size categories were established so that each category included a significant proportion of the lots and lambs. The category with the smallest lots (1 to 2 head) included more than 25 percent of the lots, but less than 4 percent of the lambs. The category with the largest lots (35+ head) included only 5.5 percent of the hair lamb lots, but more than 30 percent of the hair lambs. The category with the largest lots (35+ head) included only 8.7 percent of the wool lamb lots, but more than 43 percent of the wool lambs. Thirty-five percent of the hair lambs were sold in lots of 12 or fewer head. Twenty-five percent of the wool lambs were sold in lots of 12 or fewer head. We do not have data to determine if the difference in lot size is due to hair lambs being brought to the auction in smaller lots, or hair lambs being divided into smaller lots by the auction staff in order to offer uniform lots of lambs.

Table 4. Number of lambs sold (40 to 100 pounds) and percent by month within type of lamb at San Angelo, TX 2010-2014

	Hair		Wool	
Month	**Lambs**	**Lambs, %**	**Lambs**	**Lambs, %**
January	8,454	5.4	5,834	4.5
February	6,248	4.0	4,803	3.7
March	17,397	11.2	13,388	10.2
April	16,932	10.9	9,656	7.4
May	17,325	11.1	13,234	10.1
June	17,741	11.4	16,564	12.7
July	14,315	9.2	11,296	8.6
August	15,122	9.7	15,126	11.6
September	14,620	9.4	13,666	10.5
October	10,533	6.8	13,424	10.3
November	9,225	5.9	7,546	5.8
December	8,143	5.2	6,172	4.7
Total	156,055		130,709	

Table 5. Percent of lots (L=25,916) and lambs (N=286,764) by lot size within type of lamb at San Angelo, TX 2010-2014

	Hair		Wool	
Head in Lot	**Lots, %**	**Lambs, %**	**Lots, %**	**Lambs, %**
1 - 2	27.9	4.0	25.0	2.7
3 - 5	26.0	10.2	23.0	6.9
6 - 12	24.5	20.8	23.4	15.0
13 - 34	16.1	33.2	19.9	32.0
35 +	5.5	31.7	8.7	43.4

Price Differences

All main effects and interaction effects were significant sources of variation for price ($P < .01$). Because of the significant interaction effects, the results of interest for this study are the least squares means estimates of the interaction effects (Table 6).

The least squares means estimates of the price for hair and wool lambs were \$154.53±\$1.28 per hundredweight and \$157.95±\$1.29 per hundredweight, respectively. However, the \$3.42±\$0.33 (estimate of the difference ± standard error of the estimate) discount for hair lambs was not uniform across years, months, weight classes or lot sizes.

Figure 1 illustrates price differences between hair lambs and wool lambs by year using the least squares mean estimates of this price model. There was substantial price variation during this five year period. The strong market of 2011 was followed by two weak years, which were followed by another strong year (2014). The price of wool lambs was significantly higher than hair lambs in 2010 and 2011. Feeder lamb prices in this period were being pulled successively higher by carcass prices that were on their way to record highs in July 2011. Carcass prices collapsed in early 2012 (Anderson, 2013). As market signals were transmitted back through the market channels, the price of wool lambs was significantly lower than hair lambs in 2012 and 2013.

Hair lambs are typically not sent to feedlots because they reach preferred levels of fatness at an earlier age or lighter weight than most wool breeds commonly used in the United States (Shackelford et al., 2012). Therefore, when lamb feeding was projected to be more profitable, wool lambs commanded a premium over hair lambs. From January of 2011 to January of 2012, Texas breeding-ewe numbers decreased by 18 percent (NASS, 2012), primarily because of drought in 2011 over much of the sheep producing regions of Texas. The number of lambs sold through this auction in 2012 decreased accordingly. The number of hair lambs sold within the 40-pound to 100-pound weight range in 2012 decreased by 30 percent from 2011. The total number of lambs sold in the same weight range increased the following year such that the number

Table 6. Least Squares Means and standard errors for Model Effects on Lamb Price.

Effect	Estimate	Hair	Wool
Year		**\$/hundredweight**	
2010	136.88±2.81	134.75±2.82	139.01±2.82
2011	185.72±2.78	170.36±2.79	201.08±2.80
2012	143.96±2.82	148.77±2.83	139.16±2.84
2013	128.22±2.90	131.78±2.91	124.65±2.92
2014	186.42±2.87	187.00±2.87	185.84±2.89
Month			
January	170.00±4.47	172.29±4.48	167.71±4.50
February	176.76±4.73	179.44±4.75	174.09±4.76
March	168.65±4.14	168.32±4.14	168.98±4.16
April	157.31±4.23	154.86±4.24	159.76±4.26
May	144.44±4.13	139.89±4.14	148.99±4.15
June	132.16±4.23	126.37±4.24	137.96±4.24
July	136.01±4.57	133.79±4.58	138.24±4.59
August	139.40±4.13	133.84±4.15	144. 95±4.15
September	149.89±4.23	145.00±4.25	154.78±4.25
October	159.84±4.24	160.31±4.26	159.38±4.26
November	164.16±4.71	163.60±4.72	164.73±4.74
December	176.27±5.02	176.70±5.03	175.84±5.06
Weight Class, lbs			
40s	161.57±1.33	163.16±1.34	159.98±1.45
50s	164.64±1.30	164.65±1.31	164.62±1.36
60s	161.27±1.29	160.36±1.30	162.19±1.33
70s	156.46±1.29	153.88±1.31	159.04±1.32
80s	149.24±1.30	145.43±1.32	153.05±1.32
90s	144.26±1.31	139.72±1.37	148.81±1.34
Lot Size, Head			
1 - 2	146.78±1.39	145.80±1.44	147.77±1.55
3 - 5	152.69±1.32	152.80±1.34	152.57±1.39
6 - 12	157.28±1.29	156.58±1.30	157.97±1.33
13 - 34	160.83±1.28	158.15±1.29	163.51±1.30
35 +	163.63±1.28	159.34±1.30	167.93±1.30

Figure 1. San Angelo Lamb Prices by Type and Year; 2010-2014.

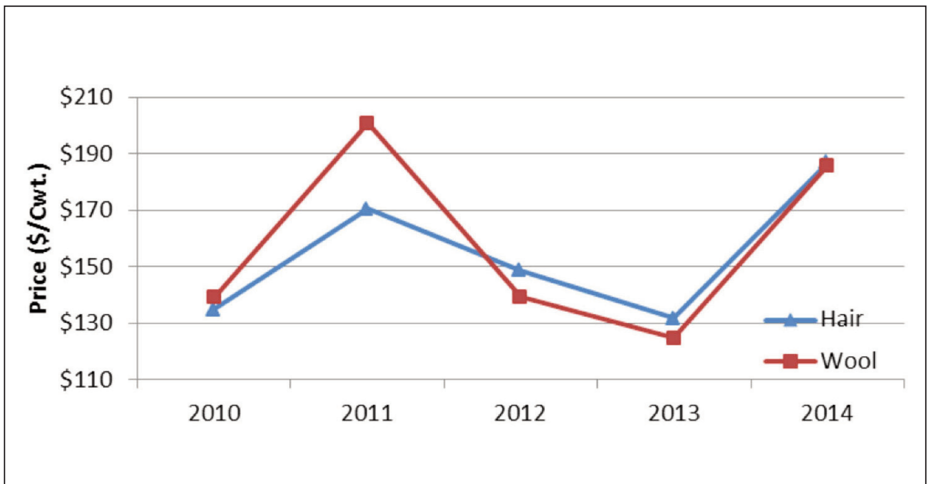


Figure 2. San Angelo Lamb Prices by Type and Month; 2010-2014.

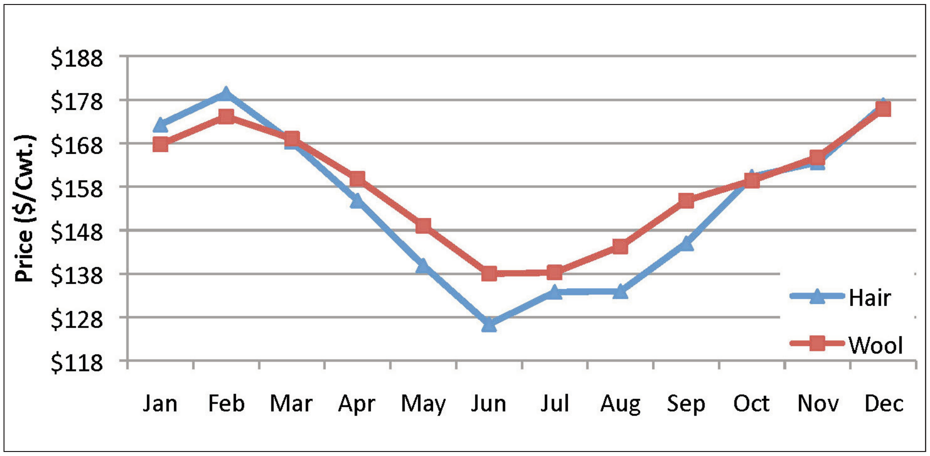


Figure 3. San Angelo Lamb Prices by Type and Weight Class; 2010-2014.

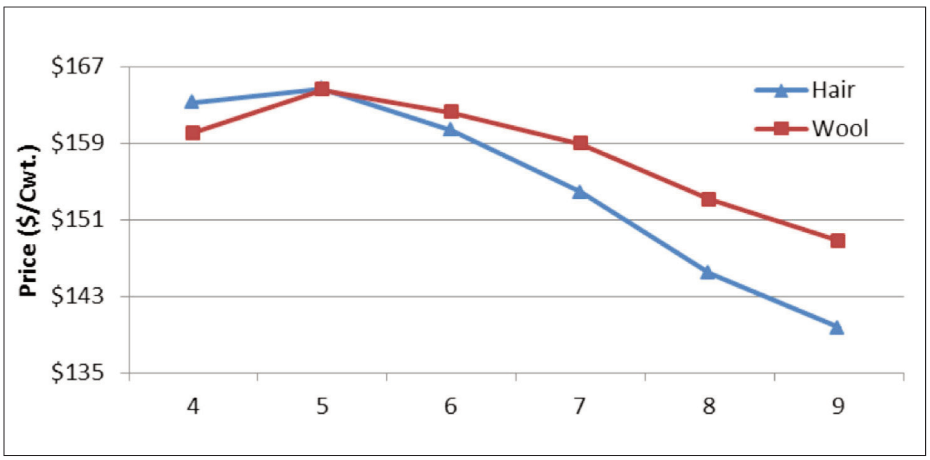
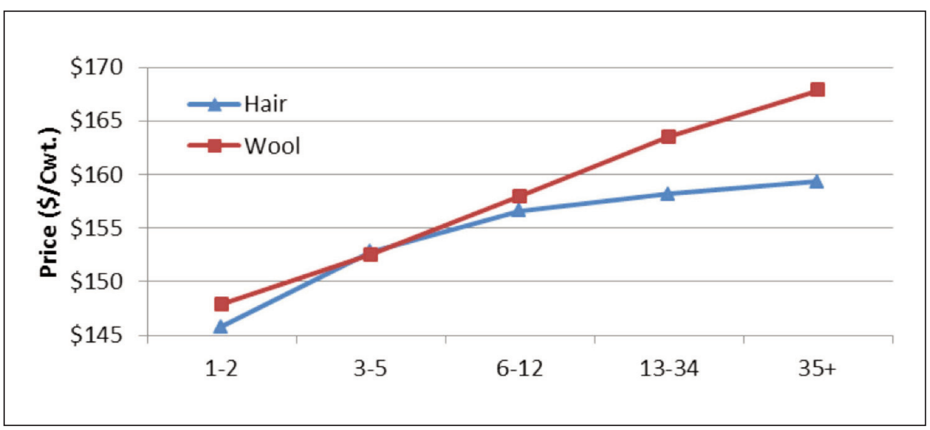


Figure 4. San Angelo Lambs Prices by Type and Lot Size; 2010-2014.



of lambs sold in 2013 was 5 percent below that of 2011. In 2014, the number of hair lambs sold increased and the number of wool lambs sold decreased. The increased proportion, and number, of hair lambs sold after 2012 suggest that as sheep producers, both commercial and small acreage, were restocking after the 2011 drought, they did so with hair sheep more than wool sheep. There was a significant premium paid for hair lambs in 2012 ($9.62 ± $0.61/cwt) and 2013($7.13 ± $0.53/cwt). From 2012 to 2014 there was an increasing proportion of hair lambs sold (Table 1). It is likely that producers were obtaining replacement-ewe lambs to be used as breeding stock through this auction market, which contributed to the premium paid for hair lambs. However, sex of lamb was not recorded at the auction, so this cannot be verified from the available data.

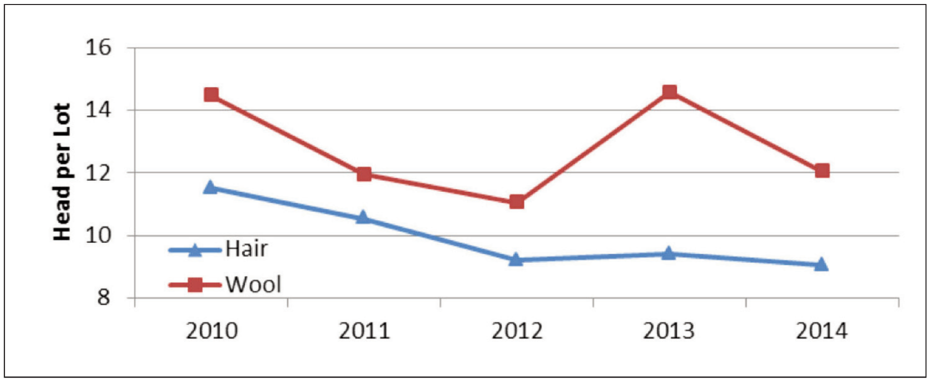
Both types of lambs displayed traditional seasonal price movement (Table 6 and Figure 2). This pattern results from the seasonal reproduction of sheep in Texas, with most producers lambing in late winter through early spring, producing an associated increase in sales volume in May and June (Table 4). The months with the greatest number of hair lambs were March, April, May, and June. The months with the greatest number of wool lambs were June, August, September, and October. The largest difference in price was observed in June where the price of hair lambs was $11.58 ± 0.64 per hundredweight less than that of wool lambs. In January and February the price of hair lambs was significantly greater than the price of wool lambs. In January the lambs coming to the auction are a mix of old-crop and new-crop lambs. Old-crop lambs were born in the late spring of the previous calendar year. New-crop lambs were born in the fall of the previous year. Because of the less seasonal reproduction of hair-sheep breeds, the hair lambs coming to market in January and February are more likely to be new-crop lambs and the wool lambs are more likely to be old-crop lambs. At similar weights, new-crop lambs sell for a higher price than old-crop lambs.

Prices per hundredweight generally decreased at successively higher weight classes. The highest prices were paid for lambs in the 50-pound to 60-pound weight class. Figure 3 presents the difference in lamb price by weight category. This figure can be interpreted as suggesting that at progressively heavier weights, hair sheep lambs receive an increasingly larger discount relative to wool lambs. Hair lambs sold for $3.18 ± $0.83 per hundredweight more than wool lambs in the 40-pound to 50-pound weight class. The price advantage shifted toward wool lambs as lamb weight increased. Hair lambs sold for $9.09 ± $0.68 per hundredweight less than wool lambs in the 90-pound to 100-pound weight class. This indicates 1) a market preference for lighter hair lambs, and 2) greater market competition for the heavier wool lambs. Wool lambs weighing from 70 pounds up to 100 pounds are likely being sought for targeted slaughter markets, as well as by feeders looking to place them into feedlots. Hair lambs in these weight ranges are typically being purchased for the slaughter market only. The price differentials at weights above 70 pounds, illustrated in Figure 3, may also be symptomatic of thinner hair-lamb markets at these weights. Again, the percentage of lambs in the weight classes greater than 70 pounds was greater for wool lambs.

Prices tended to increase as lot size increased (Table 6 and Figure 4). The positive relationship between lot size and price has been well documented for feeder cattle (Faminow and Gum, 1986; Schroeder et al, 1988). Menzie et al.'s (1972) explanation of minimizing transaction costs remains plausible. The percentage of hair lambs in the San Angelo auction market has increased from 41 percent in 2010 to 65 percent in 2014. This rapid expansion may have come at the expense of uniformity as producers adapted their production systems to accommodate hair sheep. As the uniformity of groups of animals brought to the auction market decreases, auction staff sort the animals into smaller more uniform groups, Figure 5. The reduction in lot size may also be attributable to increased production from small acreage producers, who will initially deliver smaller "trailer loads" to the auction facility and then have those groups sorted into even smaller, more uniform lots. Realized-auction prices tend to increase with lot size, but the increase is more pronounced for wool lambs (Figure 4). Hair lambs do not appear to receive as great a premium for increased lot size. This largely reflects the heterogeneous nature of the non-traditional lamb market. Buyers responsible for sourcing lambs for these non-traditional markets are required to buy a wide variety of lambs. This may require lambs at different ages or weights, specific gender (intact male, ewe lamb or wether) or other specific criteria and may discourage bidding on larger lots of lambs.

The random effect of sale day accounted for 12 percent of the variation after the model was fitted. The variance component estimate for sale week was 373 and the residual variance was 2816. Sale-week effects can be from differences in short-term supply or demand. Short-term supply changes can be due to weather events, such as rain in the days prior to the sale, which can result in fewer lambs brought to market. Short-term demand changes may be due to holidays, which are associated with lamb consumption. An analysis of the sale-week effects is needed, but is beyond the scope of this paper.

Figure 5. Lot Size of Lambs Sold at San Angelo; 2010-2014.



Conclusion

The analysis of lamb prices at the largest sheep auction in the United States was initiated to provide livestock producers more complete information on the differences between the recently introduced hair sheep breeds and the more traditional Rambouillet sheep. Hair lambs and wool lambs both exhibit seasonal price patterns that are driven by the seasonal reproduction of sheep.

The interaction of weight class by type of lamb suggests that at higher weight classes, hair lambs are subject to a greater price discount than wool lambs. This may be due to market preferences for lighter hair lambs or to wool lambs having two distinct market channels; slaughter markets or feeder markets. Hair sheep typically reach preferred levels of fatness at lower weights and are not as likely to enter the feedlot channel. Individual producers will need to incorporate a cost of production analysis to more closely identify optimal market weights.

Increased lot size generally translates to higher realized bid prices at auction for both types of lamb. Wool lambs benefit from a larger lot size premium than hair lambs. Additional market-channel research is necessary to identify the factors driving this response. Producer-management ability will be key to increasing overall flock quality (sire and dam selection and breeding management) to limit sorting at the auction market.

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Selective Deworming Effects on Performance and Parameters Associated with Gastrointestinal Parasite Management in Lambs and Meat-Goat Kids Finished on Pasture

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Summary

This study evaluated performance and health parameters associated with gastrointestinal parasite control when lambs and meat-goat kids were finished on a mixed sward of orchardgrass (*Dactylis glomerata* L.), red clover (*Trifolium pratense* L.), and white clover (*Trifolium repens* L.) with and without supplemental whole cottonseed (*Gossypium hirsutum*; WCS). Overall average daily gain (ADG) for this 90-d period was increased by supplementation with WCS in Suffolk lambs ($P < 0.003$), Katahdin lambs ($P < 0.17$) and goat kids ($P < 0.10$). Fecal egg count (FEC) was variable over the grazing season each year, but was not impacted by supplementation of WCS at 0.5 percent body weight (BW). Katahdin lambs had lower FEC than Suffolk lambs and typically goat kids. Goat kids and Suffolk lambs had lower ($P < 0.001$) blood albumin and higher ($P < 0.001$) globulin concentrations than Katahdin lambs. Supplementation with WCS did not improve FAMACHA© scores, but Katahdin lambs consistently had lower ($P < 0.001$) FAMACHA© scores than Suffolk lambs and goat kids. Goat kids had the highest FAMACHA© scores. Using FAMACHA© as a means to identify *Haemonchus contortus*-induced anemia resulted in a mean 56-percent reduction in doses of dewormer administered compared to a theoretical monthly dosing of each animal. After the initial administration of dewormer, days to next dosing of dewormer were fewest for goat kids (33 d), followed by Suffolk lambs (67 d), and greatest for Katahdin lambs (77 d). By considering the use of breed groups resistant to or having high resilience to internal parasites and coupling with the use of the FAMACHA© system to determine the need to deworm individual animals, producers can improve livestock performance and reduce overall cost of production.

Key words: Lambs, Goat Kids, Breed, Supplementation, Dewormer Doses

Introduction

Finishing lambs (*Ovis aries*), and meat-goat kids (*Capra hircus*) on improved pastures is a viable production system option for many producers in the United States. However, gastrointestinal nematode (GIN) control, especially related to trichostrongylids, is a significant socio-economic and management challenge for producers wherever livestock are produced (Waller, 1997). Costs associated with treatments to control GIN may reach billions of dollars worldwide, exclusive of production losses (Roeber et al., 2013), with parasite-related veterinary care for small ruminants, adding to overall costs associated with this malady (Mortensen et al., 2003). Oral drug treatments with anthelmintics (dewormers) help control GIN. In recent years, GIN (especially *Haemonchus contortus*) have developed resistance to many of the anthelmintics (Terrill et al., 2001), and incidence of multiple anthelmintic drug resistance in GIN has increased (Howell et al, 2008).

During the grazing season, the FAMACHA© eyelid score (Kaplan et al., 2004) can be used to subjectively determine anemia caused by *H. contortus* infection, and when coupled with selective deworming of individual animals (rather than all animals on a set schedule) can help slow the rate of development of drug-resistant *H. contortus* populations. In addition, monitoring fecal egg count (FEC) allows producers to estimate GIN populations in animals, and the extent to which a pasture is potentially contaminated with GIN.

Genetic evaluation of sheep and goats is also underway in the United States to identify breeds and individual animals with resistance and resilience to GIN. Resistance to GIN is the ability to restrict establishment, rate of growth, egg shed, or persistence of a parasitic population (Coop and Kyriazakis, 1999). Katahdin sheep (a hair-sheep breed composite developed in the northeastern United States) tend to be resistant to GIN (Wildeus, 1997; Zajac et al., 1990) compared to some traditional sheep breeds (e.g. Suffolk). Improved meat-goat breeds were introduced into the United States in the 1990s to enhance meat production from already present dairy- and Spanish-type goats. The Boer meat-goat breed was introduced in to the United States from South Africa (Casey and Van Niekerk, 1988), while the Kiko meat-goat breed originated in New Zealand (Batten, 1987). Kiko goats appear to have better tolerance (possibly resistance) to GIN compared to Boer goats (Browning et al., 2011).

When finishing animals on pasture, resilience can be defined as the ability to remain productive (i.e. gain weight) yet tolerate GIN burdens (Albers et al., 1987). Increasing dietary protein levels in ruminant diets has been reported to improve sheep and goat resilience to GIN infection (Coop and Holmes, 1996; Coop and Kyriazakis, 1999). Actual mechanisms of resistance to GIN in livestock remain to be elucidated.

The effect of protein on growth in livestock is well-documented, but protein supplementation influences on GIN infection has produced mixed results (Burnett et al., 2010; Felix et al., 2012). Protein supplementation to livestock diets helps boost immunity (Coop and Holmes, 1996), and benefits young animals post-weaning (Knox et al., 2006). Increasing protein levels in the diet of grazing livestock can be accomplished with protein supplementation, especially using supplements with a significant ruminally undegradable protein (RUP) component. Supplemental feeding of high protein feedstuffs and by-product feeds include whole cottonseed (*Gossypium hirsutum* L.). Generally, low levels of supplementation (< 0.5 percent body weight [BW]) do not reduce intake of forage (Van Soest, 1994). Bowdridge et al. (2016) reported that weaned, parasitized lambs not treated with anthelmintic on pasture and supplemented at 2-percent BW with 19 percent crude protein (CP; as fed) had lower FEC and higher average daily gain (ADG) compared to lambs supplemented at 1-percent BW.

Grazing management using rotational stocking of cool-season grass pastures is an important tool to help maintain forages with high-nutritive value [including high crude protein (CP) and total digestible nutrients (TDN)] throughout the grazing season (Turner et al., 2012). Grazing high-protein forage legumes can also help improve protein levels for small ruminants. Forage legumes such as red (*Trifolium pratense* L.) and white (*Trifolium repens* L.) clovers (Pederson, 1995) can be established into cool-season grass swards such as orchardgrass (*Dactylis glomerata* L.) in the eastern United States (Rayburn et al., 2006).

Our objective was to determine if providing whole cottonseed as a supplement would help reduce the need for chemotherapeutic anthelmintic dosings in growing lambs and meat-goat kids finished on pasture. We evaluated performance, FEC, FAMACHA© scores, simple blood parameters and quantified anthelmintic doses given to individual animals during a 90-d grazing period in the summer to early fall in each of three years.

Materials and Methods

Details of pasture establishment, forage management, and animal management were reported by Turner et al. (2015). In summary, the three-year (2006 through 2008) experiment was conducted during the grazing season each year using a mixed sward of orchardgrass, red clover, and white clover pastures established on a Gilpin silt loam (fine-loamy, mixed, mesic Typic Hapludults) in Raleigh County, W.Va. (37°45' N, 80°58' W, 875 m elevation), United States. All experimental procedures using animals were previously approved by the Institutional Animal Care and Use Committee, Appalachian Farming Systems Research Center, Beaver, W.Va., United States. Wether Suffolk (with Hampshire influence) lambs (n = 36), wether Katahdin lambs (n = 36), and wether Boer (with Kiko influence) crossbred meat-goat kids (n = 36) were used in 2006 and 2007 while Boer x Kiko (F_1) meat-goat kids were used in 2008. In 2006, the lambs and kids were born March 15 through March 31, while in 2007 and 2008, all lambs and kids were born March 1 through March 15; in all years animals were procured from the same three flock vendors, and all animals were weaned June 28 (Turner et al., 2015). Mean body weights (kg ± SEM) at the start of the grazing study in 2006, 2007, and 2008 for Suffolk lambs were 25 ± 0.6, 26 ± 0.5, and 31 ± 0.6; for Katahdin lambs were 18 ± 0.6, 25 ± 0.7, and 26 ± 0.6; and for meat-goat kids were 14 ± 0.4, 15 ± 0.5, and 19 ± 0.8, respectively (Turner et al., 2015). Each year, the six grazing groups contained 18 animals each (lambs and kids) — 6 Suffolk, 6 Katahdin, and 6 goat wethers and grazed a pasture together. Three groups of animals were not supplemented, while the other three groups received whole cottonseed (WCS) at 0.5 percent BW. Every 14 d, animals were weighed and supplement amount adjusted. Animals had access to water and minerals containing salt at all times.

Grazing began in late June/early July each year. Each of the six pastures was 0.61 ha in size (29.5 animals ha^{-1}) and was subdivided into three 0.2-ha paddocks for rotational-stocking management (instantaneous stocking density of 90 animals ha^{-1}) based on a targeted 21-d occupation period. Paddocks were clipped immediately after animals were moved to the next paddocks to maintain forages with high-nutritive value.

FAMACHA© and Anthelmintic Dosing

Each year, all animals were dewormed prior to the start of the grazing study with a combination of anthelmintics: benzimidazole (albendazole [Valbazen®] 15 mg/kg BW^{-1}); imidazothiazole (levamisole [Prohibit®], 8 mg/kg BW^{-1}); and macrocyclic lactone (ivermectin [Ivomec®], 400 µg/kg BW^{-1}), administered orally. After the initial deworming, only individual animals were administered the combination of the three anthelmintics when the FAMACHA© score was 3 or greater. The FAMACHA© scores (1= no anemia and 5=severe anemia) were recorded every 14 days to estimate anemia status (Kaplan et al., 2004). During the grazing season in our temperate environment of this study, virtually all anemia is caused by *H. contortus*.

FAMACHA© and Fecal Egg Count (FEC)

After the initial deworming, FAMACHA© score from individual animals was determined and recorded every 14 days. In addition, feces were collected every 14 days from the rectum of individual animals. Plastic bags with feces were placed into chilled, insulated boxes, and transported to the lab, and refrigerated at 1° C until FEC was determined using a modified McMaster technique [Ministry of Agriculture Fisheries and Food (MAFF), 1977]; one egg represented 50 eggs per g fresh feces. Additionally and periodically, a composite sample of feces was created from each pasture group and 3rd-stage strongylid larvae (L_3) were cultured (Zajac and Conboy, 2006) for identification and determination of the percentage of *H. contortus*.

FAMACHA© and Blood Chemistry

Every 28 days (each month) and following evaluation of FAMACHA© scores, blood samples were collected via jugular venipuncture. Blood samples were collected into 10-ml tubes with and without heparin, processed, and stored (Turner et al., 2015). The packed cell volume (PCV) was determined immediately from tubes containing heparin. Tubes without heparin were centrifuged to obtain serum, and then stored (Turner et al., 2015). Total protein and albumin in serum were determined using automated, blood-chemistry procedures as described by Turner et al. (2015). Serum globulin was determined by difference (serum total protein minus serum albumin) to assess activity of the immune system (Houdijk et al., 2000).

Statistical analyses

Since the ending date of each year's grazing season duration was unequal, a data set was used from approximately July 1 to September 30 each year and included an equal number of dosing periods (based on FEC and FAMACHA© scores determined every 14-days; two-times per month). The BW and overall-ADG data presented here are for this approximate 90-d period.

The FEC data were transformed via natural log process to accommodate data of zero. Transformed FEC data statistics were used for statistical analyses and inferences while untransformed means are presented.

The BW data were analyzed using mixed-model, least-squares procedures (SAS, Cary, N.C.). The experimental design was a split, split-plot design repeated measures. The initial linear model included effects of replicate (random), pasture treatment (fixed), replicate x treatment (random), breed/species (fixed), treatment x breed (fixed), replicate x treatment x breed (pooled replicate x breed, replicate x treatment x breed; random), year (fixed), treatment x year (fixed), breed x year (fixed), breed x treatment x year (fixed), replicate x treatment x breed x year (pooled rep x year, rep x treatment x year, rep x breed x year, rep x treatment x breed x year; random), day (fixed repeated), day x treatment (fixed), day x breed (fixed), day x treatment x breed (fixed), day x year (fixed), day x treatment x year (fixed), day x breed x year (fixed), day x treatment x breed x year (fixed), and a random residual. Overall ADG was analyzed similarly, but without the repeated measures effects. Designations are as follows: **tmt** is the supplementation treatment; **breed** is the species or breed group (Suffolk, Katahdin, goat); **year** is the year of study; and **day** is the day that BW was recorded for an individual animal. Fixed interactions were omitted from subsequent analyses if the observed significance level was $P > 0.25$ using standard procedures for model reduction. Mean comparisons were done using t statistics at $P < 0.05$; $P \leq 0.10$ was considered a trend.

Bi-weekly FAMACHA© score and FEC data were analyzed using day as a repeated measure with the following linear model: rep (random) tmt (fixed) rep x tmt (random) breed (fixed) tmt x breed (fixed) rep x tmt x breed (random, pooled rep x breed, rep x tmt x breed) year (fixed) year x tmt (fixed) year x breed (fixed) year x tmt x breed (fixed) rep x year x tmt x breed (random, pooled rep x year, rep x year x tmt, rep x year x breed, rep x year x tmt x breed) day (fixed), day x tmt (fixed), day x breed (fixed), day x tmt x breed (fixed), day x year (fixed), day x year x tmt (fixed), day x year x breed (fixed), day x year x tmt x breed (fixed), residual (random). Designations are as follows: **tmt** is the supplementation treatment; **breed** is the species or breed group (Suffolk, Katahdin, goat); **year** is the year of study; and **day** is the day FAMACHA© and FEC were determined for an individual animal. Mean separations were done using t-statistics at $P < 0.05$, with $P \leq 0.10$ considered a trend.

Monthly blood data and FAMACHA© scores associated with this monthly blood collection date were analyzed as a multi-year, Randomized Complete Block Design based on the field layout of pastures (pastures were not re-randomized each year) using

PROC MIXED in SAS (SAS Institute, 2001; Cary, N.C.). Year and tmt were designated as fixed effects, while replication was random. Measurement periods within year were analyzed as a repeated measure. All differences were significant at $P < 0.05$, unless otherwise indicated, and separated using PDIFF in SAS.

Actual number of deworming events was calculated from bi-weekly FAMACHA© data for this 90-d period. Deworming events were used to determine number of doses given per pasture treatment (not supplemented and supplemented) and per breed group (Suffolk lamb, Katahdin lamb, and goat kid). This information was subsequently compared to a theoretical deworming schedule of administering a dose of dewormer once every month (~ 28 d) for the 108 animals using the same 90-d grazing period each year (COUNTQ). Within treatment and breed group, percent dosing time (COUNTQ) was also calculated for the lambs and meat-goat kids. Since all animals were dewormed prior to July 1 each year (the start of each grazing season), FAMACHA data was also used to determine the days to first re-dosing for each breed group in order to compare Suffolk lambs, Katahdin lambs, and meat-goat kids.

Deworming-dose data were analyzed using a mixed-model, least-squares procedures (SAS®, Cary, N.C.) as a split, split-plot with the main unit designed as a randomized-complete block with the following linear model: rep (random) tmt (fixed) rep x tmt (random) breed (fixed) tmt x breed (fixed) rep x tmt x breed (random, pooled rep x breed, rep x tmt x breed) year (fixed) year x tmt (fixed) year x breed (fixed) year x tmt x breed (fixed) residual (random). The COUNTQ variable was transformed by natural-log conversion prior to analyses. All differences were significant at $P < 0.05$, unless otherwise indicated with $P \leq 0.10$ considered a trend, and separated using PDIFF in SAS.

Results

BW and ADG

The BW for all groups increased during the grazing period evaluated each year (Table 1). The BW for the entire periods followed a trend ($P < 0.001$): Suffolk lambs > Katahdin lambs > goat kids. There was a weak trend for a Treatment x Breed interaction ($P = 0.13$) in overall difference in ADG between supplemented and unsupplemented being higher in Suffolks (32.3 g/d; $P < 0.003$), goats (13.6 g/d; $P < 0.10$), and Katahdins (11.2 g/d; $P < 0.17$) (Table 1).

FEC

Egg counts (epg) of *Trichuris* sp. and *Monezia* sp. were unremarkable and are not reported. *Strongyloides* sp. egg counts followed a trend of Suffolk lambs > Katahdin lambs > goat kids, but was influenced by interactions with time of sampling ($P < 0.001$).

Strongylid and *Nematodirus* sp. counts were summed to determine an overall strongylid FEC. Overall, FEC was lower ($P < 0.05$) during earlier sampling dates (i.e. 1, 2, 3, and 4) compared to later sampling dates (i.e. 5, 6, 7, and 8) (data not shown). Fourteen days after the initial deworming and prior to the start of grazing, FEC averaged 1418, 199, and 713 egg per gram (epg) in 2006, 2007, and 2008, respectively (Fig. 1). Overall, Suffolk lambs (1286 epg ± 102 epg) had greater ($P < 0.05$) FEC compared to Katahdin lambs (867 epg ± 101 epg) and goat kids (590 epg ± 102 epg); the FEC of Katahdin lambs and goat kids were similar, but the trend varied with sampling date within each year ($P < 0.001$). The different breed groups also exhibited different FEC patterns as a function of sampling date ($P < 0.001$) (Fig. 1). Supplementation did not influence FEC ($P > 0.10$); however, on the first sampling date in September, supplemented animals tended to have a higher ($P < 0.10$) FEC than those animals not supplemented (data not shown).

Blood Parameters

All blood-serum parameters were expressed as mg dL^{-1}, unless specified otherwise. Blood parameters differed among years ($P < 0.001$). Whole-cottonseed supplementation did not affect blood parameters ($P > 0.10$).

Total Protein. Total protein differed ($P < 0.001$) among breed groups and did so with different seasonal patterns (Fig. 2). Overall, serum total protein concentration was higher in July (6.6 ± 0.4) compared to June (6.3 ± 0.4), August (3.7 ± 0.4), and September (6.3 ± 0.4); June and September were similar.

Table 1. Beginning and ending body weight (BW) and overall ADG for 90-d periods in 2006-2008 when Suffolk lambs, Katahdin lambs, and meat-goat kids were finished on orchardgrass-legumes pasture without or with supplemental whole cottonseed supplement. Data are lsmeans ± standard error of the mean.

	No Supplement			Supplement					
Item	Suffolk	Katahdin	Goat	Suffolk	Katahdin	Goat	P level* Tmt Breed	P level†	P level Tmt x Breed
Begin BW, kg	31 ± 0.5	25 ± 0.5	15.9 ± 0.5	31 ± 0.5	25.1 ± 0.5	16.3 ± 0.5	NS	< 0.001	NS
End BW, kg	40.1 ± 0.5	32.7 ± 0.5	19.1 ± 0.5	42.8 ± 0.5	33.3 ± 0.5	20.1 ± 0.5	NS	< 0.001	= 0.15
Overall ADG, g/d	151.4 ± 5.1[b]	117 ± 5.1[f]	38.5 ± 5.1[d]	183.7 ± 5.1[a]	128.1 ± 5.1[e]	52.1 ± 5.1[c]	< 0.05	< 0.001	= 0.13

* Tmt = Supplement Treatment; NS = Not Significant ($P > 0.10$).
† Breed Group, Breed.
[a,b] Means with unlike letters differ ($P < 0.003$).
[c,d] Means with unlike letters differ ($P < 0.10$).
[e,f] Means with unlike letters differ ($P < 0.17$).

Figure 1. Fecal egg count (FEC) on different dates in 2006-2008 when Suffolk lambs, Katahdin lambs and meat-goat kids were finished on orchardgrass-clover pastures. Vertical bars indicate SEM. First date each year is 14 d following initial administration of the three dewormers to all animals.

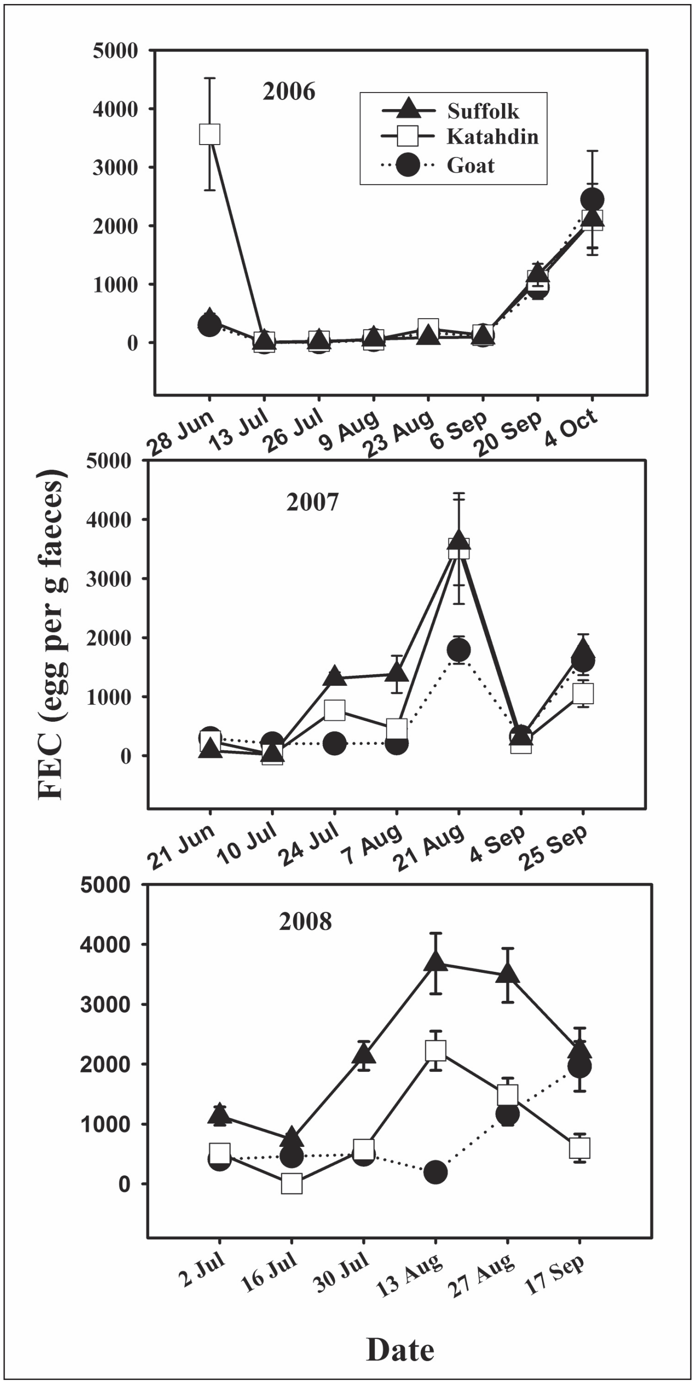
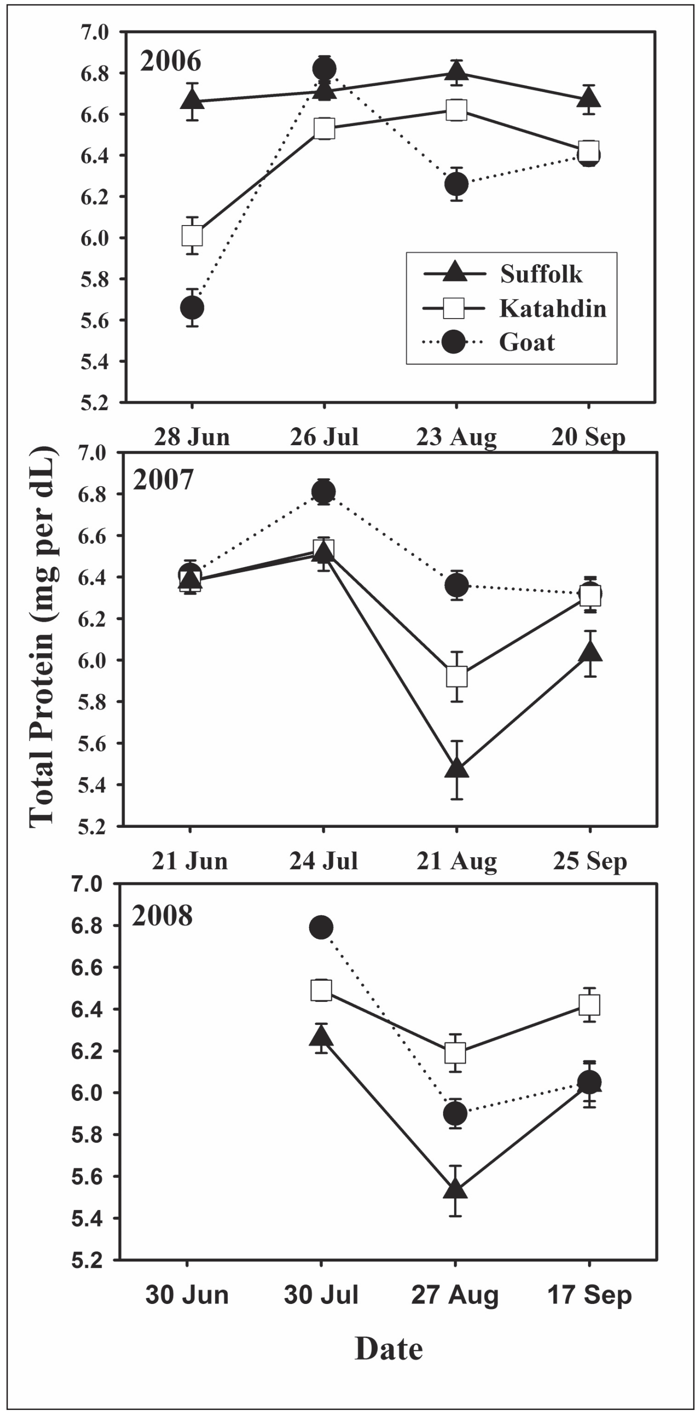


Figure 2. Serum total protein concentrations on different dates in 2006-2008 when Suffolk lambs, Katahdin lambs and meat-goat kids were finished on orchardgrass-clover pastures. Vertical bars indicate SEM.



Albumin. Blood albumin concentrations (Fig. 3) each month did not trend the same among the three breed groups (Month × Breed group interaction, $P < 0.001$). Serum albumin concentrations in June, July, and September were similar and were greater ($P < 0.001$) than those obtained in August samplings. Blood-albumin concentrations were similar for Suffolk lambs and goat kids (mean 3.7 ± 0.04); concentrations were less ($P < 0.01$) than those of Katahdin lambs (3.9 ± 0.04).

Globulin. Blood-globulin concentrations each month (Fig. 4) did not trend the same among the breed groups ($P < 0.001$). Overall, concentrations were higher in July (2.8 ± 0.03) compared to the other months, while concentrations in June (2.8 ± 0.03) were higher than August (2.4 ± 0.03) with September (2.5 ± 0.03) being intermediate. Blood-globulin concentrations in goat kids and Suffolk lambs were similar

Figure 3. Serum albumin concentrations on different dates in 2006-2008 when Suffolk lambs, Katahdin lambs and meat-goat kids were finished on orchardgrass-clover pastures. Vertical bars indicate SEM.

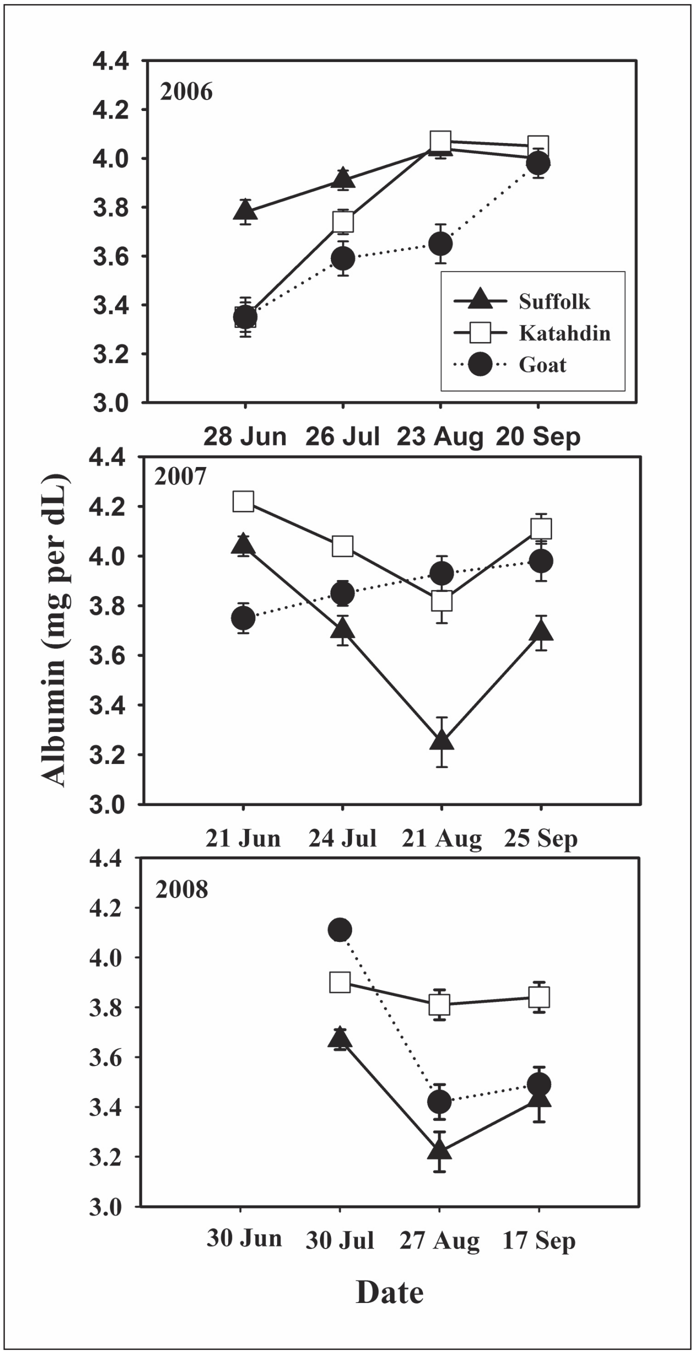
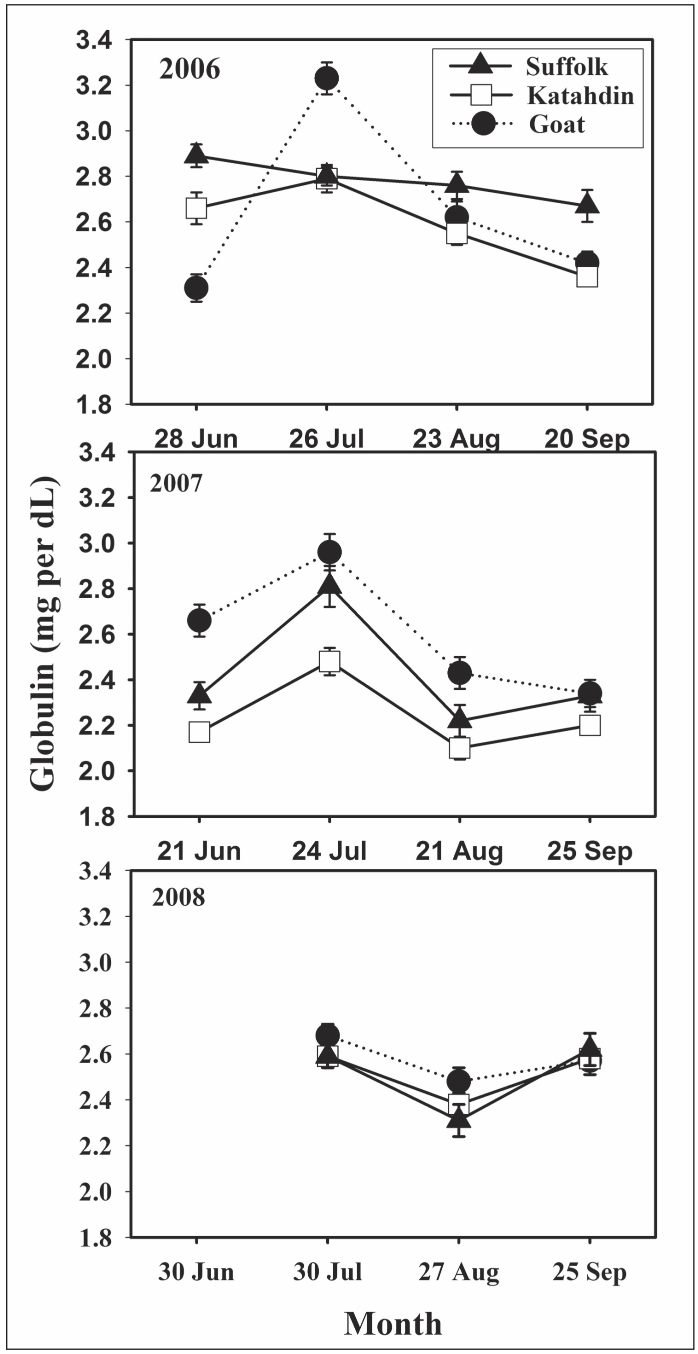


Figure 4. Serum globulin concentrations on different dates in 2006-2008 when Suffolk lambs, Katahdin lambs and meat-goat kids were finished on orchardgrass-clover pastures. Vertical bars indicate SEM.



(mean 2.6 ± 0.03); both were greater than Katahdin lambs (2.5 ± 0.03).

Packed cell volume (PCV, percent). Overall, blood PCV differed ($P < 0.001$) among the breed groups: Katahdin lambs (32.6 ± 0.6) > Suffolk lambs (31.3 ± 0.6) > goat kids (29.5 ± 0.6). The pattern of PCV differed among breed groups and did so differently during the grazing season ($P < 0.001$) (Table 2). Blood PCV in June and July were similar among breed groups (mean 33.5 ± 0.5) and were greater ($P < 0.05$) than PCV obtained later in the grazing season during August (28.7 ± 0.5) and September (28.9 ± 0.5).

Monthly FAMACHA© Scores Associated with Blood Parameters

Trends in monthly FAMACHA© scores for the breed groups were similar, but the goat kids had higher ($P < 0.01$) monthly FAMACHA© scores compared to Suffolk and Katahdin lambs (Table 2). Overall, monthly FAMACHA© scores were higher ($P < 0.001$) in August compared to the other months, while scores in July and September were similar but greater ($P < 0.05$) than scores in June. The trend ($P < 0.001$) for monthly

Table 2. Monthly blood packed cell volume (PCV) and FAMACHA© scores when Suffolk lambs, Katahdin lamb, and goat kids were finished on orchardgrass-legume pastures 2006-2008. Data are lsmean ± standard error of the mean.

Item	Month	Suffolk (n = 36)	Katahdin (n = 36)	Goat (n = 36)	*P* level Month	*P* level Breed*	*P* level Month × Breed
PCV, %					< 0.001	< 0.001	< 0.001
	Jun	36.6 ± 0.7^{a,A}	33.1 ± 0.7^{b,B}	31.5 ± 0.7^{c,A}			
	Jul	34.0 ± 0.6^{a,B}	34.9 ± 0.6^{a,A}	31.0 ± 0.6^{b,A}			
	Aug	27.0 ± 0.6^{c,C}	30.5 ± 0.6^{a,D}	28.5 ± 0.6^{b,B}			
	Sep	27.8 ± 0.6^{b,C}	31.7 ± 0.6^{a,C}	27.1 ± 0.6^{b,C}			
FAMACHA© score					< 0.001	< 0.001	< 0.01
	Jun	0.8 ± 0.1^{b,C}	0.8 ± 0.1^{b,C}	1.6 ± 0.1^{a,C}			
	Jul	1.8 ± 0.1^{b,B}	1.6 ± 0.1^{c,B}	2.3 ± 0.1^{a,B}			
	Aug	2.6 ± 0.1^{b,A}	2.2 ± 0.1^{c,A}	2.9 ± 0.1^{a,A}			
	Sep	1.7 ± 0.1^{b,B}	1.4 ± 0.1^{c,B}	2.3 ± 0.1^{a,B}			

* Breed = Breed group.
[a,b,c] Breed means within row and month with unlike lowercase letters differ ($P < 0.05$).
[A,B,C] Month means within a column and item with unlike uppercase letters differ ($P < 0.05$).

Table 3. Average deworming events when Suffolk lambs, Katahdin lambs, and goat kids were finished on orchardgrass-legumes pastures 2006-2008. Data are lsmeans ± standard error of the mean.

Item	Year	Suffolk	Katahdin	Goat	*P* level Year	*P* level Breed*	*P* level Year × Breed
Dewormer Doses					< 0.001	< 0.001	< 0.001
	2006	0.08 ± 0.2^{b,B}	0.03 ± 0.2^{b,B}	2.1 ± 0.2^{a,B}			
	2007	1.4 ± 0.2^{b,A}	0.9 ± 0.2^{c,A}	3.2 ± 0.2^{a,A}			
	2008	1.5 ± 0.2^{b,A}	0.8 ± 0.2^{c,A}	1.9 ± 0.2^{a,B}			

* Breed = Breed group.
[a,b,c] Breed means within a row and year with unlike lowercase letters differ ($P < 0.05$).
[A,B,C] Year means within a column and breed group with unlike uppercase letters differ ($P < 0.05$).

FAMACHA© scores was: goat kids > Suffolk lambs > Katahdin lambs. The FAMACHA© scores associated with these monthly blood parameters were not different ($P > 0.10$) between unsupplemented (1.9 ± 0.05) and supplemented (mean 1.8 ± 0.05) groups.

Bi-weekly FAMACHA© Scores and Doses of Dewormer

The FAMACHA© scores determined every 14 d followed a trend similar to monthly FAMACHA© scores associated with the blood parameters. Over all years, goat kids always had the highest ($P < 0.05$) FAMACHA© score (2.4 ± 0.1) compared to Katahdin lambs (0.6 ± 0.1); Suffolk lambs (1.0 ± 0.1) were either intermediate or similar to Katahdin lambs with differences among the breed groups differing ($P < 0.001$) with sampling date (Fig. 5). Over all the years, the bi-weekly FAMACHA© scores were not different ($P > 0.10$) between unsupplemented and supplemented groups (mean 1.8 ± 0.04).

Bi-weekly FAMACHA© scores were subsequently used to calculate the mean number of doses of anthelmintic given to the lambs and kids. Supplementation did not influence the number of doses of anthelmintic, but breed groups did differ ($P < 0.001$) from year to year in terms of the number of anthelmintic doses (Table 3). In 2006, the number of deworming events for Katahdin lambs and Suffolk lambs were similar and less compared to 2007 and 2008 (Table 3). Total dosing events administered to goat kids was similar in 2006 and 2008 and less compared to 2007 (Table 3). Overall, the number of anthelmintic doses administered varied among years ($P < 0.001$) with 2006 < 2008 < 2007 (data not shown).

The mean number of deworming doses for supplemented (1.4 ± 0.1) and unsupplemented (1.2 ± 0.1) groups was not different ($P > 0.10$). However, there was a Treatment × Breed group effect ($P < 0.001$) in that WCS supplementation of goat kids (2.2 ± 0.02) tended to reduce ($P < 0.10$) the number of deworming events compared to the unsupplemented goat kids (2.7 ± 0.02); the average deworming events for supplemented and unsupplemented Suffolk

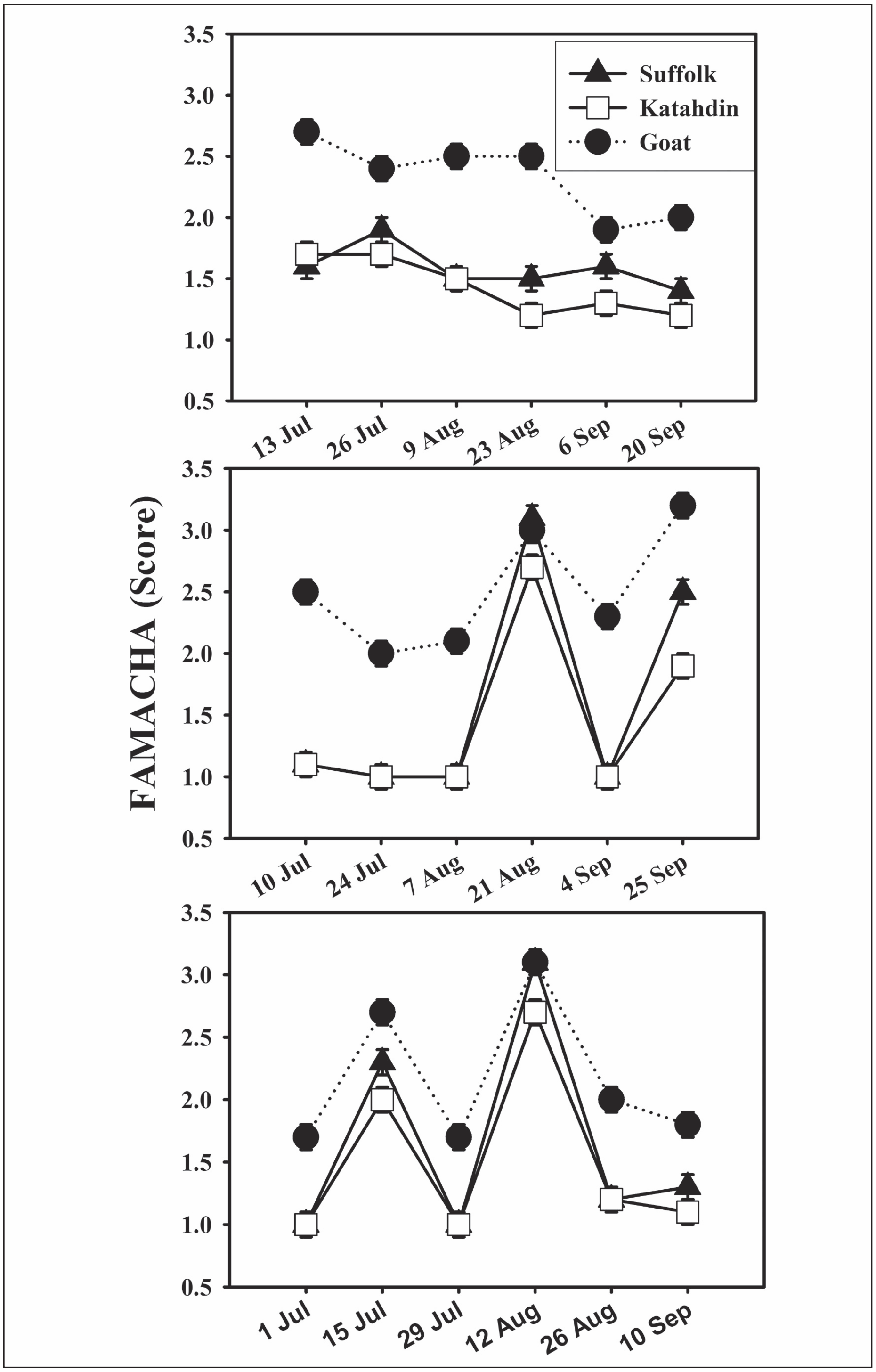


Figure 5. Biweekly FAMACHA© scores on different dates in 2006-2008 when Suffolk lambs, Katahdin lambs and meat-goat kids were finished on orchardgrass-clover pastures. Vertical bars indicate SEM.

lambs (1.0 ± 0.1 and 1.0 ± .01, respectively) and Katahdin lambs (0.5 ± 0.1 and 0.6 ± 0.1, respectively) were not different (*P* > 0.10).

After all animals were initially dewormed and in the subsequent 90 d each year (July 1 through September 30), Katahdin lambs had the longest (*P* < 0.001) number of days (76.9 ± 2.6) before the need to administer additional anthelmintic, while Suffolk lambs (66.6 ± 2.6 days) and goat kids (33.1 ± 2.6 days) required more frequent dosing. Supplementation of animals (60.0 ± 2.4 days) with WCS did not impact (*P* > 0.10) the days to first additional dosing compared to unsupplemented animals (58.0 ± 2.4 days).

Compared to a theoretical monthly (~ 28 d) deworming of each animal, use of FAMACHA© to help reduce the number of dewormer doses depended upon breed group (*P* < 0.001). The reduction in the dewormer dosed trend (*P* < 0.05) for animals used in this 3-yr study was: goat kids (19.1 percent) < Suffolk (66.7 percent) < Katahdin lambs (81.5 percent).

Discussion

BW and ADG

The present study used a cool-season grass pasture interseeded with red and white clover. Weather conditions, especially rainfall patterns each grazing season each year (Turner et al., 2015) had the greatest influence on the fluctuations in herbage mass and plant nutritive value; both of these parameters ultimately impact weighted gains by grazing lambs and goats. In addition, we compared supplemental WCS and no supplement. Suffolk lambs in both instances achieved the greater gains when compared to Katahdin lambs; lambs of both breed groups had greater gains than goat kids. Hair-sheep breeds typically exhibit less weight gain when compared to traditional sheep breeds (Wildeus, 1997). When grazing a mixed warm-season grass pasture, the ADG exhibited by lambs was double that exhibited by crossbred Boar goat kids (Animut et al., 2005). These authors also speculated that differences between lamb and goat performance on pasture was probably influenced by a stronger genetic potential for gain and greater compensatory growth exhibited by lambs compared to goats, most probably a factor in our study when grazing a mixed sward of cool-season grass and legumes.

FEC

Different groups of sheep and goats were used each year, yet these animals were from the same producer sources each year. The GIN levels on pasture herbage each year were probably influenced more by weather, forage growth patterns, and proportion of grass/legumes than by animal source.

Variation in FEC during the grazing season is, in part, related to the administration of dewormer to individual animals based on subjective anemia scores using the FAMACHA© scoring system. In the present study, Katahdin lambs received the fewest number of anthelmintic treatments and typically had higher FEC than goat kids that received a higher number of anthelmintic doses while Suffolk lambs were intermediate. Thus, deworming individual animals reduced and confounded FEC trends throughout the grazing season. Burke et al. (2009) suggested that interpretation of FEC data is difficult in studies where individual animals are treated based on FAMACHA© scoring and that data are related to the number of animals dewormed. Although there was a trend in the present study for higher FEC later in the grazing season compared to earlier sampling times, this was most likely a result of more goat kids being treated (based on FAMACHA© scores) at the beginning of the grazing season compared to Suffolk and Katahdin lambs, with relatively few Katahdin lambs requiring anthelmintic at the end of the grazing season.

Seasonal trends in GIN in pastures have been reported (González-Garduño, 2013; Wildeus and Zajac, 2005). Rinaldi et al. (2009) noted that FEC in dairy goats was greatest from April through June compared to later in the year with no effect associated with the time-of-day collection of the samples. There was also a positive relationship between FEC and *H. contortus* worm burden in their study. In our study, worm burdens were not determined, but *H. contortus* was the dominant L_3 (57 prcent to 72 percent of L_3) recovered from composite larval cultures determined periodically throughout the grazing season each year.

Susceptibility to GIN infection differs with breed for both sheep and goats (Wildeus and Zajac, 2005), which in part is related to body size and ability to tolerate higher loads of parasites and a genetic predisposition to resist parasite infection (mainly suppressing establishment in the GI tract). In pasture systems, which use grazing management based on rotational stocking of livestock, the forage nutritive value is typically high, but the canopy is shorter, possibly exposing animals to more larvae (Burke et al., 2009). Burke et al. (2009) further suggested that overall re-entry time to a previously grazed paddock can be a factor affecting FEC. In our study, re-entry time was about 42 d and possibly could have influenced FEC trends. In addition, mixed grazing (Turner and Belesky, 2010) of sheep and goats together may have resulted in goats ingesting more parasitic larvae than sheep, which can be attributed to goats grazing around their feces; sheep typically do not (Jallow et al., 1994). However, grazing a parasite-resistant breed (such as Katahdin lambs) could result in Katahdin lambs consuming larval parasites, thus reducing overall pasture GIN levels and reducing FEC in goats, whereas goats grazing alone in pastures would tend to have more internal parasites.

A low FEC has been used as an indicator of overall resistance by sheep to GIN. Low FEC typically can indicate low adult populations of GIN in sheep, but is not always correlated with adult parasite loads (Stear and Murray, 1994), especially during non-grazing season (dormant herbage) times of the year. Shaw et al. (1995) reported that lambs grazing canary grass (*Phalaris arundinacea* L.)-perennial ryegrass (*Lolium perenne* L.)-white clover pasture and supplemented with protein-rich, cottonseed-meal pellets had lower FEC compared to grazing lambs not supplemented. In our study, lambs and kids were supplemented as a group in the pastures, so a targeted amount of supplement based on BW may not have been consumed by each breed group (Turner et al., 2015). In addition, administering anthelmintics to individual animals based on FAMACHA© scores would also confound results. Typically during the first two weeks of September, supplemented animals had higher FEC than animals not supplemented even though the number of anthelmintic doses administered to the grazing groups was about the same. Generally, low levels of supplementation (< 0.5 percent BW) can stimulate intake of fiber (Van Soest, 1994), thus supplemented animals could be consuming more parasite-larval-laden forages in the three weeks prior to the September sampling date resulting in higher adult GIN populations and a higher FEC compared to animal groups not supplemented.

Animals with high-dietary nutrient requirements, such as growing lambs and meat-goat kids, are more sensitive to infections with GIN compared with older animals. Manipulation of dietary nutrients may improve tolerance, resilience, and/or resistance to GIN parasites (Hoste et al., 2008). In goats, Nnadi et al. (2007) reported that West African Dwarf adult doe goats on a low-protein diet had higher FEC compared to adult does on a high-protein diet. In addition, the high-protein diet limited *H. contortus* establishment. Marley et al. (2005) suggested that grazing clovers (high protein) can reduce dependence on anthelmintics for control of abomasal GIN in lambs.

The overall energy:protein ratio in the rumen is important to optimizing rumen microbial growth and nutrient-use for maximizing animal performance (Poppi and McLennan, 1995). Growing lambs (20kg to 30 kg) and gaining 200 g/d require a energy TDN to protein (CP) ratio in the diet of around 3.7 to 4.4, while growing goat kids (20 kg to 35 kg) and gaining 100 g/d require a TDN:CP ratio in the diet of around 4.4 to 4.8. The mixed sward of orchardgrass-red clover-white clover in the present study had an average TDN:CP of 4.1 (Turner et al., 2015), which was close to sufficient for meeting requirements. The TDN:CP ratio in the whole cottonseed supplement was 3.2 and typically has high levels of intake protein from RUP (Turner et al., 2015). Even with an optimal energy (metabolizable energy; Houdijk, 2012) to protein ratio for the rumen microbial ecosystem, the RUP from grazed pasture alone may fall short of supplying rumen-escape protein to support the immune function in these animals. We did not evaluate the effect of RUP from herbages and supplement on immune function in our study. Aspects of this need further evaluation in small ruminants.

Supplemental protein can suppress FEC in sheep and goats probably through an enhancement of the immune system, which could result in a decreased frequency of dewormer administration. Immune system development is slower in goats compared to sheep (Hoste et al., 2010). Goats tend to reduce intake of larval parasites by grazing high in the sward canopy. In intensive grazing systems that use rotational stocking to maintain swards with high nutritive value, the resulting sward is leafy, with a low profile. These vegetative swards would allow for ingestion of more larval parasites by grazing animals (Burke et al., 2009) if animals are returned to graze these paddocks too soon (short frequency of rotation), but most probably is dependent on the ambient temperature for GIN egg hatch and larval development (esp. *H. contortus*) and to the days of return to initial paddocks (Colvin et al., 2008). We had about 42 d of return in a temperate environment during summer.

Although FEC was not affected by the level (0.5 percent BW) of WCS supplementation used in this study, the WCS does contain gossypol, a polyphenolic secondary metabolite that may have influenced results. Gossypol is a dimeric sesquiterpene (Puckhaber et al., 2002) found in whole cottonseed. Sesquiterpene lactones have been suggested to act as anthelmintics (Foster et al., 2011). Additional research is needed to understand how meat goats respond to secondary plant compounds in forages, including impacts of compounds, such as gossypol, on abomasal and intestinal GIN in meat goats. In addition, research to evaluate genetics of parasite resistance in small ruminants will help improve GIN resistance and reduce dependence on anthelmintics.

Blood Parameters

Seasonal growing conditions each year influenced plant growth, nutritive value, energy-to-protein ratios, and resultant-metabolic responses in animals (Turner et al., 2015). In addition, blood parameters changed as the animals adapted to treatment pastures each year and reflect forage nutrient and supplemental nutrients (substantiated by significant date × treatment interactions).

Fraser et al. (2004) reported higher serum-total protein and albumin concentrations when lambs were finished on red clover compared to perennial ryegrass; there was no difference in serum globulin concentrations among their lamb groups. Serum albumin has been used as an additional indicator of protein status (Walz et al., 1998). Highly parasitized animals tend to have low serum-albumin concentrations (Thamsborg and Hauge, 2001). The Katahdin lambs appear to maintain a higher concentration of blood albumin than Suffolk lambs or goat kids, suggesting that Katahdin lambs were not heavily infected with GIN or that elevated blood-albumin concentrations may be an important mechanism to help maintain resilience in animals with high GIN-parasite levels (especially *H. contortus*) during the grazing season. Protein supplementation can also increase resilience defined as the ability to tolerate higher GIN parasite loads and still remain productive (gain weight). The increase in resilience may be linked to blood-albumin levels.

Although variable over the season in the present study, serum globulin in Suffolk lambs was higher than in Katahdin lambs; goat kids were intermediate. This suggested that Suffolk lambs, and probably goat kids, were mounting an immune response to GIN infection, whereas Katahdin lambs had some innate resistance to GIN. Goats typically exhibit a subdued immune response to GIN (Hoste et al., 2010), which agrees with the ranking of serum-globulin concentrations among the animal groups (Suffolk lambs > goat kids > Katahdin lambs) in the present study. Suffolk sheep typically do not show the same higher level of breed resistance to GIN (*H. contortus*) as Katahdin sheep.

Dietary nutrients, especially CP from legumes, are important in helping to maintain the immune system (as measured by blood globulin in this study) for resilience. Serum-total protein, albumin, and globulin were variable over the grazing season each year of the present study. High serum-total-protein and globulin concentrations can be indicative of damage caused by GIN and a heightened immune response (Hoskin et al., 2000). Marley et al. (2005) suggested that lambs grazing clovers (red or white) had improved nutrients available for body weight gain in addition to nutrients needed for the immune response to GIN. These researchers further suggested that white clover reduced the adult parasite loads without influencing the blood-globulin status. In our experiment, grazing a mixed sward of red clover, white clover, and orchardgrass did not allow us to separate effects, plus we only measured FEC and not adult parasite loads. Based on improved weight gain with a higher FEC, Turner et al. (2012) suggested that meat-goat kids grazing red-clover pasture were more resilient to GIN infection compared to goats grazing orchardgrass pasture. In the present study, it is not clear if additional protein via supplementation with WCS helped lambs and goat kids to be resilient to GIN. Supplementation may have helped Suffolk lambs to be better tolerate GIN, since these lambs had higher FEC and weight gains compared to Katahdin lambs and goat kids. The data is confounded, as goats received more doses of dewormer and Katahdin lambs tend to be naturally (genetically) more resistant to GIN compared to Suffolk lambs and Boer goat kids.

PCV, FAMACHA©, Doses of Dewormer, and Days until Additional Dewormer was Needed

The blood PCV was variable throughout the grazing seasons (Turner et al., 2015), but in the present study was within the normal range of 22 percent to 38 percent (Jain, 1993) for sheep and goats. Blood PCV is a quantitative means to determine degree of anemia in livestock, whereas FAMACHA© is a qualitative measure of anemia. Trends in monthly PCV and FAMACHA© were inversely related, meaning that when PCV scores were high (low degree of anemia) then FAMACHA© scores were low. The FAMACHA© score trend in our study was goat kids > Suffolk lambs > Katahdin lambs with PCV trending as Katahdin lambs > Suffolk lambs > goat kids. The FAMACHA© score averaged 2 to 3 over the season (on a 5-point scale; 1= no anemia and 5=severe anemia; Kaplan et al., 2004). Overall supplementation with WCS at 0.5 percent BW did not impact the FAMACHA© score. Katahdin lambs consistently had the lowest FAMACHA© scores each year.

Supplementation with WCS tended to reduce the number of doses of dewormer administered to goat kids, but not to Suffolk and Katahdin lambs. Protein supplementation may not be necessary to breeds of sheep (such as Katahdin) resistant to GIN parasites (Steel, 2003).

The average number of dewormer-dosing events per breed group of animals was different, as was the days until additional deworming was necessary. Part of the variation each year was that Suffolk and Katahdin lamb source genetics were the same each year, whereas goat kids were different genetic sources each year. For goat kids, the main difference among years was that in 2006 and 2007 meat goats used in the study were predominantly Boer breeding with Kiko goat breed influence. In 2008 goat kids were BoKi (F1 Boer x Kiko) genetics. Differences exist in goat-breed susceptibility to GIN parasite infection (Wildeus and Zajac, 2005). Kiko goats typically are more resistant to GIN parasite infection than Boer goats (Browning et al., 2011). The frequency of administering dewormer can vary as a result of animal breed/genetics (Burke and Miller, 2004), age of animal (Coles, 1997; Bartley et al., 2003), grazing management (Burke et al., 2009), climate/time of year (Domke et al., 2011), and a higher-parasitic challenge or parasite resistance to dewormers (Domke et al., 2011).

Nadarajah et al. (2015) suggested that when there was no additional administration of dewormer based on a FAMACHA© score ≤ 2 and after an initial dosing using a combination of dewormers from multiple classes, then goat bucks were classified as being resistant to gastro-intestinal parasites. Frequency of dosing in the present study was based on GIN-parasite-clinical signs evaluated via FAMACHA© score. Compared to a theoretical monthly dosing event per animal (three-month period; July, August, and September), using FAMACHA© to determine the need for deworming resulted in a mean 55.8 percent reduction in the number of doses of dewormer administered to lambs and goat kids over the three-year study, but percentage reduction varied by animal-breed group. In addition, using a GIN-parasite-resistant breed, such as Katahdin, with FAMACHA© resulted in the greatest reduction in the number of deworming events (81.5 percent) while using FAMACHA© with the GIN-susceptible goats resulted in a reduction of 19.1 percent; Suffolk lambs were intermediate (66.7 percent).

Wildeus and Zajac (2005) reported that Katahdin ewes were dewormed less frequently than Blackbelly ewes. Grazing a GIN-resistant breed group, such as Katahdin, with a GIN-susceptible breed group, such as Boer meat goats, may help to reduce severity of GIN infection in the goats, in that the Katahdin lambs may help to eliminate/reduce the larval loads in pastures, thus reducing frequency of dewormer administration. This aspect needs to be evaluated more thoroughly, and strategic-supplementation practices for pasture-based finishing of small ruminants need to be refined to improve GIN-parasite control for improved forage utilization, nutrient-use efficiency, and performance in grazing livestock.

Summary

Supplementation with WCS helped improve overall weight gain in Suffolk lambs, Katahdin lambs, and goat kids, but did not influence FEC ($P > 0.10$) when lambs and kids were finished on cool-season, grass-legume pastures. Overall, Suffolk lambs had a higher ($P < 0.05$) FEC compared to Katahdin lambs and goat kids; the FEC of Katahdin lambs and goat kids were similar. Variation in FEC over the grazing season was, in part, related to the use of the FAMACHA© system for determining the need to administer dewormer to individual animals. Trends in monthly PCV and FAMACHA© score were inversely related. Suffolk lambs and goat kids had lower blood albumin and higher blood globulin concentrations than Katahdin lambs, suggesting that Suffolk lambs and goat kids had a heightened immune response to GIN infection. Compared to a theoretical monthly deworming, use of FAMACHA© as an indicator of anemia helped reduce (mean 55.8 percent) the amount of dewormers administered to grazing Suffolk lambs, Katahdin lambs, and goat kids, but differed by breed group. Overall use of the FAMACHA© system allowed adequate control of GIN and a reduction of drug-treatment cost due to fewer anthelmintic doses, when compared to a monthly serial-treatment regime.

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Genetic Parameters for Internal Parasite Resistance, Reproduction, and Growth Traits in a Closed Line of Kiko × Boer Goats Divergently Selected for Internal Parasite Resistance[1]

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Summary

Prevalence of gastrointestinal nematodes is a major challenge for goat producers. One approach to combating internal parasites is to utilize the host animal's natural or acquired resistance to parasites in a selection program. Therefore, our objective was to estimate genetic parameters for parasite resistance, reproduction, and growth traits in a closed line of Kiko (K) × Boer (B) goats divergently selected for internal parasite resistance. Beginning in 2011, 146 mixed-age (1-yr-old to 6-yr-old) B does were assigned to one of two selection lines: a high line (HL) selected for high resistance to internal parasites and a low line (LL) selected for low resistance to internal parasites. Unrelated K bucks, purchased on the basis of parasite resistance, were exposed to each corresponding doe line. Resulting F_1 doe progeny were selected based on parasite resistance and were then backcrossed within line to K bucks to produce F_2 ¾ K × ¼ B progeny. Fecal egg count (FEC), blood packed cell volume (PCV), and FAMACHA© scores were measured monthly to evaluate impact of *Haemonchus contortus* parasite load. Genetic parameters were estimated with linear mixed models using restricted maximum-likelihood procedures. Heritability estimates for FEC, PCV, and FAMACHA© score were 0.13, 0.06, and 0.11, respectively and estimates for litter size, birth weight, and weaning weight were 0.23, 0.18, and 0.17, respectively. The genetic correlation between FEC and FAMACHA© was 0.46, while genetic correlations between FEC and PCV and FAMACHA© and PCV were 0.00 and -0.09, respectively. Results indicate that parasite resistance may be lowly heritable, regardless of parasite indicator trait measured, suggesting that selection progress would be possible, yet slow.

Key words: Genetic Correlation, Goat, Heritability, Parasite, Resistance

Introduction

In recent years, goats have become increasingly popular as an alternative livestock enterprise. However, goats are more susceptible to internal parasites than any other type of livestock (Vagenas et al., 2002; Schoenian, 2003). Arguably, parasitism is the most serious economic constraint affecting goat production in the United States.

The parasitic nematode of most concern for goat producers is *Haemonchus contortus* (Hendrix and Robinson, 2014), which traditionally has been controlled through commercial anthelmintic treatments. However, there has been increasing concern about the development of anthelmintic resistance in parasite populations (Terrill et al., 2001; Howell et al., 2008). Alternatives to commercial anthelmintics, such as herbal remedies, mineral supplements, and condensed tannins are being used; and rotational stocking or mixed-grazing systems have been developed. However, even if effective, these alternatives require intensive inputs and efforts that are not always conducive to all operations.

One approach is to utilize the host animal's natural immunity in a selection program to increase the level of parasite resistance in a herd. Genetic variability of parasite resistance within sheep flocks has been utilized and manipulated by selection in numerous research projects, especially in Australia and New Zealand (for review, see Windom, 1996). In goats, there is promising evidence that parasite resistance is under genetic control as well, but the number of studies is limited, especially from the United States (Wildeus and Zajac, 2005). Without research-based guidance on parasite resistance, much of the selection emphasis of goat producers in the central United States has been directed toward production traits, with little regard given to parasite resistance.

Our objective was to estimate genetic parameters for parasite resistance, reproduction, and growth traits in a closed line of Kiko × Boer goats divergently selected for internal parasite resistance.

Materials and Methods

Foundation Herd Establishment

In fall 2011, a divergent selection program for parasite resistance in goats was initiated at the Lincoln University George Washington Carver Farm located in Jefferson City, Missouri. All experimental procedures were reviewed and approved by the Institutional Animal Care and Use Committee (approval # 1410) at Lincoln University prior to initiation of the project. The experiment began with 146 mixed-age (1-yr-old to 6-yr-old) Boer and high-percentage Boer does (B) that were assigned to one of two divergent selection lines: a high line (HL; n = 74) selected for high resistance to internal parasites and a low line (LL; n = 72) selected for low resistance to internal parasites. The B does were not previously selected for internal parasite resistance; however, all available parasite-related data collected were used to calculate Expected Progeny Differences (EPD) to rank and sort does into each corresponding line. Expected Progeny Differences were computed prior to each selection point using a repeated records model via ASREML (described later; Version 4; VSN International, Hemel Hempstead, UK). Unrelated Kiko (K) bucks (n = 12) were purchased from individual producers on the basis of internal parasite resistance (six high and six low), as indicated by mean fecal egg count (FEC) collected and summarized by unbiased buck performance tests in Oklahoma and Maryland. After this, lines were closed and all selection was from within line. Kiko bucks were exposed to each corresponding doe line in separate breeding pens beginning in December, 2011 to produce F_1 K × B progeny. Breeding between K bucks and B does continued in 2012 and 2013; however, natural death loss and removal of non-pregnant B does from the experiment reduced the number of B does each year (Table 1).

Selected Animals

Each year from 2012 to 2014, F_1K × B doe progeny were selected (described in detail below) prior to the breeding season based on parasite resistance as determined by FEC EPD. Selected F_1 K × B HL and LL does were then backcrossed within line to original foundation HL and LL K bucks, respectively, to produce F_2 ¾K × ¼B progeny. Care was taken to avoid mating F_1 K × B does to related K bucks. Selected F_1 K × B HL and LL does remained in the herd for the duration of the project; however, death loss and disposal of non-pregnant does from the experiment reduced numbers each year (Table 1).

Selection and Parasite Sampling Procedures

First generation K × B HL and LL does were selected each fall of their birth year, prior to the breeding season, based on FEC EPD. Multiple FEC measurements were taken in an effort to improve accuracy of selection decisions because of environ-

Table 1. Description of the data analyzed.

Pedigree		Total no.		
	No. of sires	85		
	No. of dams	253		
	No. of paternal grand sires	31		
	No. of maternal grand sires	34		
	No. of paternal grand dams	50		
	No. of maternal grand dams	105		
			Treatment[a]	
Foundational herd		Total no.	HL	LL
	No. of Boer does	146	74	72
	No. of Kiko bucks	12	6	6
Bred (exposed)	2011	146	52	57
	2012	142	70	72
	2013	79	40	39
Progeny born[b]	2012 (F_1)	123	66	57
	2013 (F_1)	176	75	101
	2013 (F_2)	19	10	9
	2014 (F_1)	90	48	42
	2014 (F_2)	41	20	21

[a] Treatment: HL = high line (high resistance to internal parasites); LL = low line (low resistance to internal parasites).
[b] Progeny born: F_1 = Kiko × Boer; F_2 = ¾ Kiko × ¼ Boer.

mental conditions associated with traits such as FEC (Falconer and Mackay, 1996). Fecal egg counts, packed cell volume (PCV), and FAMACHA© scores were measured monthly on all animals, beginning at weaning in August until just prior to selection and breeding in December. Approximately 2 g of feces were collected from the rectum to estimate FEC using the modified McMaster's technique (Whitlock, 1948) with the precision of each egg counted representing 50 eggs per g of wet feces. Approximately 2 mL of blood were collected via jugular venipuncture using 18 gauge needles attached to evacuated-sample collection tubes containing heparin to estimate PCV. The PCV was subsequently determined by the micro-hematocrit centrifuge method using a HemataSTAT® II Centrifuge (Separation Technology, Inc., Sanford, Fla.). A FAMACHA© score for each animal was recorded as 1 (red, non-anemic), 2 (red-pink, non-anemic), 3 (pink, mild-anemic), 4 (pink-white, anemic), or 5 (white, severely anemic; Kaplan et al., 2004). Selection was based on EPD calculated from FEC data taken on a monthly basis. In the event that two of the following three criteria: a FEC of over 2,000 eggs per g (Machen et al., 1988), a FAMACHA© score of 4 or more, or PCV of 21 or less were recorded, that animal was immediately treated with commercial anthelmintics according to label recommendations (Valbazen® Suspension; Zoetis Inc., Kalamazoo, Mich. or Cydectin©; Boehringer Ingelheim, Inc., St. Joseph, Mo., or a combination). In treated cases, animals were selected on the basis of the number of doses administered rather than FEC data. Thus, selected HL individuals were those that were treated the fewest times or had the lowest FEC EPD, and for LL, selected individuals were those that were treated the most times or had the highest FEC EPD. No other criteria were used for selection with the exception of removal of non-pregnant does. For F_1 K × B does, selected individuals represented the most parasite resistant 80 percent from the HL and the least parasite resistant 80 percent from the LL.

Animal Management

All does (except F_1 and F_2 doelings after weaning) were managed as one group throughout the year, except at breeding. Breeding occurred once a year beginning in December by natural service in single-sire mating pens. Equal numbers of randomly selected does from each line were assigned to unrelated bucks of the same line. The breeding season lasted for 63 d, annually. During the breeding season, does were allowed access to pasture composed predominately of endophyte-infected tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh] and were hand fed a 14-percent crude protein corn-grain, soybean-meal, oat-grain-based supplement at NRC (2006) recommended levels. Does also had *ad libitum* access to water, trace minerals, and medium-quality grass hay composed predominately of endophyte-infected tall fescue if pasture was limited. Pregnancy status was determined within 45 d post-breeding by a trained technician using ultrasound equipment.

Does were wintered on pasture composed predominately of endophyte-infected tall fescue and medium-quality endophyte-infected tall fescue hay when pasture was limited and supplementation with a 14-percent crude protein corn-grain, soybean-meal, oat-grain-based diet continued at NRC (2006) recommended levels until it was increased 6 wk prior to kidding. Just prior to kidding in May, does were moved to large pens with indoor and outdoor access and observed at approximately 0700 and 1900 daily. Kids were ear-tagged, litter size (LS) was recorded, and birth weight (BWT) was measured within 24 h of birth. Starting at two wk of age, kids were allowed access to an 18-percent crude protein corn-grain, soybean-meal, oat-grain-based creep feed, offered until weaning at approximately 90 d of age. Kids were vaccinated according to label recommendations approximately 30 d pre-weaning for *Clostridium Perfringens* Types C and D and *Tetanus Toxoid* (Bar-vac© CD/T; Boehringer Ingelheim, Inc., St. Joseph, Mo.). At weaning, kids were re-vaccinated, sorted by sex, and weaning weights (WWT) were recorded. Until breeding, F_1 and F_2 doelings were moved to separate endophyte-infected tall fescue-based paddocks and were offered a 14-percent crude protein corn-grain, soybean-meal, oat-grain-based supplement at NRC (2006) recommended levels. All F_1 bucklings were removed from the study and all F_2 bucklings were kept separate on endophyte-infected tall fescue-based paddocks with additional corn grain-soybean meal-oat grain based diet supplementation (NRC, 2006) provided.

Statistical Analysis

A pedigree describing the ancestral lineage of the population was utilized for genetic evaluation procedures. The pedigree file included 85 sires, 253 dams, 31 paternal grand sires, 34 maternal grand sires, 50 paternal grand dams, and 105 maternal grand dams (Table 1). Heritabilities and genetic correlations were estimated for parasitological measurements, reproductive, and growth traits using ASREML Version 4 (VSN International, Hemel Hempstead, UK).

Parasitological Measurements

A trivariate, repeated-records animal model was used to calculate EPD and estimate genetic parameters for FEC, PCV, and FAMACHA© score on 686 animals and included fixed effects of contemporary group, age at observation, sex, and heterozygosity (100 percent for F_1 and 50 percent for F_2). Contemporary group was defined for each observation as age, generation (F_1 or F_2), and animals that had the same anthelmintic treatment scheme based on time and number of doses administered. Additive genetic and residual (co)variances for each trait and linear functions thereof, including heritabilities and genetic correlations, were computed.

In matrix notation the mixed model with repeated records equations can be expressed as follows:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Za} + \mathbf{Zp} + \mathbf{e}$$

where $\mathbf{y}$ is the vector of the observations, $\mathbf{b}$ is the vector of fixed effects, $\mathbf{a}$ is the vector of additive genetic effects, $\mathbf{p}$ is the vector of permanent environmental effects and $\mathbf{e}$ is the vector of residual effects. The matrix $\mathbf{X}$ is the incidence matrix for the fixed effects and $\mathbf{Z}$ is the incidence matrix relating observations to animals. Each animal has an additive genetic as well as a permanent environmental effect; hence both effects have the same design matrix. The three random effects have the following distribution:

$$\text{var}\begin{bmatrix} a \\ p \\ e \end{bmatrix} = \begin{bmatrix} A\sigma^2 a & 0 & 0 \\ 0 & \sigma^2 c & 0 \\ 0 & 0 & I^2\sigma_e \end{bmatrix} = \begin{bmatrix} G & 0 \\ 0 & R \end{bmatrix} G = \begin{bmatrix} A\sigma^2 a & 0 \\ 0 & I^2\sigma_e \end{bmatrix}$$

where **A** is the numerator relationship matrix among animals, **I** is the appropriate identity matrix, σ_a^2 is the direct-additive-genetic variance, and σ_c^2 is the variance due to permanent environmental effects. In this model, permanent environmental effects for different animals are uncorrelated, and within an animal there is no correlation between its additive and its permanent environmental effect. The total phenotypic variance is the sum of the three variance components. The mixed-model equation for a model with repeated records is:

$$\begin{bmatrix} X'X & X'Z & X'Z \\ Z'X & Z'Z + \lambda A^{-1} & Z'Z \\ Z'X & Z'Z & Z'Z + \gamma I \end{bmatrix} \begin{bmatrix} b \\ a \\ p \end{bmatrix} = \begin{bmatrix} X'y \\ Z'y \\ Z'y \end{bmatrix}$$

where now $\lambda = \sigma^2 e / \sigma^2 a$ and $\gamma = \sigma^2 e / \sigma^2 c$.

Reproductive Traits

Litter size was recorded for 458 animals and was analyzed using a single-trait analysis. The model for this analysis included additive direct animal and fixed effects of LS, contemporary group, and heterozygosity. Data were pre-adjusted to an adult doe basis using previously developed industry adjustments (Table 2). For this study, adjustments were derived from data collected at Texas A&M-San Angelo, the American Boer Goat Association (San Angelo, Texas), and Virginia Tech University-Blacksburg with adjustment factors developed similar to those researchers involved with the National Sheep Improvement Program (Notter et al., 2005).

In matrix notation the single-trait, mixed-model equation for analyses of LS can be expressed as follows:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Za} + \mathbf{e}$$

where **y** is the vector of reproductive trait observations, **b** is the vector of unknown fixed effects, **a** is the vector of direct-genetic effects with associated incidence matrices **X** and **Z**, respectively, and **e** is a vector of random-residual effects. The mean vector is **E(y) = Xb** and

$$\text{var}\begin{bmatrix} a \\ e \end{bmatrix} = \begin{bmatrix} A\sigma^2 a & 0 \\ 0 & I\sigma^2 e \end{bmatrix}$$

where **A** is the numerator relationship matrix among animals, **I** is the appropriate identity matrix, and $\sigma^2 a$ and $\sigma^2 e$ are variances due to direct genetic and residual effects, respectively.

Growth Traits

Birth weights on 458 and WWT on 232 animals were recorded. Birth weight and WWT were used in a maternal-effects-model analysis because the dam has influence on the performance of her offspring over and above that of her additive genetic contribution. In this instance, maternal effects are strictly environmental for the offspring, but can have both genetic and environmental components (Willham, 1972). Any record with a missing or invalid birth date, weaning date, doe birth date, sire identification, or doe identification was omitted from the data set. Correct dates were necessary to calculate adjusted BWT and WWT and to ensure that contemporary groups were formed properly. If weaning age was not between 90 d to 120 d, then the record was removed.

Table 2. Multiplicative industry factors used to adjust litter size for effects of age of dam.

Age of dam	Industry adjustment factors[a]
1	1.48
2	1.17
3	1.05
4	1.01
5	1.00
6	1.00
7	1.02
8	1.05
9+	1.13

[a] Multiplicative factors used to adjust litter size for effects of age of dam presented by Notter et al. (2005).

Multiplicative factors derived from data collected at Texas A&M-San Angelo, the American Boer Goat Association (San Angelo, TX), and Virginia Tech University-Blacksburg (Notter et al., 2005) were used to adjust BWT and WWT for non-genetic factors of kid sex, type of birth (for BWT) or birth and rearing (for WWT), and age of dam (Table 3). In the data set, mean BWT and WWT weight prior to adjustment were 2.94 kg and 13.07 kg, respectively. After adjustments, mean adjusted BWT (BWT_{adj}) and adjusted WWT (WWT_{adj}) were 3.27 kg and 13.27 kg, respectively. Weaning weight was pre-adjusted for age of kid at weaning using the following formula:

$$90\text{ d } WWT_{adj} = (((\text{actual WWT} - \text{actual BWT}) / \text{weaning age}) * 90) + BWT$$

The maternal effects model used to analyze BWT and WWT can be represented as follows:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Z_1a} + \mathbf{Z_2m} + \mathbf{e}$$

In this model the direct genetic and maternal genetic effects are considered: where **y** is the vector of observations, **b** is a vector of fixed effects, **a** is a vector of additive-genetic effects, **m** is a vector of maternal genetic effects and **e** is a vector of residual effects. **X** is the incidence matrix for the fixed effects and $\mathbf{Z_1}$ and $\mathbf{Z_2}$ are incidence matrices relating observations to random animal (additive genetic) and dam (maternal genetic), respectively. The random effects had the following distribution:

Table 3. Multiplicative industry factors used to adjust birth and weaning weights for non-genetic effects.

		Industry adjustment factors[a]	
Effects	**Level**	**Birth weight[b]**	**Weaning weight[b]**
Kids sex	Buck	0.91	0.90
	Doe	1.00	1.00
	Wether		0.97
Type of birth-rearing	1-1	1.00	1.00
	1-2		1.14
	2-1		1.04
	2-2	1.13	1.18
	3-1		1.08
	3-2		1.23
	3-3	1.27	1.27
Age of dam	1	1.27	1.10
	2	1.07	1.09
	3-7	1.00	1.00
	8+	1.05	1.00

[a] Actual birth weights and age-adjusted (to 90 d) weaning weights are multiplied by the factor shown to correct for non-genetic effects of kid sex, type of birth (for birth weight) or birth and rearing (for weaning weight), and age of dam. Birth weights were adjusted only for type of birth. This table was adopted from Notter et al. (2005).
[b] Multiplicative factors for birth weight and weaning weight by Notter et al. (2005).

$$\text{var}\begin{bmatrix} a \\ m \\ e \end{bmatrix} = \begin{bmatrix} A\sigma^2 a_2 & A\sigma a_2 m & 0 \\ A\sigma^2 am & A\sigma^2 m & 0 \\ 0 & 0 & I\sigma^2 e \end{bmatrix} = \begin{bmatrix} G & 0 \\ 0 & R \end{bmatrix}$$

$$G = \begin{bmatrix} A\sigma^2 a_2 & A\sigma a_2 m \\ A\sigma^2 am & A\sigma^2 m \end{bmatrix} = G_0 \;\; x \;\; A$$

where G_0 is a 2 by 2 matrix: $\begin{bmatrix} \sigma^2 a_2 & \sigma a_2 m \\ \sigma^2 am & \sigma^2 m \end{bmatrix}$ and × **A** is a direct product.

Further, $\sigma^2 a$ is a direct genetic variance, $\sigma^2 m$ is the maternal genetic variance, σam is the covariance between direct and maternal genetic effects, and $\sigma^2 e$ is the error variance. The model shows that both random effects have a covariance structure depending on the genetic relationships. Related dams have related maternal effects, and there is a correlation between dam's direct additive genetic effects and her maternal genetic effects. The total phenotypic variance is equal to:

$$\sigma^2 p = \sigma^2 a + \sigma^2 m + \sigma^2 am + \sigma^2 e.$$

The mixed model equations are:

$$\begin{bmatrix} X'X & X'Z_1 & X'Z_2 \\ Z_1'X & Z_1'Z_1 + \alpha_{11}A^{-1} & Z_1'Z_2 + \alpha_{12}A^{-1} \\ Z_2'X & Z_2'Z_1 + \alpha_{21}A^{-1} & Z_2'Z_2 + \alpha_{22}A^{-1} \end{bmatrix} \begin{bmatrix} b \\ u \\ m \end{bmatrix} = \begin{bmatrix} X'y \\ Z_1'y \\ Z_2'y \end{bmatrix}$$

$$\text{where} \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix} = G_0^{-1}\sigma^2 e.$$

Results

Parasitological Measurements

Descriptive statistics for parasitological traits are shown in Table 4. Mean FEC, PCV, and FAMACHA© scores were 1,591, 27, and 3, respectively. Heritability estimates for FEC, PCV, and FAMACHA© are presented in Table 5. The heritability estimate for FEC was 0.13, which was similar to estimates of 0.13 reported by Baker et al. (2001) in 4.5-mo-old and 8-mo-old Galla and Small East African goats, 0.14 by Mandonnet et al. (2001) in 4-mo-old Creole goats, 0.18 by Gunia et al. (2011) in Creole goats, 0.05 in New Zealand involving Saanen milk goats by Morris et al. (1997), 0.02 in Australia with Angora goats by Bolormaa et al. (2009) and 0.05 and 0.13 (depending on the model used) in India with Barbari goats by Mandal and Sharma (2008). Findings from this study were lower than the 0.32 FEC heritability estimate by Vagenas et al. (2002) in Scottish feral goats and crosses, and the 0.20 FEC heritability at 82 d of age and 0.33 FEC at 10 mo of age in a population of Creole goats (Mandonnet et al., 2001). Overall, FEC is a lowly heritable trait in goats.

The heritability estimate for PVC was 0.06 (Table 5). Our estimate is somewhat lower than the heritability estimate reported by Baker et al. (2001) of 0.18 in Galla and Small East African goats and by Gunia et al. (2011), who reported a heritability estimate of 0.13 for PCV in Creole goats. Our heritability estimate for FAMACHA© score was 0.11 (Table 5), which was lower than the estimate of 0.55 for FAMACHA© score in Merinos reported by Van Wyk and Bath (2002). No heritability estimates for FAMACHA© score in goats were found in the literature.

Reproductive Traits

Number of records and descriptive statistics for adjusted LS (LS_{adj}) are shown in Table 6. The heritability estimate for LS_{adj} was higher ($h^2 = 0.23$; Table 7) than previous reported estimates including: 0.10 in Boer goats reported by Notter et al. (2005), using the same multiplicative factors applied in this study to adjust for LS, 0.12 in Boer goats (Zhang et al., 2009), 0.09-0.12 in Polish goats (Bagnicka and Lukaszewicz, 2000), 0.11-0.18 in dairy goats (Bagnicka et al., 2007), and 0.18 and 0.11 in Creole goats reported by Menendez-Buxadera et al. (2004) and Gunia et al. (2011), respectively.

Growth Traits

Number of records and descriptive statistics for BWT and WWT are shown in Table 6. Multiplicative factors were used to

Table 4. Summary statistics for parasitological measurements.

Trait[a]	No. of records	Mean	Minimum	Maximum	Standard deviation
FEC	3,826	1,591	50	23,350	2,433.0
PCV	3,872	27	10	41	8.3
FAMACHA© score[b]	3,875	3	1	5	0.9

[a] Parasitological measurements: FEC = fecal egg count; PCV = packed cell volume.
[b] FAMACHA© scores range from 1-5 with: 1 - red, non-anemic; 2 - red-pink, non-anemic; 3 - pink, mild-anemic; 4 - pink-white, anemic; 5 - white, severely anemic (Kaplan et al., 2004).

Table 5. Direct (h_d^2) heritability estimates for FEC, PCV, and FAMACHA© score.

Trait[a]	h_d^2
FEC	0.13 ± 0.07
PCV	0.06 ± 0.04
FAMACHA© score[b]	0.11 ± 0.08

[a] Parasitological measurements: FEC = fecal egg count; PCV = packed cell volume.
[b] FAMACHA© scores range from 1-5 with: 1 - red, non-anemic; 2 - red-pink, non-anemic; 3 - pink, mild-anemic; 4 - pink-white, anemic; 5 - white, severely anemic (Kaplan et al., 2004).

adjust BWT and WWT for non-genetic factors of kid sex, type of birth (for BWT) or birth and rearing (for WWT), and age of dam and resulted in heritability estimates for BWT_{adj} and maternal BWT_{adj} of 0.18 and 0.26, respectively (Table 7). Heritability estimates from this study were similar to heritability estimates of 0.15 for direct BWT and 0.10 for maternal BWT in Boer goats, in which the same adjustments factors were applied (Notter et al., 2005), 0.19 for direct BWT (using a smaller sample size and fitting an animal model ignoring parity of dam and interactions among the effect factors) in Boer goats (Zhang et al., 2008), 0.17 for direct BWT in Boer goats (Zhang et al., 2009), 0.16 for direct BWT in Boer goats (Schoeman et al., 1997), and 0.18 for direct BWT in Emirati goats (Al-Shorepy et al., 2002).

Heritability estimates for 90 d WWT_{adj} and maternal WWT_{adj} (pre-adjusted for non-genetic effects) were 0.17 and 0.04, respectively (Table 7). Zhang et al. (2009), analyzing Boer goats, reported an estimate of direct genetic heritability for 90 d WWT of 0.22, which was similar to the estimate found in our study. In a study with Boer goats, Schoeman et al. (1997) found similar results (h^2 = 0.18) for direct WWT in herds that occupied two different locations in Africa. Higher estimates were found by Supakorn and Pralomkarn (2012), who utilized three different goat breeds (Boer, Thai Native, and Saanen) and reported direct heritabilities of 0.26 to 0.36 (depending on the model used) for WWT at 150 d to 155 d of age. In another experiment with Emirati goats weaned at 2 mo, Al-Shorepy et al. (2002) reported a WWT heritability estimate of 0.32.

Genetic Correlations

Parasitological measurements

Estimated genetic correlations among FEC, PCV, and FAMACHA© scores are presented in Table 8. Genetic correlations between FEC and PCV and between FAMACHA© scores and PCV were slight (r = 0.00 and r = -0.09, respectively), while the genetic correlation between FEC and FAMACHA© was large and positive (r = 0.46). In contrast to current findings, Baker et al. (2001) with Galla and Small East African goats and Gunia et al. (2011) with Creole goats indicated that the average genetic correlation between FEC and PCV was -0.53 and -0.21, respectively. Genetic correlations between the various parasitological measurements were scarce in the literature for goats.

Table 6. Summary statistics for litter size, birth weight, and weaning weight after pre-adjustment using industry standard adjustment factors.

Trait[a]	No. of records	Mean	Minimum	Maximum	Standard deviation
LS_{adj}[b]	458	1.6	1.0	4.2	1.00
BWT_{adj}, kg[c]	458	3.3	1.5	5.4	0.63
WWT_{adj}, kg[c]	232	13.3	5.4	25.6	3.72

[a] Performance trait: LS_{adj} = adjusted litter size; BWT_{adj} = adjusted birth weight; WWT_{adj} = adjusted weaning weights.
[b] Multiplicative factors were used to adjust litter size for effects of age of dam.
[c] Actual birth weights and age-adjusted (to 90 d) weaning weights were corrected for non-genetic effects of kid sex, type of birth (for birth weight) or birth and rearing (for weaning weight) and age of dam. Birth weights were adjusted only for type of birth.

Table 7. Direct (h_d^2) and maternal (h_m^2) heritability estimates for performance traits from analysis that used data pre–adjusted using industry standard multiplicative adjustment factors.

Trait[a]	h_d^2	h_m^2
LS_{adj}[b]	0.23 ± 0.15	
BWT_{adj}[c]	0.18 ± 0.52	0.26 ± 2.10
WWT_{adj}[c]	0.17 ± 0.10	0.04 ± 0.02

[a] Performance trait: LS_{adj} = adjusted litter size; BWT_{adj} = adjusted birth weight; WWT_{adj} = adjusted weaning weights.
[b] Multiplicative factors were used to adjust litter size for effects of age of dam.
[c] Actual birth weights and age-adjusted (to 90 d) weaning weights were corrected for non-genetic effects of kid sex, type of birth (for birth weight) or birth and rearing (for weaning weight), and age of dam. Birth weights were adjusted only for type of birth.

Table 8. Genetic correlations (r) among FEC, PCV, and FAMACHA© score.

Parasitological measurement[a]	r
FEC – PCV	0.00 ± 7.71
FEC – FAM[b]	0.46 ± 0.11
FAM[b] – PCV	-0.09 ± 0.04

[a] Parasitological measurements: FEC = fecal egg count; PCV = packed cell volume; FAM = FAMACHA© score.
[b] FAMACHA© scores range from 1-5 with: 1 - red, non-anemic; 2 - red-pink, non-anemic; 3 - pink, mild-anemic; 4 - pink-white, anemic; 5 - white, severely anemic (Kaplan et al., 2004).

Growth traits

The genetic correlation between direct BWT and direct WWT was positive (0.24; data not shown). The American Boer Goat Association reported a genetic correlation of 0.50 between BWT and WWT (Notter et al., 2005). The positive genetic correlation between BWT and WWT suggests that selection for increased WWT can lead to increased BWT in goat kids.

Conclusion

Results of this study indicate that parasite resistance may be lowly heritable, regardless of parasite indicator traits measured. Heritability estimates for parasite related measurements in the current study were similar to previous estimates reported in literature and suggested that selection progress may be possible, but slow.

When heritability estimates were calculated for reproductive and growth traits using a model to estimate non-genetic fixed effects for kid sex, birth/rearing type, and age of dam from the data, our results were lower than reported estimates. However, if data was pre-adjusted for these factors using industry standard adjustments, heritability estimates for both reproductive and growth traits were in the range of previously reported literature. These results emphasize the importance of properly adjusting records before making selection and breeding decisions.

Because *H. contortus* has a short lifecycle and extreme prolificacy, control in goats typically is a major management challenge. Selection for parasite resistance in goats may be a sustainable way to control this internal parasite and limit reliance on commercial anthelmintics.

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The Use of Organic Pinot Noir Grape Extract as a Natural Anthelmintic in Katahdin Lambs

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Summary

Gastrointestinal nematode parasitism is one of the greatest threats to economic sheep production in the United States. With increased incidences of anthelmintic resistance and constraints of organic production, there is heightened interest in alternative natural dewormers, such as plants containing condensed tannins. Therefore, the objective of this study was to evaluate effects of organic fermented Pinot Noir (PN) grape extract on parasite level and performance in Katahdin lambs. On October 14, 2014, Katahdin ewe and ram lambs (n = 45; 23.13 kg ± 0.60 BW) were stratified by fecal egg count, weight, sex, and were allocated randomly to one of three treatments: 1) an oral dose (10-mL per 4.5 kg of BW) of fermented PN at 7 d (D7) intervals, 2) the same dose of PN at 14 d (D14) intervals, or 3) control (C; 30-mL oral dose of water at 14 d intervals). Condensed tannins were extracted, purified, and standardized from organic PN and were found to have a concentration of 0.20 mg/mL. Lambs were maintained on tall fescue [*Lolium arundinaceaum* (Schreb.) Darbysh] pasture, with no additional feed for the duration of the 63-d study. Data were analyzed using PROC MIXED of SAS. Two contrast statements were used to compare the mean of C compared with D7 and D14 and the mean of D7 compared with D14. Average daily gain and total weight gain were greater (P = 0.02) from D7 and D14 compared with C. Start, end, and start to end change body condition scores and FAMACHA© scores did not differ ($P \geq 0.05$) across treatments. End of study and change from start to end fecal egg counts were greater ($P \leq 0.05$) from C compared with D7 and D14. Change in packed cell volume from start of study to end were greater (P = 0.05) from D7 compared with D14. End monocytes and white blood cell counts were less (P = 0.05 and P = 0.03, respectively) from D7 compared with D14. Other blood parameters were similar across treatments. Therefore, fermented grape extract may be an effective organic and sustainable strategy for controlling gastrointestinal nematodes and increasing performance in Katahdin lambs.

Key Words: Anthelmintic, Condensed Tannin, Lambs, Organic Grape Extract

Introduction

Gastrointestinal nematodes (GIN) can endanger animal health and welfare and cause severe economic damage in small ruminants (Miller and Horohov, 2006; Shaik et al., 2006). Since their introduction in the 1960s, broad-spectrum, synthetic anthelmintics have been the primary defense against GIN infection in small ruminants worldwide (Hoste, 2011). However, with evolution of resistant strains of parasites, there is a greater necessity for exploration of natural alternatives (Shaik et al., 2006; Rahmann and Seip, 2007; Terrill et al., 2009).

Research by Rahmann and Seip (2007) suggested that phytotherapy (the use of plants as a natural anthelmintic) should be evaluated. Found in nearly all families of plants, the most abundant phytochemicals are tannins. Tannins are plant secondary metabolites, which are closely associated with plant-defense mechanisms against insects (Githiori et al., 2006; Oksana et al., 2012) and are broken into two groups, condensed tannins (CT) and hydrolysable tannins (Anthanasiadou et al., 2001). Condensed tannins are compounds that may demonstrate biological activities in ruminants, such as binding to proteins and suppression of GIN infection (Naumann et al., 2013). Collectively, it has been reported (King and Young, 1999; Gu et al., 2004; Mattivi et al., 2009) that high concentrations of CT have been measured in fruits with dark red, blue, or black pigment skin, such as grapes; many dark orange or red-skin vegetables; some legume cereals and beans; tree nuts, such as almonds, pecans and hazelnuts; cocoa beans, coffee, tea, wine, and spices, such as cinnamon. Components of pH, astringency or dryness, and bitterness are indications of CT concentration (King and Young, 1999). As degree of polymerization and molecular weight increases, astringency may also increase (Naumann et al., 2013). Further, an increase in concentration of CT is observed comparing red grape juice to red wine (King and Young, 1999), suggesting that fermentation may influence CT accessibility to the ruminant animal (Githiori et al., 2006). Therefore, our objective was to evaluate effects of organic, fermented Pinot Noir grape extract on parasite level and performance in Katahdin lambs.

Materials and Methods

Animals and experimental design

This project was conducted at the Lincoln University Allen T. Busby Farm in Jefferson City, Mo. and was approved by the Animal Care and Use Committee (14-4). Certified organic Katahdin mixed-sex lambs (n = 45; 23.13 kg ± 0.60 BW) were weaned and grazed tall fescue [*Lolium arundinaceaum* (Schreb.) Darbysh] pastures for 81 d. Lambs were then weighed, fecal egg counts (FEC) were determined, and body condition scores (BCS) and FAMACHA© scores were assigned by an experienced evaluator. Starting October 14, 2014, lambs were then stratified by FEC, weight, and sex, and allocated randomly to one of three treatments: 1) drenched with organic PN every 7 d (D7) at a rate of 10-mL per 4.5 kg of BW; 2) drenched with organic PN every 14 d (D14) at a rate of 10-mL per 4.5 kg of BW; and 3) drenched with 30-mL of water every 14 d (C). In accordance with established farm protocols, animals were removed from the study if they met three out of the following four criteria: 1) FEC of ≥ 4,000; 2) FAMACHA© score of ≥ 4; 3) packed cell volume (PCV) of ≤ 21 percent; or 4) a BCS ≤ 2. For the duration of the 63 d trial, lambs rotationally grazed six tall fescue [*Lolium arundinaceaum* (Schreb.) Darbysh] pastures, had *ad libitum* access to water and organic approved mineral (Redmond Naturals, Redmond, Utah), with no additional supplementation to the diet. Throughout the study, lambs were maintained in a single group with ear tag numbers as the primary identification method.

Chemical analysis and quantification of condensed tannins

Condensed tannins were extracted and purified from organic PN by the CT isolation method using Sephadex LH-20 gel filtration (GE Healthcare Bio-Sciences Corp, Piscataway, N.J.; Strumeyer and Malin, 1975) then quantified by the Protein-Precipitable Phenolic method (Hagerman and Butler, 1978, which uses iron phenolate to detect tannins by UV Spectrophotometer (Beckman Coulter Inc., Model DU730, Fullerton, Calif.).

Condensed tannins were purified using Sephadex LH-20 for subsequent use as a standard from PN extract according to Naumann et al. (2013). The aqueous portion containing the CT was retained. The extract, along with enough 1:1 (v/v) methanol:water to form a slurry, was mixed with Sephadex LH-20, and the slurry was repeatedly washed with 1:1 methanol:water until cast off was near clear. Condensed tannins bound to the Sephadex were released by washing with 7:3 (v/v) acetone:water followed by evaporation of residual acetone by air stream/vacuum. The aqueous phase containing CT was frozen at -80°C and lyophilized (Strumeyer and Malin, 1975; Cooper et al., 2014).

To determine Protein-Precipitable Phenolic, 50 µL of supernatant from PN extracts were combined with 250 µL buffer A (0.20 M acetic acid, 0.17 sodium chloride, pH 4.9), 50 µL bovine serum albumin, and 50 µL 1:1 (v/v) methanol:water and incubated at room temperature for 30 min prior to centrifuging for 5 min. Supernatant was removed by vacuum aspiration and the protein-phenolic pellet was washed with 250 µL buffer A before re-centrifuging and aspirating. The protein-phenolic pellet was dissolved in 800 µL of SDS/TEA (sodium dodecyl sulfate [1 percent w/v]-triethanolamine [5 percent v/v] before adding 200 µL FeCl3 (0.01 M FeCl3 in 0.01 M HCl). Absorbance was read at 510 nm after 30 min and quantified via external standards (Hagerman and Butler, 1978).

The concentration of protein bound by CT was determined as described by Naumann et al. (2014). The procedure was carried out as described above, but the protein-phenolic pellet was analyzed for N to quantify precipitated protein. Rather than dissolving the protein-phenolic pellet in SDS/TEA, the pellet was dissolved in 500 µL of buffer A, and the solution was transferred into foil cups and allowed to dry. A Elementar Vario Macro Cube C-N Analyzer (Donaustraße 7, Hanau, Germany) was used to analyze the dried protein-phenolic residue for percent N, which was multiplied by 6.25 to calculate the amount of protein bound CT. To determine total phenolics, 50 µL of supernatant from the crude plant extract was combined with 850 µL of SDS/TEA before adding 200 µL of FeCl3. Absorbance at 510 nm was read after 30 min and quantified via external standards as described for the Protein-Precipitable Phenolic assay.

The procyanidin:prodelphinidin ratio of CT from organic PN grape extract was measured by High Performance Liquid Chromatography (Li et al., 2010) using a Thermo Fisher Dionex Ultimate 3000 UHPLC (Thermo Scientific, Indianapolis, Ind.).

Feedstuff analysis

Carbon, N, CP, and ratios were analyzed for fescue pasture, by a C/N analyzer (Elementar Vario Macro Cube; Donaustraße 7, Hanau, Germany). Organic PN was analyzed for CP by the same method. Neutral detergent fiber, ADF, and DM were determined on grab samples, harvested at a 2.54 cm stubble height, which were taken from pastures pre-, mid-, and post-grazing of the trial. Samples were freeze dried with a FreezeZone12 (Labconco Corp., Kansas City, Mo.), ground to pass through a 1 mm screen using a Wiley Mill (Arthur H. Thomas, Penn., USA), and analyzed using the Van Soest (1991) method without α-amylase, using an ANKOM200 Fiber Analyzer (ANKOM Technology, Macedon, N.Y.).

Parasitological procedure and measures

During the 63-d trial, individual fecal samples were taken from the rectum of each animal every 7 d. Fecal egg count was determined within 24 h by the modified McMaster procedure (Whitlock, 1948; Mines, 1977) and quantified by using 2-g subsamples of fresh feces from each lamb. Oocytes were counted under a microscope, but not identified by species; however, based on previous work in our lab, *Haemonchus Contortus* is the primary GIN at this locale. Every 7 d, individual blood samples were taken by jugular venipuncture into hematocrit tubes and PCV was determined using a HemataSTAT II Centrifuge (Separation Technology, Inc., Sanford, Fla.) within 6 h of blood collection. Additionally, weights, FAMACHA© scores (Hepworth et al., 2006) and BCS (Russell, 1991) were taken every 7 d by the same experienced evaluator throughout the entirety of the study.

Analysis of complete blood cell counts

Blood samples for complete blood cell (CBC) counts were taken by jugular venipuncture every 14 d into BD Vacutaine K3 EDTA 12-mg blood collection tubes (Fisher Scientific, Pittsburgh, Penn.). Samples were shipped to University of Arkansas (Fayetteville, Ark.) in cold storage to maintain sample integrity, and within 24 h of collection CBC counts were analyzed by an Abbott Cell-Dyn 3700SL Automate Hematology Analyzer (GMI Inc., Ramsey, Minn.).

Table 1. Effects of organic Pinot Noir on performance in Katahdin lambs.

	Treatment[a]				
Item	C	D7	D14	SEM[b]	Contrast[c]
Start BW, kg	23.8	22.7	23.4	1.06	ns
End BW, kg	28.0	28.2	28.9	1.05	ns
ADG, kg	0.07	0.09	0.08	0.01	W
Gain, kg	4.2	5.4	5.2	0.39	W
Start BCS[d]	2.9	2.9	2.7	0.14	ns
End BCS[d]	2.5	2.6	2.5	0.11	ns
BCSd change[e]	-0.3	-0.3	-0.3	0.13	ns

[a] C = Control drenched with 30 mL of water every 14 d, D7 = drenched with Pinot Noir every 7 d at a rate of 10-mL per 4.5 kg of BW, and D14 = drenched with Pinot Noir every 14 d at a rate of 10-mL per 4.5 kg of BW.
[b] SEM = Pooled standard error of means.
[c] Contrast statements: W = mean of C compared with the mean of D7 and D14 ($P \leq 0.05$); ns = no significant difference ($P > 0.10$).
[d] BCS = Body condition score, based on 5-point scale, with 1 being thin and 5 being obese.
[e] BCS change = Change of start body condition score compared with end body condition score.

Table 2. Effects of organic Pinot Noir on parasite parameters in Katahdin lambs.

	Treatment[a]				
Item	C	D7	D14	SEM[b]	Contrast[c]
Start FEC, eggs/g[d]	43.0	39.6	48.7	8.11	ns
End FEC, eggs/g[d]	50.6	28.1	24.7	9.57	W
FECd change, eggs/g[e]	10.5	-13.1	-18.5	10.82	W
Start FAMACHA©[f]	1.6	1.4	1.8	0.60	ns
End FAMACHA©[f]	1.5	1.5	1.5	0.12	ns
FAMACHA©[f] change[g]	-0.2	-0.1	0.0	0.20	ns
Start PCV, %[h]	34.2	31.4	33.4	1.31	ns
End PCV, %[h]	36.3	37.0	36.8	1.05	ns
PCVh change, %[i]	2.2	5.6	2.2	1.19	X

[a] C = Control drenched with 30 mL of water every 14 d, D7 = drenched with Pinot Noir every 7 d at a rate of 10-mL per 4.5 kg of BW, and D14 = drenched with Pinot Noir every 14 d at a rate of 10-mL per 4.5 kg of BW.
[b] SEM = Pooled standard error of means.
[c] Contrast statements: W = mean of control compared with the mean of D7 and D14 ($P \leq 0.05$); X = mean of D7 compared with the mean of D14 ($P \leq 0.05$); ns = no significant difference ($P > 0.10$).
[d] FEC = Fecal egg count.
[e] FEC change = Change of start fecal egg count compared with end fecal egg count.
[f] FAMACHA© score = 1 - not anemic to 5 - severely anemic.
[g] FAMACHA© change = Change of start FAMACHA© compared with end FAMACHA©.
[h] PCV = Packed cell volume.
[i] PCV change = Change of start packed cell volume compared with end packed cell volume.

Statistical analyses

Data were analyzed using PROC MIXED of SAS 9.3 (SAS Inst. Inc., Cary, N.C.). Animal was considered the experimental unit. Treatment means are reported as least squares means with the contrast statements of the mean of control compared with D7 and D14 and the mean of D7 compared with D14. Differences were considered significant at $P \leq 0.05$.

Results

Pasture averages for all sample dates included: CP = 14.2 percent; NDF = 56.7 percent; ADF = 30.1 percent; DM = 91 percent. Organic PN grape extract was found to have a concentration of 0.20 mg/mL of CT. Crude protein was 1.6 mg/mL by sample. The concentration of PBCT was determined and found to bind 12.7 mg/mL of protein with a 32.8 percent binding capability. The level of combined procyanidins and prodelphinidin was 0.0007 mg/mL with 15.5 percent Galloylated tannin.

As shown in Table 1, ADG and total weight gain were greater ($P = 0.02$) from D7 (5.4 kg) and D14 (5.2 kg) compared with C (4.2 kg) lambs. Start, end, and change BCS averaged 2.5 and did not differ ($P \geq 0.50$) across treatments.

Natural GIN infection was apparent in all lambs with an average FEC of 43.8 ± 8.11 eggs per g of feces. Two lambs were removed from D14 because they met three of four health threshold criteria. As displayed in Table 2, end of study ($P = 0.05$) and change from beginning to end ($P = 0.04$) FEC were greater from C compared with D7 and D14. Change in PCV from start of study to end differed ($P = 0.05$) from D7 and D14. Overall, FAMACHA© scores were not different ($P \geq 0.50$) across all treatments.

White blood cell (WBC) counts and monocytes (MONO) were higher ($P = 0.03$ and $P = 0.05$, respectively) at end of study from D7 compared with D14. A significant ($P = 0.02$) change was found in basophil (BASO) concentrations from D7 compared with D14. A tendency ($P = 0.07$, $P = 0.09$, and $P = 0.09$, respectively) was found for change in WBC, hemoglobin (HGB), and mean corpuscular hemoglobin concentrations (MCHC percent) from D7 compared with D14, with D7 concentrations being less than D14 concentrations. Other blood parameter concentrations were similar ($P \geq 0.10$) across treatments (Table 3).

Discussion

The main purpose of chemical anthelmintics is to achieve >90 percent reduction of adult and larval parasites in the host animal (Ketzis et al., 2006). However, remaining refugia create the opportunity for resistant parasitic infections to occur (Ketzis et al., 2006). Consequently, the purpose of novel anthelmintics establishes a different approach towards the control of GIN in ruminants. Novel control methods do not always have a direct effect on the parasite, but instead use the animal's own ability to recover and assist in maintaining parasite infections below the economic threshold of the physical capabilities of the animal (Ketzis et al., 2006). This not only relates to the efficacy of the control method used, but also to the epidemiology of the parasites, climate, animal management program, and the ease of integration as a sustainable program (Ketzis et al., 2006). The precise mechanism by which CT acts as a natural anthelmintic needs to be better understood, and a concerted effort on isolation, development, and validation of the effects needs to be undertaken before they are more widely accepted (Githiori et al., 2006). High CT content of red grape products (Mattivi et al., 2009; Yang et al., 2009) and world-wide availability, make it a potential source of natural anthelmintics (Kammerer et al., 2004).

All lambs grazed the same forages with nutritional constituents averaged for all samples. These included CP = 14.2 percent; NDF = 56.7 percent; ADF = 30.1 percent; DM = 91 percent. Organic PN grape extract used in this study had a CT concentration of 0.20 mg/mL and demonstrated a natural bioactive anthelmintic effect by reducing nematode FEC of pasture-grazed Katahdin lambs. Reduction in FEC may have been due to temporary reduction of nematode numbers, reductions in female worm fecundity, reduced nematode excretion (measured by FEC) and/or egg output (Heckendorn et al., 2007; Hoste et al., 2006). It is also possible that CT may alter the L3 larval ex-sheathment process, thereby reducing persistence to the host animal (Alonso-Diaz et al., 2011). In research conducted by LeShure (2014), grape pomace extract resulted in 100 percent inhibition of egg hatching into third-stage larvae. Results indicated that grape pomace had efficacy in decreasing hatchability of helminth eggs, as well as decreasing parasite viability in an in vitro setting (LeShure, 2014). Research by Iqball et al. (2007) found when sheep were divided into three treatment groups of low CT, high CT, and a control, that high CT facilitated protection of protein from degradation by rumen microbes, which minimized the effects of internal parasites. This was due in part to CT binding with plant protein following mastication. The result was the formation of larger CT-protein complexes while in the rumen, which protected the protein from rumen microbes. It remained as a complex until reaching the abomasum where pH changes and protein was released (Hoste et al., 2006). The CT directly affect overall GIN numbers and increase animal performance by influencing the physiological function and environment available to the parasite (Githiori et al., 2006). At this point, free CT may interact with the parasite and proteins are released to be absorbed in the lower gastrointestinal tract (Min and Hart, 2003). Parasite level may also be indirectly influenced through improved availability of protein allowing the animal to launch a counter attack by increased immunity (Hoste and Torres-Acosta, 2011).

In the current study, an increase in total weight gain and ADG in D7 and D14 lambs could suggest an added benefit of CT ability to bind protein, causing a by-pass protein effect. Research conducted by Dawson et al. (2011) found there were no difference in weaning weights or weight gain in lambs offered low protein diets compared with high protein diets. When a high protein diet was offered without CT tannins, lambs gained less weight as compared to lambs fed a low-protein diet with 80 g Quebracho CT tannin extract/kg BW. Therefore, diets with CT added may be more effective than diets concerned with protein content exclusively. The widely accepted explanation for positive effects of CT on protein digestion and metabo-

Table 3. Effects of organic Pinot Noir on complete blood cell counts in Katahdin lambs.

Item[b]	Treatment[a] C	D7	D14	SEM[c]	Contrast[d]
Start WBC, K/μL	10.20	9.95	9.56	0.737	ns
End WBC, K/μL	9.59	10.26	7.97	0.728	X
WBC change, K/μL[e]	0.61	-0.31	1.95	0.845	x
Start NEU, K/μL	3.67	3.12	3.22	0.397	ns
End NEU, K/μL	3.67	3.49	2.95	0.456	ns
NEU change, K/μL[e]	0.00	-0.37	0.50	0.426	ns
Start LYM, K/μL	3.16	3.56	3.26	0.329	ns
End LYM, K/μL	3.24	3.35	2.52	0.362	ns
LYM change, K/μL[e]	-0.08	0.21	0.76	0.427	ns
Start MONO, K/μL	2.64	2.57	2.34	0.310	ns
End MONO, K/μL	2.10	2.59	1.89	0.246	X
MONO change, K/μL[e]	0.54	-0.02	0.53	0.319	ns
Start EOS, K/μL	0.15	0.29	0.67	0.057	ns
End EOS, K/μL	0.26	0.42	0.27	0.077	ns
EOS change, K/μL[e]	-0.11	-0.13	-0.09	0.065	ns
Start BASO, K/μL	0.57	0.40	0.56	0.064	ns
End BASO, K/μL	0.32	0.41	0.33	0.056	ns
BASO change, K/μL[e]	0.25	-0.01	0.23	0.079	X
Start RBC, K/μL	10.35	9.53	10.16	0.541	ns
End RBC, K/μL	10.19	9.76	9.89	0.669	ns
RBC change, K/μL[e]	0.16	-0.23	0.66	0.778	ns
Start HGB, g/dL	10.19	9.42	9.97	0.554	ns
End HGB, g/dL	10.28	10.29	9.68	0.522	ns
HGB change, g/dL[e]	-0.09	-0.87	0.69	0.641	x
Start HCT, %	33.20	33.34	32.57	1.180	ns
End HCT, %	33.07	33.89	33.87	1.044	ns
HCT change, %[e]	0.13	-0.22	0.31	0.973	ns
Start MCV, fL	32.03	32.71	32.20	0.412	ns
End MCV, fL	32.45	32.66	31.83	0.522	ns
MCV change, fL[e]	-0.42	0.17	0.08	0.324	ns
Start MCH, pg	9.79	9.89	9.81	0.109	ns
End MCH, pg	10.08	10.11	9.77	0.154	ns
MCH change, pg[e]	-0.29	-0.19	0.02	0.094	ns
Start MCHC%, g/dL	30.59	30.24	30.53	0.261	ns
End MCHC%, g/dL	31.05	31.01	30.75	0.223	ns
MCHC% change, g/dL[e]	-0.46	-0.77	0.02	0.311	X
Start RDW, %	26.39	25.35	25.85	0.536	ns
End RDW, %	31.65	29.39	29.30	1.403	ns
RDW change, %[e]	-5.27	-4.16	-2.75	1.340	ns
Start PLT, K/μL	745.60	750.43	747.80	85.924	ns
End PLT, K/μL	582.60	514.47	541.34	96.560	ns
PLT change, K/μL[e]	163.00	235.96	191.97	108.570	ns

[a] C = Control drenched with 30 mL of water every 14 d, D7 = drenched with Pinot Noir every 7 d at a rate of 10-mL per 4.5 kg of BW, and D14 = drenched with Pinot Noir every 14 d at a rate of 10-mL per 4.5 kg of BW.

[b] WBC = White blood cells; NEU = Neutrophils; LYM = Lymphocytes; MONO = Monocytes; EOS = Eosinophils; BASO = Basophils; RBC = Red blood cells; HGB = Hemoglobin; HCT = Hematocrit; MCV = Mean corpuscular volume; MCH = Mean corpuscular hemoglobin; MCHC% = Mean corpuscular hemoglobin concentration percent; RDW = Red cell distribution width; PLT = Platelets.

[c] SEM = Pooled standard error of means.

[d] Contrast statements: W = mean of C compared with the mean of D7 and D14 ($P \leq 0.05$); X = mean of D7 compared with the mean of D14 ($P \leq 0.05$); lowercase letters represent statistical tendencies ($P \leq 0.10$); ns = no significant difference ($P > 0.10$).

[e] Change = Change of start complete blood cell parameters compared with end complete blood cell parameters.

lism is that CT-protein complexes escape ruminal degradation resulting in greater protein availability in the abomasum (Reed, 1995). In compiled research, Min and Hart (2003) found that moderate concentrations of 20 g to 40 g CT/kg of DM bind to protein by hydrogen bonding at near neutral pH (pH 6.0-7.0) in the rumen to form CT-complexes, but dissociate and release bound protein at pH less than 3.5 in the abomasum. Therefore, protecting dietary protein against degradation in the rumen subsequently increases amino acid supply to the abomasum and small intestine, resulting in improved nutritional status of the animal and possible improved production (Min and Hart, 2003; Hoste et al., 2006). The protein binding activity of CT could be affected by procyanidin:prodelphinidin and percent galloylation of CT. Condensed tannins with greater proportions of prodelphinidin and galloyl groups may have greater bioactivity (Naumann et al., 2015) and subsequent increased ability to bind protein over other types of tannins. It could also be suggested that organic PN is more easily absorbed in the abomasum of the ruminant animal due to solubility of tannin in fluid. Concentration and structure of CT present in different plant species seem to be the major factors modulating efficacy against nematodes (Oksana et al., 2012). However, there is some indication that molecular weight of CT also plays a role and that smaller molecular weight CT is more bioactive against GIN than those of larger molecular weight (Naumann et al., 2014).

Laboratory examination of the ruminant CBC can be an important addition to the physical examination (Jones and Allison, 2007). Consulting a CBC can often show an immune response to infection or virus before symptoms are presented in the animal. In this research, some changes were found in CBC results, including a significant increase in both MONO and WBC from D7 compared with D14 at the end of the study. A significant change in BASO concentrations were found, as well as tendencies for change in WBC, HGB, and MCHC percent from D7 compared with D14, with D7 concentrations tending to be less. An increase in PCV, MONO, and WBC concentrations may indicate that internal parasite load was depressed. Further exploration is needed to determine the anthelmintic properties and the biological processes by which CT enhances the response of the host to the nematode. It can be hypothesized that the improved ability of the host to tolerate the negative effects of the parasite, or host resilience, and to respond to the parasite by resistance, might result from feed supplementation (Miller and Horohov, 2006; Hoste and Torres-Acosta, 2011). As such, it is possible that an enhanced immune response or resistance could be mediated by improved protein availability (Heckendorn et al., 2007). The ability of CT to bind proteins and increase an animals nutritional plane, could thereby increase the animals ability to fight GIN (Hoste et al., 2006). Key characteristics of CT that are most important to antiparasitic activity need to be elucidated.

Conclusion

Pinot Noir may be an effective organic and sustainable strategy for controlling nematodes and increasing performance in lambs. Use of Pinot Noir may be desirable because it is a sustainable resource, it is an easily accessible source of condensed tannins, and as a liquid it is simple to administer. The use of Pinot Noir could be applied by organic producers, thereby improving profitability of organic, small-ruminant production. However, additional research is needed to determine the extent of immunological response that may be observed by using phytochemicals in ruminant animals

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Factors Affecting Meat Goat Prices in San Angelo, Texas[1]

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Summary

The objective of this study was to estimate factors affecting auction prices of kid goats at San Angelo, Texas from 2010 to 2015. Transaction records of 395,009 goat kids sold in 38,862 lots were analyzed with a hedonic-price model that included fixed effects for year and month of sale, weight class, and the size of the lot, and random effects for week of sale, nested within year, and residual. From 2010 to 2015 the Texas-goat population decreased, sales volume decreased, and prices increased. The least squares means price estimates per hundredweight were \$150.23 ± \$2.41 in 2010 and \$251.50 ± \$2.38 in 2015. Prices were highest in the first three months of the year, \$207.82 ± \$1.99 per hundredweight and \$38.96 ± \$2.78 per hundredweight greater ($P < 0.01$) than prices in the months of July, August, and September, which had the lowest prices of the year, \$168.86 ± \$1.94 per hundredweight. The highest unit price received occurred in the 50 to 59 pound weight class (\$197.95 ± \$1.00 per hundredweight) and was significantly greater than prices for all other weight classes ($P < 0.01$). Lots that included 35 or more kids, received a \$9.96 ± \$0.47 per hundredweight greater price ($P < 0.01$) than lots that sold in lots of 1 or 2 kids (\$191.76 ± \$1.00 vs \$181.79 ± \$1.08) Significant differences in prices can be captured by producers who market kids early in the year and within the highest priced weight range and in larger lots.

Key Words: Meat Goats, Auction Prices, Texas, Seasonality, Non-Traditional Markets, Hedonics

Introduction

The sheer size of Texas (268,580 square miles) allows for a very large diversity of ecoregions from east to west, as well as north to south. The ability of goats to adapt to this diversity has allowed Texas to be the largest meat-goat producing state in the United States, eclipsing the production of the next ten states combined (NASS, 2016). This adaptability also allows goats to be found in measurable quantities in nearly every state because they are potentially economically viable in many environments.

As a multi-purpose animal, goats are one of the oldest domesticated species, providing meat, milk, fiber and leather for centuries. Goat production in Texas also has a long history, likely introduced to North America and present day Texas by Spanish explorers in the 16th century (Shelton, 1978). Today, in addition to being a primary economic engine in the form of meat and fiber production on many Texas ranches, goats have been used in concert with other ruminants for a variety of ground cover/brush control strategies. Goats are often used to utilize lower quality forage/browse that cattle will not consume, increasing the production efficiency of a ranch. Goats can also be used to improve pasture/rangelands by consuming encroaching woody species and various noxious weeds, making more sunlight, nutrients and water available to the desired grasses.

Goats are increasingly being employed in non-ranch settings for prescribed/targeted ground cover/brush control projects, which can include traditional brush management or may include fire suppression (fuel reduction), right of way clearing or noxious weed control. Ranchers, managers and land owners of all sizes are on a continual quest for a production system ideally suited for their individual mix of resources (land, labor and capital). Both large- and small-acreage operations may look at meat goats as the primary revenue generator or to complement or supplement other livestock or wildlife operations. Goats can utilize a wide variety of forage and can negotiate terrain that would limit other livestock species. Meat-goat production generally requires less physical infrastructure on a ranch, and not having to gather for shearing reduces required labor relative to wool/lamb production. Meat goats also have relatively high reproduction rates.

Texas is by far the largest meat-goat producing state in the United States, with 37 percent of the nation's meat-goat inventory (Figure 1). Texas meat-goat production exceeds $100 million in annual sales (Figure 2) (Salinas and Robinson, 2015, 2016) providing an important source of revenue for an estimated 25,000 operators (NASS, 2012). As the largest goat auction in the United States, the San Angelo, Texas market is of great interest to goat producers across the entire United States. Many goat producers sell their animals at livestock auctions and derive much of their market information from auction market summaries. If producers are more aware of what factors affect the prices paid for goats, then it will enable them to make more profitable marketing decisions.

Slaughter/Kid Goat Market

By all accounts, U.S. meat-goat production is driven by ethnic consumer demand (Glimp, 1995; APHIS, 2004; Spencer, 2008; Ajuzie, 2009, Gillespie et al., 2014). While it is widely accepted

Figure 1. U.S. and Texas Meat and Other Goat Inventory; 2007-2016.

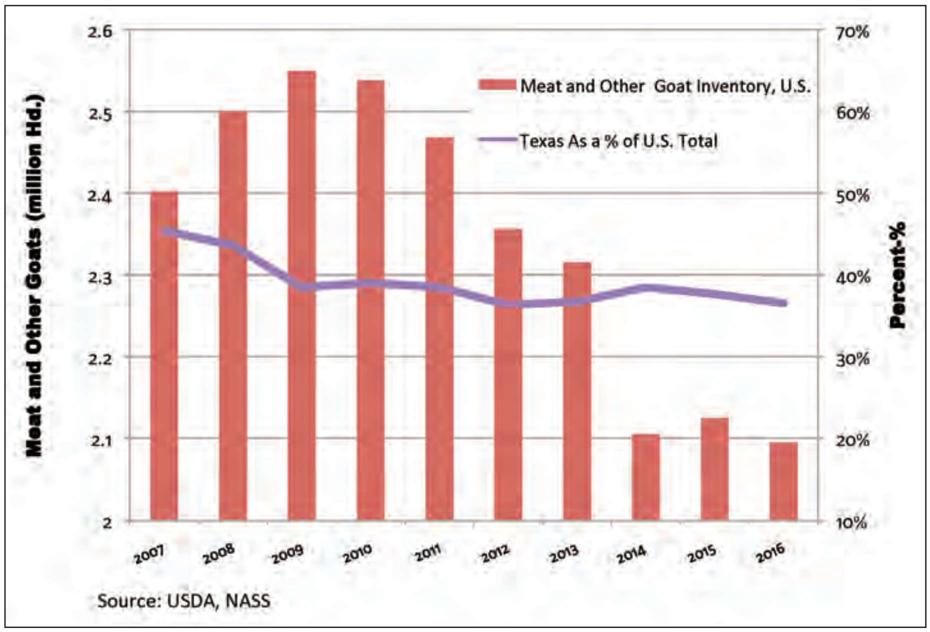
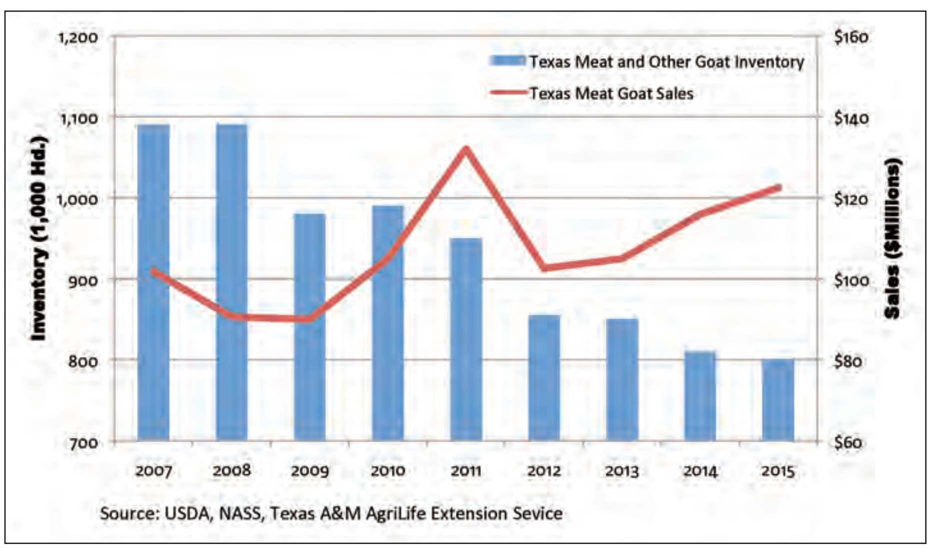


Figure 2. Texas Meat Goat Inventory and Estimated Annual Sales; 2007-2015.



that total goat inventory estimates are low, the reported Meat and Other Goat inventory for both the United States and within Texas are on the decline. Drought and other environmental conditions may be responsible for some of the decrease, though some of the reduction in goat numbers may be attributed to increased interest in several breeds of hair sheep.

The market channels for Texas meat goats are very similar to the market channels for hair sheep, as described by Waldron et al. (2016). The final slaughter weight of marketed kids is largely determined by the initial producer. The kids are either sold at or within a week or two after weaning, or are allowed to continue to gain a limited amount of weight after weaning on pasture and may receive some supplemental feeding. Kid goats are not typically purchased with the intent of being placed into confined animal feeding operations (feedlots or finishing facilities).

The goat market also resembles what is referred to as the "non-traditional" lamb market that 1. typically does not send animals to a feedlot (finishing facility), 2. does not have large, centralized slaughter facilities but rather depends on large numbers of meat markets, small processors and other resellers located near population centers and larger ethnic communities, and 3. does not receive some of the formal USDA market reporting. Though various forms of "direct to consumer" market channels exist, a large majority of kids move through the livestock auctions, where buyers at these auctions are able to source a variety of goats of different size (weight), age and sex as demanded by non-traditional consumers (Gillespie et al., 2014). These non-traditional markets typically demand whole carcasses or portions of carcasses rather than individual cuts. Texas goat producers are fortunate to have multiple livestock auctions across the state that have weekly goat sales.

Little formal price analysis has been directed towards the U.S. meat-goat market. Seasonal variation in kid-goat prices at auction was described by Pinkerton (2010), who used reported ranges from USDA market news reports from 2004 through 2007. Gillespie et al. (2015), estimated price differentials for meat-goat-selection class based on weight, weekly market volume, state where market was located and week of the sale. The present study differs from previous work in that raw auction data is being analyzed before extraneous and possibly subjective classification or aggregation of sales data takes place.

The objective of this study is to estimate factors affecting prices paid for meat-goat kids at the San Angelo auction from 2010 to 2015.

Materials & Methods

Attempting to estimate the factors affecting prices paid for kid goats in San Angelo implies that differences in the observed characteristics of these kid goats are responsible for any price differences (Lancaster, 1966; Rosen, 1974). Goat transaction records from the weekly sales at San Angelo, Texas from 2010 through 2015 were obtained from Producers' Livestock Auction. The transaction records included number of head sold in the lot, price, total weight of the lot, and codes to describe the lot. A lot is defined as an animal or a group of animals sold in a single transaction. The price was typically expressed as dollars per hundredweight ($/cwt). Because prices are reported in dollars per hundredweight, this paper uses pounds as the weight unit instead of kilograms. Some lots were priced by the head. Codes were used to distinguish among different classes of goats. There were 115,133 lots coded as goats over the six-year period. There were 48,401 lots coded as kid goats. Approximately 1 percent of the kid lots were coded as Angora goats, which were excluded from further analysis. Angora was the only breed code used in the data file. Nearly all other goats in this auction were Boer, Spanish, or crosses of those breeds. No other differentiation was available from these livestock auction records.

Sellers bring their animals to the sale facility and the auction staff will typically sort a seller's animals into uniform groups or lots. Order buyers like to buy groups of animals that are mostly similar to each other, as that makes meeting the preferences of their intended market easier. Similarly, auction staff want to showcase livestock to potential buyers in the best light possible to generate maximum bid prices for their livestock selling customers. Auction personnel adhere to the premise that an entire lot of animals will be valued based on the least valuable animal in the group. If a seller delivers a group of 50 animals, they may sell as one lot, or be sorted into several lots based on weight, conformation, color or numerous other subjective criteria. Some of these lots (approximately 10 percent) were priced by the head instead of dollars per hundredweight. Lots that were priced by the head typically included those where the animals were atypically small or young. The mean weight of goat kid lots sold by the head was 32 pounds compared to the mean weight of 56 pounds for kids sold by dollars per hundredweight. A dollar per hundredweight price was calculated for the lots that were sold by the head. The calculated dollars per hundredweight mean for lots sold by the head was $108 compared to the mean of other kid lots of $170. A small number of lots were sold by the head because of their value as potential breeding stock. All lots that were priced by the head were excluded from further analysis.

After these initial exclusions, 43,001 lots of kids remained that were sold by dollars per hundredweight. The distribution across years is shown in Table 1. Table 2 shows the distribution

Table 1. Lots sold, kids sold, number of head per lot, average weight by year for kid goats in San Angelo, TX; 2010-2015.

Year	Lots	Kids	Head/lot	Wt, lbs
2010	7,271	81,259	11.2	56.2
2011	8,148	86,446	10.6	52.6
2012	6,408	59,871	9.3	56.8
2013	6,632	64,178	9.7	56.2
2014	7,438	63,912	8.6	58.0
2015	7,104	61,682	8.7	55.5
Total	43,001	417,348	9.7	55.8

Table 2. Distribution of lots and kids by weight class for kid goats in San Angelo, TX; 2010-2015.

Wt Class, lbs	Number of lots	% of lots	Number of kids	% of kids
< 20	11	0.03	99	0.02
20 - < 30	790	1.84	7,099	1.70
30 - < 40	4,844	11.26	46,461	11.13
40 - < 50	9,957	23.16	103,312	24.75
50 - < 60	11,225	26.10	127,882	30.64
60 - < 70	8,323	19.36	84,556	20.26
70 - < 80	4,513	10.50	32,798	7.86
80 - < 90	2,024	4.71	10,871	2.60
90 < 100	834	1.94	3,023	0.72
100 - < 110	310	0.72	876	0.21
110 - < 120	106	0.25	243	0.06
120 - < 130	37	0.09	86	0.02
130 - < 140	15	0.03	27	0.01
140 - < 150	7	0.02	10	< 0.01
> 150	5	0.01	5	< 0.01
	43,001	100.00	417,348	100.00

across weight classes.

The wide range of kid goat weights in the data set represents different segments of the kid goat market. Kids with low weights may be those that were early weaned, or orphaned, or were small for some other reason. Kids with high weights have likely been on feed after being weaned. In order to have a data set that is representative of the target for this study (goat producers who sell kids within fourteen days of weaning), all lots with an average weight less than 30 pounds or greater than 80 pounds were excluded. Kid goats weighing less than 30 pounds or greater than 80 pounds are atypical for the type of production system used by the target goat producers. Lots with an average weight less than 30 pounds included less than 2 percent of the kid lots and less than 2 percent of the kids. Lots with an average weight of more than 80 pounds included less than 8 percent of the kid lots and less than 4 percent of the kids.

After the weight restriction was applied, 38,862 lots with a total of 395,009 kids remained in the data set. The distribution of goats across 10-pound weight classes in this edited data set is shown in Table 3. The weight class that included kids from 30 pounds to less than 40 pounds was designated as weight class 3, from 40 pounds to less than 50 pounds, was designated as weight class 4, and so on, up through 70 pounds to less than 80 pounds designated as weight class 7.

Table 3. Distribution of kid goat sales by weight class in San Angelo, TX; 2010-2015.

Class	lbs	Lots	Lots, %	Kids	Kids, %	Kids/lot
3	30 - < 40	4,844	12.5	46,461	11.8	9.6
4	40 - < 50	9,957	25.6	103,312	26.2	10.4
5	50 - < 60	11,225	28.9	127,882	32.4	11.4
6	60 - < 70	8,323	21.4	84,556	21.4	10.2
7	70 - < 80	4,513	11.6	32,798	8.3	7.3
Total		38,862	100.0	395,009	100.0	10.4

Table 4. Distribution of kid goat sales by month in San Angelo, TX; 2010-2015.

Month	Lots	% of lots	Kids	% of kids	Kids/lot	Weight
1	2,110	5.43	18,802	4.76	8.9	55.3
2	1,505	3.87	15,154	3.84	10.1	54.1
3	2,828	7.28	27,105	6.86	9.6	52.0
4	2,749	7.07	30,193	7.64	11.0	52.3
5	3,690	9.50	41,338	10.47	11.2	52.7
6	4,429	11.40	44,864	11.36	10.1	53.3
7	3,863	9.94	38,091	9.64	9.9	53.8
8	4,399	11.32	42,843	10.85	9.7	53.1
9	4,396	11.31	42,078	10.65	9.6	53.9
10	3,634	9.35	40,485	10.25	11.1	54.2
11	2,706	6.96	28,684	7.26	10.6	54.8
12	2,553	6.57	25,372	6.42	9.9	54.2
All months	38,862	100.0	395,009	100.0	10.2	53.5

There are substantial differences in numbers of goats coming to market in different months of the year (Table 4). The months with the lowest number of kids sold within the 30 to 80 pound range were January, with an average of 3,134 kids sold per year, and February, with 2,526 kids sold per year. All other months had average sales from 4,229 to 7,478 kids per month.

The number of head sold in each lot varied from 1 to 607. The mean number of head per lot was 9.7 head for all kid lots and 10.2 head in the weight restricted data set (Table 1 and Table 4). The median of the distribution of kid lots was 5 head. Number of head in each lot was assigned to lot size categories as follows: A) 1 to 2 head, B) 3 to 5 head, C) 6 to 12 head, D) 13 to 34 head, and E) 35 or more head. Table 5 provides information about the distribution of number of head per lot sold. The lot size categories were established to allocate approximately equal percentages of lots to each of the first three categories. The lots that contained 13 or more goats were arbitrarily split at 13 to 34 and 35 and above. While a relatively small per-

Table 5. Distribution of kid goat sales by lot size in San Angelo, TX; 2010-2015.

Head in Lot	Lots	Lots, %	Kids	Kids, %
1 - 2	11,626	29.9	16,699	4.2
3 - 5	10,279	26.5	39,951	10.1
6 - 12	9,072	23.3	74,846	19.0
13 - 34	5,518	14.2	110,784	28.1
35 +	2,367	6.1	152,729	38.7
Total	38,862	100.0	395,009	100.0

centage of lots (6.1 percent) fall into the 35+ head category, this represents a significant percentage of the kids (38.7 percent).

Statistical Analysis

Kid prices, in dollars per hundredweight, were analyzed with SAS PROC MIXED using a mixed linear model or hedonic price model (SAS, 2011; Cary, N.C.). The model used for analysis included fixed effects for year (2010 to 2015), month, weight class (five 10-pound classes), lot size (A: 1 to 2 head, B: 3 to 5 head, C: 6 to 12 head, D: 13 to 34 head, and E: 35+ head), and random effects for sale day nested within month, and residual. The weight statement of PROC MIXED was used to weight observations by number of head in a lot. The LSMEANS statement of PROC MIXED was used to produce estimates and standard errors of least squares means of fixed effects. The ESTIMATE statement of PROC MIXED was used to produce estimates and standard errors of differences between least squares means.

Results and Discussion

From January of 2011 to January of 2012, Texas meat and other goat population decreased by 12 percent (NASS, 2012), primarily because of drought in 2011 over much of the goat producing regions of Texas. The lower weight of kids sold (Table 1) in 2011 was another indicator of the severity of the 2011 drought. The number of kids sold through this auction in 2012 decreased by 29 percent from the 2011 level (Table 1). The total number of kids sold the following year increased, but not to the levels of 2010 and 2011.

The trend from 2010 to 2015 has been that of unevenly increasing prices (Figure 3 and Figure 4). Prices in 2010 were 20.13±3.38 dollars per hundredweight lower than 2011 ($P < 0.01$). There were no significant differences among the least squares means estimate for 2011, 2012, and 2013 ($P > 0.05$). Prices paid in 2014 were 41.65 ± 2.82 dollars per hundredweight greater than the average of the estimates for 2011, 2012, and 2013 ($P < 0.01$). Prices paid in 2015 were 37.76 ± 3.42 dollars per hundredweight greater than in 2014 ($P < 0.01$). Figure 4 shows within year variation in the monthly weighted average of selection 1 kids at the San Angelo auction as reported by USDA-AMS (AMS, 2016).

Month was a significant source of variation for price. Kid prices displayed traditional, seasonal-price movement (Figure 5). Producers in the area served by this auction generally avoid kidding in the months of June, July, August, and September because of the seasonality of goat reproduction and because of low

Figure 3. Kid Goat Prices by Year in San Angelo, TX; 2010-2015.

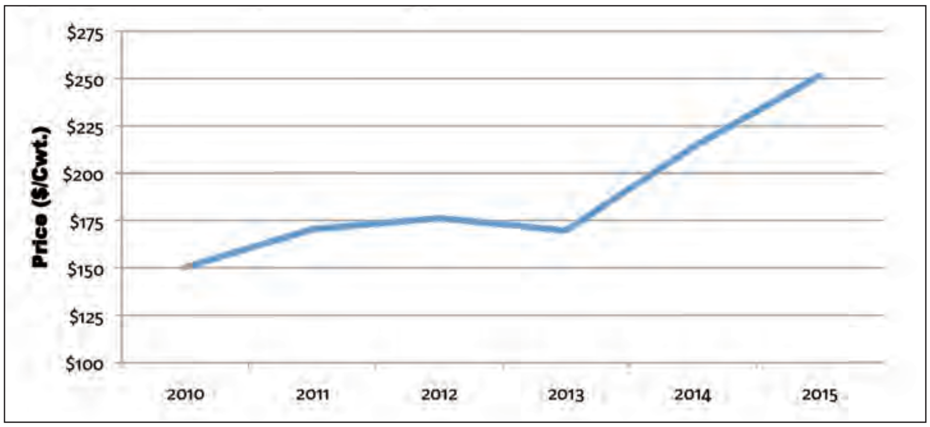


Figure 4. Monthly Weighted Average of Selection 1 Kids in San Angelo, TX; 2010-2015.

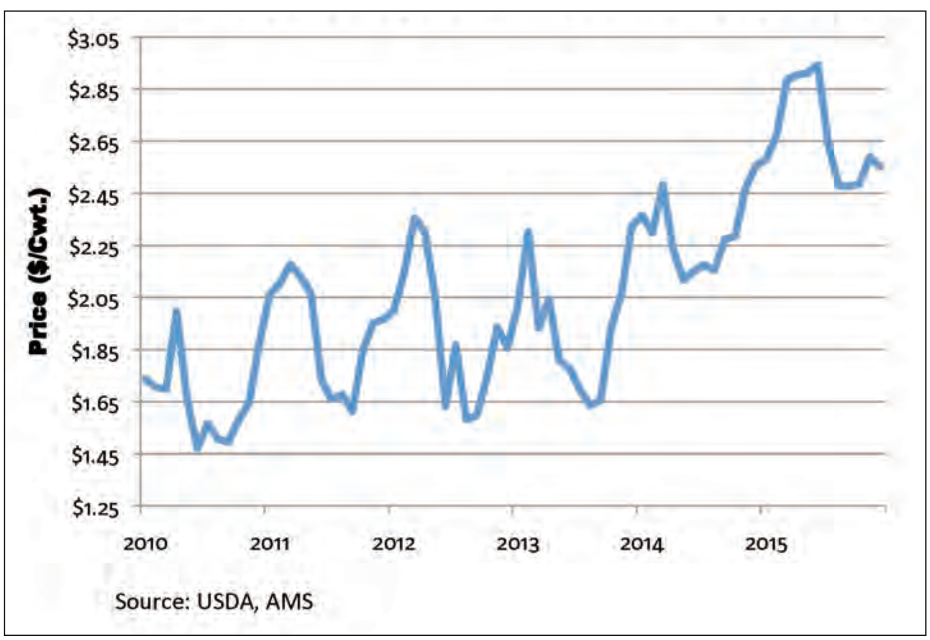


Figure 5. San Angelo Kid Goat Prices and Marketings by Month; 2010-2015.

milk production and low kid growth rates that are a result of high temperatures and decreasing pasture quality. Kids in the 30 to 80 pound weight range are typically 4 to 5 months old. Therefore, there are relatively few kids available to sell from December through March (Table 4). The highest prices were also observed in December through March. Kids sold from December through March received 26.27 ± 2.14 dollars per hundredweight higher prices ($P < 0.01$) than those sold in the remainder of the year. Prices were 38.96 ± 2.78 dollars per hundredweight greater ($P < 0.01$) in the first three months of the year than the three months (July-September) with the lowest prices, (207.82 ± 1.99 vs. 168.86 ± 1.94 dollars per hundredweight). The months with the highest number of kids sold were May through October. May through October were also the months with the lowest prices. Figure 5 concisely illustrates the inverse relationship between the average number of head sold in a month and the price received for kid goats that month. Similar patterns were evident in 2004 through 2007, but at lower price levels (Pinkerton, 2010).

There are opportunities to sell kids at higher prices during the months with fewer kids sold. However, changing the kidding season to take advantage of selling at a different time of year may increase feeding costs if does are expected to produce adequate milk to sustain normal kid growth during a period of low forage quality and/or availability. Kids could conceivably be held over to sell in the November to March period. The costs of maintaining the animals (feed, pasture, death loss, interest, etc.) will need to be evaluated and compared to the expected difference in price. There also exists the risk that the entire market decreases or the older kids are discounted by buyers. Such a cost-benefit analysis is beyond the scope of this study.

Thirty-three percent of the kids were sold in lots of 12 or fewer head (Table 5). As lot size increased, prices increased (Table 6 and Figure 6). The positive relationship between lot size and price has been well documented for feeder cattle (Faminow and Gum, 1986; Schroeder et al., 1988) and Menzie et al.'s (1972) explanation of minimizing transaction costs remains both plausible and applicable to goat markets. The price differences among the three largest lot sizes were smaller than those between the smaller lot sizes. The difference in price between having 6-12 head per lot versus having 13-34 head per lot was not significant ($P > 0.05$). Kids are sold in small lots when a producer delivers a small number of animals or when a producer delivers a non-uniform group of kids and the auction staff sort them into lots of more uniform kids. The decreasing premium for larger lots reflects the heterogeneous nature of the non-traditional goat market. Buyers responsible for supplying goats for these non-tradi-

Table 5. Distribution of kid goat sales by lot size in San Angelo, TX; 2010-2015.

Head in Lot	Lots	Lots, %	Kids	Kids, %
1 - 2	11,626	29.9	16,699	4.2
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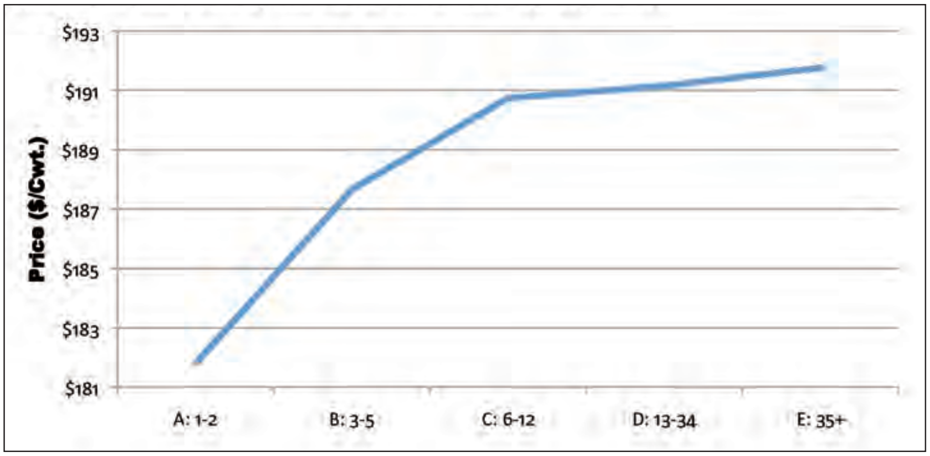
35 +	2,367	6.1	152,729	38.7
Total	38,862	100.0	395,009	100.0

Table 6. Least Squares Means and standard errors for Model Effects on Goat Price in San Angelo, TX; 2010-2015.

Effect	Estimate
Year	$/cwt
2010	150.23 ± 2.41
2011	170.36 ± 2.38
2012	176.20 ± 2.41
2013	169.69 ± 2.48
2014	213.74 ± 2.46
2015	251.50 ± 2.38
Month	
January	203.12 ± 3.48
February	213.67 ± 3.65
March	206.67 ± 3.21
April	198.38 ± 3.33
May	188.33 ± 3.26
June	175.20 ± 3.32
July	171.16 ± 3.54
August	166.17 ± 3.26
September	169.25 ± 3.26
October	176.75 ± 3.32
November	193.66 ± 3.72
December	201.09 ± 3.82
Lot Size, Head	
1 - 2	181.79 ± 1.08
3 - 5	187.66 ± 1.03
6 - 12	190.74 ± 1.01
13 - 34	191.15 ± 1.00
35 +	191.76 ± 1.00
Weight Class, lbs	
30s	184.00 ± 1.03
40s	193.41 ± 1.01
50s	197.95 ± 1.00
60s	190.94 ± 1.01
70s	176.80 ± 1.04

Figure 6. Kid Goat Prices by Lot Size in San Angelo, TX; 2010-2015.



tional markets are required to buy a variety of goats. This may require kids of different ages, weights or specific gender. Any given load of goats leaving San Angelo is very likely to have goats destined to several buyers or markets. This may have the effect of discouraging buyers from bidding on larger lots.

Estimated coefficients, standard errors and significance values from the mixed model are presented in Table 7. All effects were significant sources of variation for price ($P < .01$).

Prices per hundredweight generally increased to the 50 to 60 pound weight class and then decreased in successively higher weight classes (Table 6 and Figure 7). The market appears to prefer goats in the 50-60 pound class. Several production and consumer factors are likely responsible for this price pattern. The non-traditional market typically uses whole carcasses or portions of carcasses. A larger goat may yield more meat than a consumer wants, or cost more than a consumer wants to pay. The per head price still increases as weight increases, even though the per hundredweight price starts to decrease at weights above 60 pounds. Larger kids may have little potential to be profitable in a feedlot or other weight gain regimens while lighter weight kids may receive bids from buyers looking for animals to slaughter immediately as well as from buyers looking for animals that can be turned back out to pasture, or fed, for a period for additional weight gain. These animals bought for resale may be resold in Texas or may be headed to livestock auctions closer to the final consumer outside of Texas. One factor negatively affecting prices of kids in the two lower weight classes is that those animals are more likely to incur death loss than are the animals in the heavier weight classes. Buyers will factor the higher death loss into their bids.

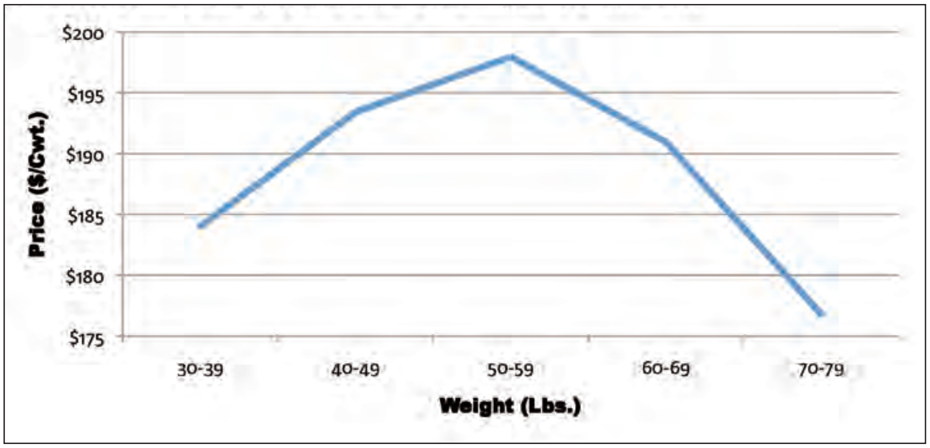
Demand for kids in the various weight classes may vary with different segments of the goat market. Pinkerton (2010) reported higher prices ($/cwt) for kids less than 40 pounds in the New Holland, PA auction, but not in the San Angelo auction in 2005. It is important for producers to know their cost of gain of their kids to evaluate the expected consequences of selling kids at different weights.

The random effect of sale day accounted for 8 percent of the variation after the model was fitted. The variance component estimate for sale week was 273 and the residual variance was 3316. Sale week effects can be from differences in short term supply or demand. Short term supply changes can be due to weather events such as rain in the days

Table 7. Estimates for Goat Price Model.

Variable	Coefficient	Standard Error	*t*-Value	*p*-Value
Intercept	255.30	4.3523	58.66	<0.0001
Saleyear				
2010	-101.27	3.3819	-29.95	<.0001
2011	-81.1414	3.3623	-24.13	<.0001
2012	-75.3060	3.3839	-22.25	<.0001
2013	-81.8068	3.4373	-23.80	<.0001
2014	-37.7637	3.4168	-11.05	<.0001
Month				
January	2.0216	5.1649	0.39	0.6958
February	12.5724	5.2801	2.38	0.0180
March	5.5750	4.9842	1.12	0.2643
April	-2.7139	5.0646	-0.54	0.5925
May	-12.7664	5.0195	-2.54	0.0115
June	-25.8923	5.0590	-5.12	<.0001
July	-29.9338	5.2052	-5.75	<.0001
August	-34.9286	5.0184	-6.96	<.0001
September	-31.8467	5.0168	-6.35	<.0001
October	-24.3460	5.0609	-4.81	<.0001
November	-7.4331	5.3290	-1.39	0.1642
Lotsize				
A	-9.9648	0.4746	-21.00	<.0001
B	-4.0990	0.3305	-12.40	<.0001
C	-1.0134	0.2633	-3.85	0.0001
D	-0.6020	0.2334	-2.58	0.0099
Wtclass				
3	7.1947	0.4281	16.81	<.0001
4	16.6046	0.3742	44.37	<.0001
5	21.1445	0.3637	58.14	<.0001
6	14.1327	0.3808	37.11	<.0001

Figure 7. Kid Goat Prices by Weight Class in San Angelo, TX; 2010-2015.



prior to the sale, which can result in fewer kids brought to market. Short-term-demand changes may be due to holidays, which are associated with lamb consumption. An analysis of the sale-week effects is needed, but is beyond the scope of this paper.

Conclusions

The analysis of kid-goat prices at the largest goat auction in the United States was initiated to provide goat producers more complete information on the factors affecting prices. The size of the Texas goat industry and the visibility of the San Angelo market to producers in Texas and the rest of the nation suggest that better market information could impact a large portion of the U.S. goat industry.

The highest prices paid were for goats in the 50- to 60-pound weight class. Up to that point, producers can increase the gross revenue per kid by increasing their weight and by receiving the greater price per hundredweight. Past sixty pounds producers can only increase their gross revenue per kid, through increased weight. Individual producers will need to incorporate a cost of production analysis to more closely identify optimal market weights.

The market is also making clear its preference for goats in the 50- to 60-pound weight class. Again, the non-traditional market for goats prefers whole carcasses or large portions of carcasses and goats above 60 pounds may not be as desirable for that market.

Increased lot size generally translates to higher realized bid prices at auction. Additional market channel research is necessary to identify the factors driving this response. Producer management will be key to increasing overall flock quality (sire and dam selection and breeding management) to limit sorting at the auction market. Small acreage producers may not have enough nannies to produce 6 to 12 uniform kids to market at one time, and as a result, will not be able to realize any large lot premium.

The San Angelo goat market displays a very strong seasonal pattern in both the sales volume and prices received for goats. Under proper management, smaller operations may be able to breed and kid a flock as to have marketable kids in periods of higher prices. This will be more difficult for larger commercially scaled operations that kid on the open range. Again, a careful and thorough evaluation should be conducted before any changes to a production system are made.

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Performance of Boer-Spanish and Spanish Does in Texas: *Kid Production and Doe Stayability*[1]

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Summary

Data from 271 Boer-Spanish and Spanish does and their 1,936 kids obtained between 1995 and 2004 in the Edwards Plateau region of West Texas were examined to compare Boer-Spanish and Spanish does for kid production and stayability. The does were progeny of 24 sires, and their kids were progeny of 39 sires. Goats were maintained on native pastures for most of the year and were managed in an annual kidding system. Kids from Spanish and Boer-Spanish does had similar birth weights (3.19 kg ± 0.05 kg), 90-d weaning weights (16.9 kg ± 0.8 kg), and preweaning ADG (151 g ± 3 g). There were no significant differences between Boer-Spanish and Spanish does for litter weight at birth (5.59 kg ± 0.13 kg vs. 5.36 kg ± 0.14 kg, $P = 0.12$) or at weaning (23.33 kg ± 0.81 kg vs. 23.86 ± 0.91 kg, $P = 0.57$). Kid birth weight, weaning weight, and preweaning ADG generally increased with age of dam. Litter weight at birth and at weaning increased ($P < 0.05$)with age of dam. Stayability of Boer-Spanish does tended to be greater than that of Spanish does at 6 years of age (65 percent ± 4 percent vs. 54 percent ± 5 percent $P = 0.07$) and similar at all other ages ($P > 0.2$). No significant breed differences were observed for doe reproduction and kid growth through weaning from Spanish and Boer-Spanish goats in Texas.

Key Words: Boer-Spanish Goat, Spanish Goat, Stayability

Introduction

Goats are used for meat production around the world. In Texas, the primary breed of goat used for meat production was Spanish until the introduction of Boer from South Africa in the mid-1990s. The term 'Spanish goat' has been used in the southwestern United States to refer to a diverse population of goats used for meat production that are not Angora, Boer, or dairy breeds (Shelton, 1978). Performance of Spanish goats in Texas was reported by Bogui (1986). The improved Boer goat of South Africa is known for its large mature size, muscularity, growth rate, and prolificacy (Erasmus, 2000; Greyling, 2000; Malan, 2000). The number of Boer goats raised in the United States increased rapidly in the years following the first imports. Few studies have been done that provide a direct comparison of performance of Boer vs alternative breeds. Boer does were reported to be heavier than Spanish does in Tennessee (Browning et al., 2011), and Boer-Spanish does were reported to be heavier than Spanish does in Texas (Rhone et al., 2013). In Tennessee, Boer does had lower fertility, similar number of kids born, and lower number of kids weaned compared to Spanish does (Browning et al., 2011). Rhone et al., (2013) reported that Boer-Spanish does had greater fertility, greater number of kids born, and similar number of kids weaned compared to Spanish does in Texas. Boer does had lower survival than Spanish does in Tennessee (Pellerin and Browning, 2012). Environmental conditions may impact performance and length of productive life, especially in systems where the animals are managed in an extensive environment. Crossbred animals are sometimes used to take advantage of heterosis.

There is a need to measure kid production and stayability in a variety of environments and management systems in the United States. The objectives of this study were to estimate performance differences between Boer-Spanish and Spanish does for kid production measured by kid-birth weights, weaning weights, total-litter weight at birth and weaning, and doe stayability in extensive production conditions in West Texas.

Materials & Methods

The data for this study were collected from 1995 to 2004 on does born in 1994 and 1995 at the Winters Ranch located in McCulloch County, Texas (latitude: 31°5' N, longitude: 99° 22' W, mean-annual precipitation: 700 mm). Does were progeny of Spanish dams mated to either Boer or Spanish bucks.

In 1999, the goats were transferred to the Hill Ranch located in Edwards County, Texas (latitude 30 °15' N, longitude 100° 33' W, mean-annual precipitation: 580 mm). Records were obtained from 271 (152 Boer-Spanish, 119 Spanish) does sired by 24 (16 Boer, 8 Spanish) bucks. These does were bred in single-sire groups in an annual-kidding management system. Thirty-nine Boer (n=15) and Boer-cross (n=24) sires were used to produce 1,936 kids over the course of the study (Table 1). Does were randomly assigned to single-sire breeding pastures. Each breeding group had representative samples of Boer-Spanish and Spanish does. All procedures involving animals were approved by the Texas A&M University Institutional Agricultural Animal Care and Use Committee under protocols 4-111 and 2000-157.

The breeding-herd does were maintained on native pastures for most of the year. Vegetation was characterized by dense, scattered, live-oak (*Quercus virginiana Mill.*) mottes with grass interspaces. The midgrass component of the grass interspaces was dominated by sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.] and Wright's threeawn (*Aristida wrightii* Nash). Other important midgrasses included fall witchgrass *[Leptoloma cognatum* (Schult.) Chase], Texas wintergrass (*Stipa leucotricha* Trin. & Rupr.), and silver bluestem [*othriochloa saccharoides* (Sw.) Rydb.]. Short grasses were predominantly common curly-mesquite [*Hilaria belangeri* (Steud.) Nash] and red grama (*Bouteloua trifida* Thurb.). Honey mesquite (*Prosopis glandulosa* Torr.), Ashe's juniper, and redberry juniper were prominent woody species that were scattered through the grass interspaces in a savannalike fashion. Prickly pear (*Opuntia spp*. Mill.) was also abundant. Numerous species of annual forbs were also present when adequate soil moisture was available during the fall and early winter.

The start of the breeding season varied from 23 May to 5 October from 1995 to 2004. Length of breeding season varied over the years. A late season 'cleanup' mating was used to give all does that failed to conceive during the original breeding season an opportunity to produce kids. Therefore, kidding occurred from October to May. Prior to kidding, does were taken from pasture and placed in small pens to facilitate collection of kidding records. Kids were ear tagged and weighed within 1 d of birth. Does and kids were returned to pasture when kids were from 3 d old to 14 d old. Kids were weaned at an average age of 93 d. The age at weaning ranged from 37 d to 167 d. Date of weaning was chosen based on pasture conditions and the health of the kids. There were from two to five weaning dates within a year.

Does were not culled based on production. Does were only removed from the project if they had a health problem, such as mastitis, that would prevent them from raising kids. Additional details on the foundation females and

Table 1. Numbers of does kidding and kids born by age and genotype of dam.

	Number of does kidding		Number of kids born	
Age, yr	Spanish	Boer-Spanish	Spanish	Boer-Spanish
2	92	126	139	192
3	98	124	142	189
4	77	112	107	165
5	76	102	108	167
6	56	81	95	151
7	46	67	78	128
8	30	54	51	105
9	24	40	44	75
All	499	706	764	1,172

herd management were previously presented (Rhone et al., 2013).

Data Edits and Statistical Analyses

To account for changes in environment within a year, kids were assigned to contemporary groups according to kidding dates. A new contemporary group was created when there was a 10 d or greater interval between births. Additionally, if there were no breaks of 10 or more d between kidding dates, the maximum range of kidding dates for a contemporary group was 45 d (i.e. if the kidding dates for the year spanned more than 45 days, a new contemporary group was created so that the maximum range of dates for a contemporary group was 45 d).

Weaning weights of kids that were less than 60 d old or more than 130 d old at weaning were excluded from the analysis. Weaning weights were adjusted to 90 d prior to analysis. Preweaning average daily gain (ADG) was calculated as the difference between weaning weight and birth weight divided by the age at weaning. The models used to analyze birth weight, weaning weight, and preweaning ADG included fixed effects for breed of sire of the doe, production year, sex of kid, type of birth, age of dam, and contemporary group of the kid nested within year, and random effects for sire of kid, sire of doe nested within breed, and doe nested within sire of doe and breed.

Litter weight at birth was the sum of the birth weights of all kids born to a doe at one kidding. Litter weight at weaning was calculated as the sum of the age-adjusted weaning weights of all kids reared by the doe. Therefore, when a kid did not survive to weaning, its contribution to the litter weight at weaning was zero.

The models for litter weight at birth and weaning included fixed effects for breed of sire of the doe, production year, age of doe, a contemporary group for kidding date nested within year, and random effects for sire of kids, sire of doe nested within breed, and doe nested within sire of doe and breed.

Stayability was defined as a binary trait (present = 1 or absent = 0) at the beginning of each breeding season. The first breeding season for all does started at approximately 18 mo of age, so that the first kidding was when does were near 2 yr of age. Thus, stayability at the 2nd breeding season was the presence of the doe at the beginning of the breeding season, which would result in kidding when the doe was approximately 3 yr of age. Stayability was recorded annually through the start of a doe's 8th breeding season. The 8th breeding season would result in kidding when the doe was approximately 9 yr of age. Reasons that goats left the herd included death, mastitis, or other health problems that prevented them from raising kids. A Chi-square test of reasons for leaving the herd was used to test for a difference between breeds of sire.

The model used to analyze stayability of the doe included fixed effects for breed, and year of birth, and a random effect for sire of the doe nested within breed. Seven analyses were conducted for stayability, for ages 3 through 9 yr.

In all analyses, random effects were assumed to have mean zero and a common variance. Data analyses were done using SAS PROC MIXED (SAS Inst. Inc., Cary, N.C.). Variances for random effects were estimated using restricted maximum likelihood estimation (REML) option.

Results and Discussion

Kid Birth Weight

Birth weights of kids were similar from Boer-Spanish and Spanish does (Table 2). The birth weights of kids from Spanish does (3.19 kg ± 0.05 kg) were higher than that from Spanish does reported by Bogui (1986) of 2.41 kg. Browning and Leite-Browning (2011) reported mean kid birth weights for Boer and Spanish dams of 3.1 kg when kids were sired by Boer, Kiko or Spanish bucks. When kids were sired by Boer bucks, as were most kids in the present study, Browning and Leite-Browning (2011) reported mean-birth weights of 3.3 kg. The U.S. studies that used Boer or Boer-Spanish goats reported birth weights that were lower than the range of 3.5 kg to 4.4 kg observed in Boer herds in South Africa (Van Niekerk and Casey, 1988; Schoeman et al., 1997) and China (Zhang et al., 2009). The mean birth weight differences among studies are likely due to a combination of different environments and/or the sample of the breed.

All other fixed effects in the model were significant sources of variation for birth weight. Male kids were 0.24 kg ± 0.02 kg heavier ($P < 0.05$) at birth than female kids (Table 3). Bogui (1986) reported a 0.21 kg sex difference. Browning and Leite-Browning (2011) reported a 0.34 kg sex difference for birth weight. Zhang et al. (2009) reported that Boer males were 0.4 kg heavier than females at birth.

Kid birth weight decreased ($P < 0.05$) as litter size increased (Table 3). Least squares means for kids born as singles, twins, and triplets were 3.57 kg ± 0.04 kg, 3.18 kg ± 0.04, and 2.81 kg ± 0.05 kg, respectively. The difference in birth weight between twins and singles was 0.39 kg ± 0.03 kg, which is similar to the differences reported by Bogui (1986) 0.42 kg, Browning and Leite-Browning (2011) 0.40 kg, and Zhang et al., (2009) 0.3 kg.

Least squares means for kid birth weight increased ($P < 0.05$) with age of dam up through 8-yr-old dams (Table 4). The pattern of increasing kid weight at birth with dam age was similar to that reported by both Bogui (1986) and Browning and Leite-Browning (2011). Dam body weight at the start of the breeding season also increased with age in the present study (Rhone et al., 2013). Browning et al. (2011) also

Table 2. Least squares means and standard errors of kid production traits.

	Records	Spanish	Boer-Spanish	*P*
Birth weight of kids, kg	1936	3.19 ± 0.05	3.19 ± 0.04	0.96
Preweaning ADG, g	1482	153 ± 3	153 ± 3	0.92
Weaning weight, kg	1482	16.94 ± 0.32	16.98 ± 0.28	0.92
Litter wt at birth, kg	1184	5.36 ± 0.14	5.59 ± 0.13	0.12
Litter wt at weaning, kg	1184	23.86 ± 0.91	23.33 ± 0.81	0.57

Table 3. Least squares means of factors affecting kid weight traits.

	Birth weight, kg	Preweaning ADG, g	Weaning weight, kg
Sex			
Male	3.31 ± 0.04^{a}	163 ± 3^{a}	18.01 ± 0.26
Female	3.07 ± 0.04^{b}	143 ± 3^{b}	15.91 ± 0.26^{b}
Type of birth			
Single	3.57 ± 0.04^{a}	175 ± 3^{a}	19.40 ± 0.28^{a}
Twin	3.18 ± 0.04^{b}	149 ± 3^{b}	16.61 ± 0.25^{b}
Triplet	2.81 ± 0.05^{c}	135 ± 4^{c}	14.87 ± 0.38^{c}

$^{a, b, c}$ Least squares means within a column not sharing a common superscript differ ($P < 0.05$)

Table 4. Least squares means of age of dam effects on kid production.

Age at kidding, yr	Birth wt, kg	Preweaning ADG, g	Weaning wt, kg
2	2.7 ± 0.1^{a}	115 ± 12^{a}	13.1 ± 1.1^{a}
3	2.8 ± 0.1^{a}	127 ± 9^{b}	14.3 ± 0.9^{b}
4	2.9 ± 0.1^{a}	140 ± 7^{c}	15.5 ± 0.7^{c}
5	3.0 ± 0.1^{b}	155 ± 6^{d}	17.1 ± 0.5^{d}
6	3.3 ± 0.1^{c}	168 ± 5^{e}	18.5 ± 0.5^{e}
7	3.4 ± 0.1^{d}	168 ± 7^{e}	18.5 ± 0.6^{e}
8	3.6 ± 0.1^{e}	177 ± 9^{e}	19.5 ± 0.9^{e}
9	3.7 ± 0.2^{e}	172 ±13^{e}	19.0 ± 1.2^{e}

$^{a, b, c, d, e}$ Least squares means within a column not sharing a common superscript differ ($P < 0.05$)

reported increasing dam body weights, recorded at kidding, with age.

Weaning Weight and Pre-Weaning Average Daily Gain

Approximately 9 percent of the kids that were weaned were weaned either earlier than 60 d of age, or later than 130 d of age, and therefore those records were excluded from the analysis. There was not a significant difference between kids of Boer-Spanish and Spanish dams for weaning weight and preweaning ADG (Table 2). The least squares mean 90-d weaning weight of kids in the present study (16.9 kg ± 0.3 kg) was greater than was observed in most other studies that used Boer and Spanish goats. Kids from Boer and Spanish dams in Tennessee had 90-d weaning weights of 13.9 kg (Browning and Leite-Browning, 2011). Bogui (1986) reported 120-d weaning weights of Spanish kids of 17.9 kg. If one assumes linear growth rate from 90 d to 120 d in that study, the 90-d weaning weights would be approximately 14 kg. Boer kids in China had a mean 90-d weaning weight of 15.0 kg (Zhang et al., 2009). Schoeman et al., (1997) reported 100-d weaning weights of 17.8 kg in Boer kids in South Africa, which would be approximately 16.3 kg at 90-d.

All fixed effects, other than breed, were significant sources of variation for kid-weaning weight and ADG. Male kids averaged 18.01 kg ± 0.26 kg for weaning weight and were heavier ($P < 0.05$) than female kids, which averaged 15.91 kg ± 0.26 kg (Table 3). The 2.1 kg ± 0.16 kg difference was smaller than the 2.6 kg difference between male and female kids in Tennessee (Browning and Leite-Browning, 2011). Zhang et al. (2009) reported a 1.4 kg difference in China.

Weaning weights for single kids were 2.79 kg ± 0.19 kg heavier ($P < 0.05$) than that of twins (Table 3). This difference is within the range of estimates from Browning and Leite-Browning (2011) of 2.92 kg and Zhang et al. (2009) of 2.3 kg.

Weaning weights increased as age of dam increased ($P < 0.05$) up through 6 yr of age (Table 4). Differences in weaning weights from does with ages 6 through 9 were not significantly different from zero. Similar patterns were observed in other studies (Zhang et al., 2009; Browning and Leite-Browning, 2011). Erasmus et al. (1985) however reported a decrease in kid production after 4 yr of age in Boer goats in South Africa.

Results of the analysis of preweaning ADG followed the same pattern as weaning weight (Tables 2, 3 and 4). Male kids averaged 163 g ± 3 g ADG and gained more ($P < 0.05$) than female kids, which had an ADG of 143 g ± 3 g. Single kids gained faster than twins, which gained faster than triplets ($P < 0.05$).

Total Litter Weight at Birth and Weaning

Least squares means for Boer-Spanish and Spanish dams' total litter weight at birth and weaning are presented in Table 2. Breed of sire was not a significant source of variation for total litter weight at birth or at weaning. Litter

Table 5. Least squares means of age of dam effects on weight of litter at birth and weaning (90 days).

Age at kidding, yr	Birth wt, kg	Weaning wt, kg
2	2.8 ± 0.5^{a}	7.2 ± 3.3^{a}
3	3.5 ± 0.4^{b}	11.9 ± 2.6^{b}
4	4.1 ± 0.3^{c}	15.8 ± 2.1^{c}
5	4.9 ± 0.3^{d}	21.0 ± 1.7^{d}
6	6.3 ± 0.3^{e}	26.6 ± 1.7^{e}
7	6.9 ± 0.3^{ef}	29.0 ± 2.1^{e}
8	7.6 ± 0.4^{f}	35.9 ± 2.8^{f}
9	7.8 ± 0.6^{f}	41.3 ± 3.9^{g}

$^{a, b, c, d, e, f, g}$ Least squares means within a column not sharing a common superscript differ ($P < 0.05$)

weight at birth and at weaning increased ($P < 0.05$) with age of dam (Table 5). Nine-year-old dams had the highest value for litter weight born and weaned of 7.8 kg ± 0.6 kg and 41.3 kg ± 3.9 kg, respectively. The advantage in litter weight at weaning appears to result from the higher number of kids born and weaned (Rhone et al., 2013) rather than the increased weight of kids because the differences in kid weights were not significantly different among ages 6 to 9 yr.

The litter weight at birth for Spanish does (5.36 kg ± 0.14 kg) was higher than reported by Bogui (1986) of 4.10 kg. Browning et al. (2011) reported that litter weights at birth were not different between Spanish (5.86 kg ± 0.33 kg) and Boer (5.78 kg ± 0.33 kg). However, at weaning, the litter weight produced by Spanish does (26.51 kg ± 1.48 kg) was greater than that of Boer (23.02 kg ± 1.51 kg) in Tennessee (Browning et al., 2011). The mean-litter weight of Spanish dams in the study of Bogui (1986) was 24.76 kg.

Body weights at the start of the breeding season of the Boer-Spanish dams were 3 kg greater than those of the Spanish dams (Rhone et al, 2013). Boer dams were 4.3 kg heavier than Spanish dams in the Tennessee study (Browning et al, 2011).

Stayability

The results for stayability at each age are presented in Table 6. A Chi-square test of reasons for leaving the herd did not show a difference between breeds of sire. The largest breed difference for stayability was at age 6 where the mean stayability of Boer-Spanish does was 65.0 percent ± 4.1 percent compared to 53.6 percent ± 4.5 percent for Spanish does ($P = 0.07$). At all other ages, the higher mean value for stayability of Boer-Spanish does was not significantly different from that of Spanish does. Spanish does had greater stayability than Boer does in Tennessee (Pellerin and Browning, 2012). These apparently contrasting results between the two studies could be due to heterosis, because the Tennessee study used purebred Boer does (no heterosis) and our study used Boer-Spanish does (maximum F1 heterosis). Another difference between the studies is the substantial difference between environments. The location of the Tennessee study has a mean annual precipitation of 1,222 mm and the two locations for the current study had mean annual precipitation of 700 mm and 580 mm. Internal parasites were responsible for 28 percent attrition in Boer does and 10 percent in Spanish does in Tennessee (Browning et al., 2011). The dry climate in Texas resulted in less parasitism in the goats in the present study. Boer goats were developed in South Africa in an area that has an environment that is similar to that of Texas. Another difference between the studies is that stayability, as used by Pellerin and Browning (2012), was evaluated as years in the herd rather than age, as in the current study. Stayability is an economically important trait in goats that affects profitability. However, the heritability of stayability has been reported to be low (10 percent or less) in range-raised sheep (Borg, et al., 2009). Incidence of mastitis, one of the more frequent reasons for does leaving the herd in the present study, has been shown to be heritable (13 percent to 49 percent) in meat sheep (Larsgard and Vaabenoe, 1993).

Kid production, as measured by kid weights at birth and at weaning, was similar for Spanish and Boer-Spanish goats in Texas. However, Boer-Spanish does had greater body weight than Spanish does at mating (Rhone et al., 2013). Boer does also had greater body weight than Spanish does at kidding in Tennessee (Browning et al., 2011). In a study that separated kid growth from maternal environment by removing kids from their dams and raising them on milk replacer and then feeding them on a concentrate diet, Boer-Spanish kids had a greater body weight than Spanish kids at approximately 200 d of age (Luo et al., 2000; Cameron et al., 2001). These results suggest that Boer and Boer-Spanish goats may have a greater direct postweaning-growth rate than Spanish goats. In a meat production enterprise, the importance of postweaning-growth rate is a function of when, relative to weaning, kids are marketed.

Table 6. Least squares means for stayability (percent) of Spanish and Boer-Spanish does in Texas.

Doe age, yr	Spanish	Boer-Spanish	*P*
3	96.0 ± 1.8	96.8 ± 1.7	0.75
4	86.0 ± 3.1	89.9 ± 2.8	0.35
5	66.6 ± 5.9	76.1 ± 5.0	0.23
6	53.6 ± 4.5	65.0 ± 4.1	0.07
7	41.0 ± 5.0	49.3 ± 4.5	0.23
8	34.4 ± 5.3	42.4 ± 4.6	0.26
9	26.2 ± 5.4	33.0 ± 4.6	0.34

Conclusions

The performance differences between Boer-Spanish and Spanish females in the current study are a function of breed substitution and heterosis. Kid production, as measured at kidding and weaning, in a range environment using an annual kidding management system, was similar from Spanish and Boer-Spanish does. Doe stayability was greater for Boer-Spanish does when evaluated at 6 yr of age and no differences were significant at other ages. Under Texas-range conditions, when kids are marketed at or soon after weaning, this study indicates no advantage of Boer-Spanish does over Spanish does when both produce Boer-Spanish cross kids.

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