Foreword

"Thirty years ago an Elmer Kelton article in what was then *West Texas Livestock Weekly* reported fears about the demise of the sheep industry. Numbers were rapidly declining and at the lowest number on record at 39 million head; Texas dropped 13 percent to 4.6 million head; people were going out of the sheep business and ranchers were searching for something to use their semi-desert brush land for; imports were strangling them; Mexico was taking a lot of ewes for slaughter; packers complained because they couldn't get the right kind of lambs, heavyweights being too fat, and lightweights not yielding enough; fat was restricting consumption and dual grading was going to be their salvation" (Livestock Weekly 50(27) July 9, 1998). So, how long can a declining industry survive? The American sheep and goat industry continues to survive not because consumers, or any other group for that matter, have much loyalty to the U.S. products, but rather because sheep and goats are still the most appropriate kind of livestock for utilizing millions of acres of range and pasturelands. Because sheep and goat grazing can have minimal impact, and more often, actually benefit other enterprises, sheep and goats will continue to be raised regardless of market situations.

The decline in sheep and goat numbers is due to a multitude of factors. One of the more obvious reasons is a loss of profit; However, profitability relative to competing enterprises does not provide a complete explanation of the decline in the industry because between 1972 and 1987, sheep were more profitable (or less of a liability) than cow-calf enterprises in 81% of those years. Likewise, the most recent information available for Texas indicates that in 1995 projected net return per animal unit for sheep was -$15.40 compared to -$27.52 for cattle. Of course, it is of little consolation that "if the trends continue, by the year 2035, the beef industry will look a lot like today's sheep industry" (Bill Helming quoted by Rod Smith in Feedstuffs Jan. 1997). There is one area that individual producers have the greatest control of relative to profitability, and that is the cost of production, which is precisely the area addressed by articles in this report. The research reported here incorporates a variety of issues related to efficiency of producing and marketing meat and fiber. Serious consideration should be given as to how these technologies can be used to increase profitability of the sheep and goat industry. Recently, it has been shown that the U.S. sheep industry lags behind other meat industries in this country relative to increasing production efficiencies. Similarly, U.S. investment in and adoption of sheep and goat research lags behind other sheep producing countries such as New Zealand. Because there is an apparent irreversible trend toward global markets, it is imperative that Texas sheep and goat producers use the appropriate technologies to ensure they can compete profitably in the marketplace.

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Lamb and Goat Meat

Explanation of (P > .05)

Dan Waldron

Much of the research in this report has an aim of making a comparison between different animals or animal products (wool and mohair). Some experiments have the objective of comparing different breeds of animals, while some experiments are comparing the same type of animals that are given different treatments. These treatments are often different feed and(or) management. A brief explanation of the implications of the statistical meaning of (P < .05) is given here in order to make this progress report more useful to all readers.

Significant differences when comparing groups or treatments

Several reports will show the differences among groups and include statements such as 'Group A was heavier (P < .05) than Group B' or 'Group A was significantly (P < .05) heavier than Group B' or 'Group A was not significantly (P > .05) heavier than Group B.' The word significantly, as used in this context, refers to the confidence the researcher has in the observed result. The (P < .05) is read: probability less than .05. This indicates that there is less than a 5% probability that the advantage of A over B was not due to the treatment, A vs B, but was due to chance. If P > .05 probability greater than .05, is used, it indicates that there is greater than a 5% chance that the difference between the averages of the two groups is due to chance. In general, a researcher will consider differences between two groups to be not significant if the probability of the difference being due to chance, rather than the treatment used in the experiment, is greater than 10%. The p-value in P < .05, is a measure of the confidence that a researcher has in the result of the experiment. Smaller values indicate a greater confidence.

As a simplified example, assume that a research project was conducted to measure weight gain of two groups of lambs, A and B, in a 30-d period. The average gain of Group A was 14 lb and the average gain of Group B was 12 lb. This would be a significant difference if each of the lambs in Group A gained 14 lb and each of the lambs in Group B gained 12 lb. However, if the Group A lambs' gains ranged from 8 to 20 lb and the Group B lambs ranged from 6 to 18 lb, the difference between the treatments (14 - 12 = 2) might not be significant. Therefore, the variation within a group is considered when determining how much confidence one should have in a difference between groups. A research report may include a statement such as 'The higher average gain of Group A over Group B was not statistically significant.' This could be restated as 'Because the variation of gain within each group of lambs was so high, the fact that the average for Group A was greater than the average for Group B may not be repeated if this experiment were conducted again.'

A group of animals of similar breeding will not all gain the same or have fleeces with the same fiber diameter. This variation among animals has to be taken into account when describing differences seen in research trials. Using the concept of statistical significance is the accepted way to take into account the biological variation. The variation may be due to genetics (unless animals are identical litter mates or clones they will have some differences in their genetic makeup), health, nutrition, behavior, environment, or a combination of these factors.

Accuracy of Central Performance Test Wool Evaluations in Rambouillet Sheep

D.F. Waldron, C.J. Lupton, T.D. Willingham, P.V. Thompson, and F.A. Pfeiffer

ABSTRACT

A progeny test of seventeen centrally tested Rambouillet rams obtained from the Sonora Central Performance Test in 1994 and 1995 was conducted. The postweaning central performance test was 140 d long. Objective traits evaluated on the central test included average daily gain, fleece weight, fleece fiber diameter and staple length. Rams were also given subjective scores for face cover and belly wool. Female progeny records included objective measures of yearling fleece weight, fiber diameter, and staple length and subjective scores of face cover and belly wool. Progeny performance was regressed on sire's central test performance in order to estimate the accuracy of central test records for predicting genetic merit for each trait. Significant relationships were observed between sire's central test evaluation and progeny evaluation for grease and clean fleece weights, fiber diameter, staple length and belly wool score. No significant relationship between sire's face cover score and daughter's face cover was found. However, there was a small range of face cover scores among the sires with progeny. Evaluations of fleece characteristics on a 140-d postweaning central performance test of Rambouillet rams can be used to predict progeny fleece characteristics.

Introduction

Differences in animal performance can be attributed to differences in genetics of the animal or the environment in which performance is measured. If animal performance is to be improved, separation of genetic from environmental differences in performance is essential, because only genetic differences will be passed on to progeny. This is particularly true when comparing performance of animals raised on different ranches. A central performance test of Rambouillet rams has been conducted annually at the Sonora Station since 1948 (Shelton, 1979). A purpose of such a central performance test is to allow for valid comparisons of performance of animals from different ranches. If pretest environment has no effect on ram's performance on central test, then central performance testing will separate genetic differences from environmental differences. Research work conducted during the early years of the Sonora test (Shelton, 1959) showed a positive relationship between central test performance and progeny performance. However, central test practices have changed since the 1950s. Some of the central tests used in the 1959 report were 308 d long. The test has been 140 d long since 1972. The test length was shortened to decrease the cost of testing and to reduce the incidence of overfat rams (Shelton and Lewis, 1986). A study conducted with Suffolk rams from Midwest central performance tests in the 1980s showed no significant relationship between central test performance and progeny performance for post weaning growth rate (Waldron et al., 1990). The central tests in the Midwest were only 63 d long (Waldron et al., 1989). The objective of this study was to estimate the relationship between performance observed during the 140-d central performance test and subsequent progeny performance under commercial conditions. This report gives results on yearling fleeces of female progeny for the first two years of a three year project.

Materials and Methods

Seventeen unrelated rams that completed the Sonora Central Performance Test in either February 1994 or February 1995 were selected for a progeny test. Nine rams were chosen in each of the two years, but one ram chosen in 1995 failed to produce any offspring. Each phase of this project includes obtaining rams from the central performance test, mating them to ewes the next breeding season, evaluating growth rate of progeny as lambs (Waldron et al., 1996), and fleece production and fiber characteristics of daughters at 1 yr and 2 yr of age. The rams were chosen so that a wide range of performance was represented for average daily gain (ADG), clean fleece weight (CFW) and fiber diameter (FD). Details about measurements and scores on the central test were given by Waldron and Lupton (1997). Measures of performance among all rams completing the performance test in 1994 or 1995, and the 17 selected rams are shown in Table 1.

Commercial Rambouillet ewes on the Winters Ranch near Brady, Texas, were assigned at random to sires. Ewes were mated in single sire pastures in September 1994 and September 1995. All lambs were weighed at birth and at weaning. After weaning, ewe lambs were maintained on native pastures and received some

supplemental feed. Ewe lambs were shorn in August at approximately 6 mo old so that the fleeces obtained at 1 yr of age would have the same growth period. No analysis was done on the fleeces shorn at an average age of 6 mo. Prior to shearing at 1 yr of age, ewes were scored for face cover and amount of belly wool, and staple length measurements were taken at the shoulder, side, and thigh. The three staple measurements were averaged for analysis. Yearling ewes were shorn in May. Yearling fleece growth was 281 d and 285 d in 1995 and 1996, respectively. At shearing, fleeces were individually bagged and transported to Texas A&M Wool and Mohair Research Lab for analysis. Data collected included grease fleece weight, lab scoured yield, clean fleece weight and mean fiber diameter.

Grease fleece weight, clean fleece weight, and staple length were adjusted to a 365-d growth period prior to analysis. Grease fleece weight, clean fleece weight, fiber diameter, staple length, face cover score, and belly wool score were analyzed with PROC MIXED (SAS, 1992). The model used for analysis included fixed effects for year and type of birth, covariates for age within year and sire's central test performance, and random effects for sire of the ewe and residual. The partial regression coefficient of progeny performance on sire's performance was used to evaluate the relationship between progeny performance and the sire's central test performance.

Results

The mean performance of progeny is shown in Table 2. The progeny had lighter, finer fleeces with a shorter staple than their sires. However, these differences are due to sex of animal as well as a different environment. The results of the regressions of yearling progeny fleece production, fiber characteristics and scores on sire's central test performance are shown in Table 3.

Fleece weights

The regressions of daughter's yearling fleece weight (grease and clean) on sire's clean fleece weight on central test were significantly different from zero. This indicates that selecting for increased clean fleece weight on central test will result in an increase in grease and clean fleece weights of progeny. A difference of 1 lb of clean fleece weight, between two rams, on the central test would be expected to result in an increase of .19 lb of wool on each yearling daughter. If a ram produces 50 daughters they would be expected to grow a total of 9.5 lb more grease wool in 365 days. The partial regression of .10 (Table 3) for clean fleece weight is very similar to the .11 regression found in an earlier evaluation (Shelton, 1959) of the Sonora Central Performance test.

Fiber diameter

The regression of daughter's yearling side fiber diameter on sire's side fiber diameter on central test was significantly different from zero. This indicates that selection for decreased fiber diameter on central test will result in a decrease in progeny's fiber diameter. The sires' mean FD was approximately 4 microns coarser than the daughters. However, the significant regression coefficient of .24 indicates that the finer-fleeced rams on test produced finer-fleeced daughters. A difference of 1 micron on central test is expected to result in a difference of .24 microns in yearling ewes raised under typical commercial conditions.

Staple length

Regression of daughter's yearling staple length on sire's staple length on central test was significantly different from zero. Selection for increased staple length on central test will result in a correlated increase in staple length of progeny. Shelton (1959) reported a regression of .24 for staple length in the 1950s which is very similar to the value of .28 (Table 3) found in this experiment.

Face cover score

The regression of daughter's face cover score on sire's face cover score on central test was not significantly different from zero. However, there was little variation among selected sires (Table 1) for face cover score (0.8 to 1.7), and none of the selected sires had objectionable face cover. Therefore, because of the small amount of variation among selected sires, a nonsignificant relationship is not unexpected.

Belly wool score

The regression of daughter's belly wool score on sire's belly wool score on central test was significantly different from zero. Selection for decreased belly wool on central test will result in a reduction of belly wool scores of yearling daughters. The subjective scores used to evaluate amount of belly wool appear to adequately assess a heritable trait.

Table 1. Mean, minimum and maximum of wool traits on central test by year

	1993-1994 Central Ram Test				1994-1995 Central Ram Test			
Trait	No *	Mean	Min.	Max.	No *	Mean	Min.	Max.
Clean fleece wt., lb yr	N = 203	11.5	6.3	19.2	N = 169	11.6	6.2	19.5
	n = 9	12.2	9.2	15.3	N = 8	5.1	4.1	6.2
Staple length, in yr	N = 203	4.7	2.9	6.1	N = 169	5.1	3.6	6.6
	n = 9	4.9	4.5	5.6	N = 8	5.1	4.1	6.2
Fiber diameter, µm	N = 203	23.7	17.8	29.6	N = 169	23.3	19.2	27.5
	n = 9	23.8	20.2	27.0	N = 8	23.4	20.7	27.5
Face score	N = 203	1.1	.4	3.5	N = 169	1.1	.5	3.9
	n = 9	.9	.8	1.1	N = 8	1.2	1.0	1.7
Belly wool score	N = 203	2.2	1.1	3.5	N = 169	1.8	1.1	3.5
	N = 9	2.1	1.9	2.6	N = 8	2.2	1.3	3.5

* N is the number of rams finishing the central performance test within that year, n is the number of rams chosen for progeny test each year.

Table 2. Mean, standard deviation(SD), minimum and maximum values of wool traits of yearling progeny sired by centrally tested rams

Trait	No.	Mean	SD	Min.	Max.
Grease fleece wt., lb yr	151	9.6	1.5	6.4	13.7
Clean fleece wt., lb yr	151	5.5	.9	3.4	8.3
Fiber diameter, µm	152	19.7	1.4	16.6	23.7
Staple length, in yr	152	4.5	.6	3.2	6.4
Face score	152	1.7	.7	.5	4.0
Belly wool score	152	1.5	.7	1.0	4.0

Table 3. Partial regression coefficients (b) ± standard error (SE) of progeny performance on sire's central test performance

Progeny trait	N	b ± SE	P
Grease fleece wt., lb yr	151	.19 ± .05	.01
Clean fleece wt., lb yr	151	.10 ± .03	.01
Fiber diameter, µm	152	.24 ± .05	.01
Staple length, in yr	152	.28 ± .08	.01
Face score	152	.29 ± .43	.5
Belly wool score	152	.32 ± .13	.05

Discussion

The relationship between Sonora central test performance and progeny performance for the traits discussed is generally strong. Sire's central test performance was a good indicator of daughter's yearling fleece production and characteristics even though the performance of sires and progeny were evaluated in two substantially different environments. Further data is being collected for the evaluation of progeny fleece production at 2 yr of age.

Implications

Preliminary results suggest that performance on the 140-d Sonora Central Ram Performance Test is positively related to female progeny fleece production and fiber characteristics. A 140-d postweaning central performance test does provide accurate genetic evaluations of rams for wool traits.

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Relationships among Production Traits in Angora Goats

B. Podisi, D.F. Waldron, M. Shelton, and C.J. Lupton

ABSTRACT

Phenotypic and genetic parameters were estimated from records of 1,625 Angora goats representing 42 sires. Records on fiber diameter (FD; n = 4,329), grease fleece weight (FW; n = 7,073), body weight (BW; n = 4,171) and fertility (FERT; n = 2,118) were collected from 1984 to 1997. Heritability estimates were obtained using Restricted Maximum Likelihood procedures with a multivariate repeatability animal model for animals ranging in age from .5 to 7.5 yr. The model for FW and FD included fixed effects for sex-age-season, production year, and herd; while the model for BW and FERT included age, production year and herd as fixed effects. The models for all traits included additive genetic, permanent environment, and residual as random effects. Heritability estimates for FW (.15), FD (.41), BW (.47), and FERT (.02) were calculated. Positive genetic correlations were obtained between FW and FD (.33), FW and BW (.29), FW and FERT (.35), FD and BW (.24), FD and FERT (.64), and BW and FERT (.88). Estimated phenotypic correlations were .44 between FW and FD, .35 between FW and BW, .10 between FW and FERT, .30 between FD and BW, .11 between FD and FERT and .23 between BW and FERT. Heritability estimates suggest that FW, FD, and BW would respond to mass selection but genetic response in FERT would be small. The correlations indicate that selecting to decrease fiber diameter will lead to correlated decreases in FW (.04 lb), BW (1.03 lb) and FERT (.5%) per generation of selection. Older does had higher fertility than younger does and all traits studied increased with age.

Introduction

The substantial differences in value among kid, young adult, and adult mohair is primarily due to fiber diameter. Several factors have been shown to influence mohair fiber diameter. If Angora goat producers select for and achieve a decrease in fiber diameter, income could be increased if no other factors are adversely affected. However, if a change in genetic potential to produce finer mohair is associated with changes in other economically important traits, the net result may not be favorable. Reliable estimates of the phenotypic and genetic relationships among production traits are required to assess the consequences to selection for finer mohair. Estimates of heritability and correlations of some mohair traits and other related production traits on Texas Angora goats were reported by Shelton and Bassett (1970) and by Shelton and Snowder (1983). These estimates were from limited data sets, and the values were, to some extent, contradictory (Shelton and Snowder, 1983).

The objectives of this study were, therefore, to use grease fleece weight, fiber diameter, body weight, and fertility records from Angora goats in a research herd to 1) estimate the effects of age and season (fall vs spring), 2) estimate genetic and phenotypic parameters, and 3) use the parameter estimates to predict direct and correlated responses to selection for decreased fiber diameter.

Materials and Methods

Herd Management

In 1984, an Angora research herd was assembled at the Hill Ranch in Edwards County, Texas, on the Edwards Plateau. The herd was divided into two lines with the intent to have a line selected for mohair fineness and a control line. The climate and vegetation of the plateau was described by Lupton et al. (1996). The original does came from 14 different herds. For the first four breeding seasons, all sires used were from outside the herd. From 1988 through 1996 some bucks that were born in the herd were used for breeding. In an effort to increase the amount of genetic variation present, some bucks from outside the herd were used for breeding. Most of the males that came from outside the herd had been on the Angora Billie Goat Central Performance Test, conducted at the Texas Agricultural Experiment Station in Sonora (Shelton et al., 1992). Twenty-one of the 42 sires that produced kids were born in the herd. All replacement females wer born in the herd. The only culling done on females was for age or health through most (1984 to 1994) of the duration of this project.

The does were bred in the months of October and November. Single-sire matings occurred in breeding pastures. Body weights were obtained on all does at the start of the breeding season. Does were maintained on pasture until the spring shearing. Kidding occurred in a barn where kids were ear tagged and identified with their dams within 24 hr of birth. Date of birth, type of birth (single, twin, or triplet), birth weight, sex, and sire

were also recorded. Approximately 96% of the kids were born in March and April from 1984 to 1997. Does and kids were returned to pasture when kids were approximately 2 wk old and remained there until weaning, at the time of the fall shearing (at an average age of 157 d).

Within a year, all kids were weaned on the same day. Across the years, the date of weaning varied from August 19 to September 25. Weaning weight was recorded for kids present at weaning. After weaning, the doe kids were typically maintained on pasture with supplemental feeding through the winter. Doe kids were returned into the breeding herd when they were approximately 18 mo old.

Data Collection and Analysis

Records from 1984 to 1997 were used in the analyses. There were 1,625 animals with records. Of these, 129 were the base generation females and 1,496 were progeny born in the herd. The 1,496 progeny were offspring of 42 different sires, with the progeny number per sire ranging from 5 to 106.

Fleece Weight and Fiber Diameter

All progeny were shorn for the first time at an average age of 157 d, in August or September. Subsequent shearings were at approximately 6-mo intervals, in February or March and August or September each year. Therefore, age at the second shearing was approximately 12 mo; age at the third shearing was approximately 18 mo, age at the 15th shearing was approximately 90 mo or 7.5 yr. Therefore, animals had two records per year, a spring record and a fall record. At each shearing, grease fleece weight (FW) was recorded. The numbers of FW records by shearing are shown in Table 1.

Midside samples of mohair were obtained for fiber diameter (FD) determination. Samples were typically obtained immediately prior to the first, second, and third shearings on all doe kids. In order to limit costs, approximately 50% of the does were sampled for FD determination at later shearings. The numbers of FD records by shearing are shown in Table 1.

Body Weight and Fertility

Body weights (BW) were recorded on all kids present at weaning and at the second and third shearings, at approximately 12 and 18 mo of age, respectively. Subsequently, BW was recorded on all females at the initiation of the breeding season in October. Each BW record was therefore considered to be associated with the closest shearing (either fall or spring).

Fertility was recorded for all females that were exposed for breeding. Fertility was coded as 1 if a doe produced one or more kids and as 0 if she failed to produce a kid.

Table 1. Numbers of fleece weight and fiber diameter records by shearing[a]

Shearing	Fleece weight	Fiber diameter
1st	1,496	1,391
2nd	688	681
3rd	613	483
4th	531	184
5th	526	217
6th	436	198
7th	524	290
8th	427	228
9th	420	175
10th	358	211
11th	347	246
12th	250	62
13th	229	124
14th	117	13
15th	111	26
Total	7,073	4,329

[a] Animals were shorn at approximately 6-mo intervals, therefore the age at 1st shearing was approximately 6 mo, at the 2nd shearing was approximately 12 mo, up through the 15th shearing at approximately 90 mo.

Statistical Analysis

Data Adjustments

Fleece weights were standardized by adjusting to a 180-d growth period. Because the data set included records from a wide range of ages, FW, FD, and BW records of young animals were adjusted to that of a single-born animal at the average age of measurement. Generally, these factors were significant ($P < .10$) sources of variation for the first through the third or fourth shearings but were not significant sources of variation for later shearings.

Data records were organized for analysis according to age and season (fall and spring). A complete record of a mature doe for fall of 1990 included the FW shorn in the fall of 1990, a FD measurement from the side sample obtained in the fall of 1990, a BW recorded in the fall of 1990 and a fertility record (1 or 0) for kid production in the spring of 1991. The fertility record was included on the fall record because the fall was the season when the ovulation and conception occurred. Spring records on mature does did not have BW or fertility.

The number of animals with data records for each trait, number of sires and dams with progeny with data, as well as mean, phenotypic standard deviation (SD), and coefficient of variation (CV) for each trait are summarized in Table 2.

Table 2. Numbers of animals with records, numbers of sires, dams, mean, standard deviation (SD) and coefficient of variation (CV) for each trait

Trait	Fleece weight	Fiber diameter	Body weight	Fertility
No. of records	7,073	4,329	4,171	2,118
No. of animals with records	1,625	1,474	1,536	649
No. of sires with progeny with records	42	42	42	38
No. of dams with progeny with records	534	522	523	314
Mean	4.29 lb	29.76 µm	55.61 lb	.793 %
SD	1.52 lb	5.142 µm	18.01 lb	.405 %
CV	.35	.17	.32	.51

Model Description

A multivariate repeatability animal model was used to obtain solutions of fixed effects and estimates of variance components for additive genetic, permanent environment and residual effects for FW, FD, BW, and fertility. The model used for FW and FD included fixed effects for line, sex-age-season, and year of production. The model used for BW and fertility included fixed effects for line, age (in years), and year of production. The models for all four traits included random effects for animal, permanent environment, and residual. The numerator relationship matrix included 1,664 animals, which was the sum of the number of animals that had records and their ancestors that did not have records, but did contribute genetic ties. Variance and covariance components were estimated with Multiple Trait Derivative-Free Restricted Maximum Likelihood (MTDFREML) written by Boldman et al. (1993).

Calculation of Selection Response

The predicted direct and correlated responses to selection were calculated assuming that within-herd selection would be used and 6% of the males born would be used for breeding with no selection among females. The direct response (R) of FD to selection was calculated using the expression:

$$R = i\, h_{FD} \sigma_a$$

where: i (selection intensity) = 1, h_{FD} = the square root of the heritability of FD and σ_a = the standard deviation of the additive genetic effects. The correlated response (CR) of a given trait Y, due to selection for FD was calculated from the following expression:

$$CR_y = i\, h_{FD}\, r_G\, \sigma_{ay}$$

where r_G = the genetic correlation, and the symbols are interpreted as above where the Y and other subscripts are according to the character referred to.

Results and Discussion

Effect of Season on Fiber Diameter and Fleece Weight

Season contrast results for FW and FD are shown in Table 3. The effect of season on FW was not uniform across ages. The fall fleeces were significantly heavier on goats less than 4 yr of age, but no consistent significant differences in FW were found at 4 yr of age and older. The increased FW in fall fleeces only at younger ages suggest an age effect rather than a season effect. Because all kids were born in the spring, age and season were confounded. In the contrasts shown in Table 3, the fall-spring comparisons used were those within a calendar year. Therefore, the goats were approximately 6 mo older at the fall shearing than they were at the spring shearing. When contrasts were calculated using the fall fleece from one year and the spring fleece from the subsequent year, so that the goats were approximately 6 mo older at the spring shearing, the only contrast where the fall FW was significantly greater than the spring FW was that which compared the fleece shorn at 18 mo with that shorn at 24 mo. Lupton et al. (1996) reported that Angora wethers produced .9 lb greater FW in the fall compared to the spring in the Edwards Plateau area of Texas whereas no significant season effect was observed for similar goats in the South Texas Plains. It was suggested that the seasonal differences in the FW of Angora wethers in the two environments was due to difference in nutrient availability. Seasonal differences in nutrient availability were also a factor for the goats of the present study. However, seasonal effects are generally confounded with the production status of the does. A high proportion of the does were lactating for much of the time that the fall fleece was growing. The season effect on FW, observed for wethers, may not be realized in does because of the effects of kid production or lactation.

The FD results showed a more consistent difference between fall vs spring across ages. The estimated

average season effect showed fibers from fall fleeces were 2.1 (P < .001) microns coarser than those from spring fleeces.

Table 3. Estimates of difference between fall and spring seasons for fleece weight and fiber diameter of Texas Angora goats by age

Age, yr	Fall - Spring Fleece weight, lb		Fall - Spring Fiber diameter, µm	
1	.97 ± .037	***	2.3 ± .11	***
2	.84 ± .044	***	2.8 ± .19	***
3	.42 ± .048	**	2.3 ± .18	***
4	-.02 ± .051	ns	1.4 ± .19	**
5	-.04 ± .055	ns	2.0 ± .17	***
6	-.20 ± .066	†	1.2 ± .29	*
7	-.00 ± .097	ns	2.9 ± .63	*

*** P < .001
** P < .01
* P < .05
† P < .10

Effect of Age on Fleece Weight

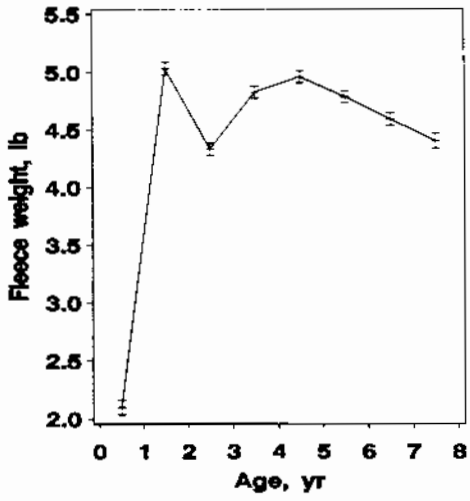
The plot of estimated FW at various ages is shown in Figure 1. Age of .5 yr includes the first fleece shorn at about 6 mo of age, but the rest of the ages on the graph reflect an average of the two seasons' FW that were shorn in the same year. The FW for age 1.5 is the average FW at the second and third fleeces, which were shorn at approximately 12 and 18 mo of age, respectively. There was a sharp increase in FW from .5 to 1.5 yr of age and a decrease at 2.5 yr of age. The fleeces contributing to the point labeled 2.5 yr were grown during the doe's first gestation and first lactation. The decrease between 1.5 and 2.5 yr of age suggests that the stress of gestation and lactation during a time when BW was also increasing (Table 4) contributed to reduced FW. The extent of the decrease in FW is likely a function of nutrition level and the proportion of does kidding.

Table 4. Estimates of fleece weight, fiber diameter, body weight, and fertility by age in years[a]

Age	Fleece wt., lb ± (SE)	Fiber diam. µm ± (SE)	Body wt., lb ± (SE)	Fertility, % ± (SE)
.5	2.09 (.06)	24.48 (.28)	34.5 (.93)	-
1.5	5.03 (.06)	30.37 (.26)	55.9 (.86)	.63 (.02)
2.5	4.32 (.04)	31.19 (.25)	64.3 (.84)	.78 (.02)
3.5	4.83 (.04)	32.70 (.24)	70.0 (.79)	.88 (.02)
4.5	4.96 (.04)	33.49 (.23)	73.0 (.75)	.81 (.02)
5.5	4.78 (.04)	33.68 (.22)	76.2 (.75)	.81 (.03)
6.5	4.59 (.04)	34.72 (.24)	80.0 (.84)	.83 (.04)
7.5	4.41 (.06)	34.24 (.36)	80.0 (1.19)	.95 (.07)

[a] Age of .5 represents the first shearing only. Each age after .5 represents the average of two fleeces, shorn at 6-mo intervals, where the 2nd fleece was shorn at the age indicated.

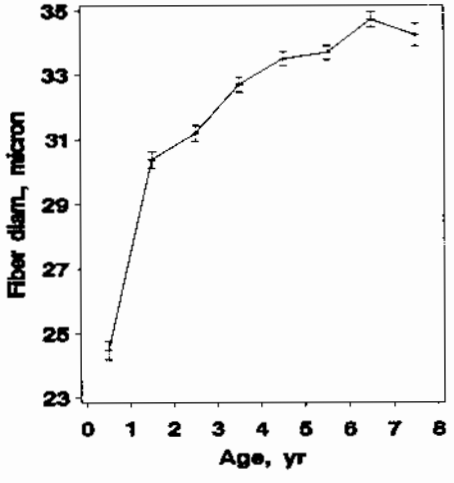
Figure 1. Effect of age on mohair fleece weight. Each point after age = .5 yr represents the average of the spring and fall fleeces.



Effect of Age on Fiber Diameter

Fiber diameter increased with age with the largest increase observed between .5 and 1.5 yr of age (Figure 2). The small decrease from 6.5 to 7.5 yr of age may be a result of relatively few observations at those ages (Table 1).

Figure 2. Effect of age on mohair fiber diameter.



Effect of Age on Body Weight

The plot of BW by age (Figure 3) indicates that BW increases with age, rapidly at younger ages and gradually at older ages.

Effect of Age on Fertility

In the case of fertility, the age shown on the horizontal axis of Figure 4 is the age at which mating occurred, not when the doe gave birth. Therefore, the

environmental factors affecting fall FW, fall FD, and BW at a given point on the horizontal axis were the same environmental factors affecting fertility at the same point. The plot of estimated fertility by age (Figure 4) shows that fertility increased markedly for the first three kiddings. This increase was concurrent with an increase in BW (Figure 3). After the third kidding there was a small decrease in fertility. The standard errors of the estimates increase at older ages because of fewer observations. The observed superiority in fertility of older does could be a function of the increased BW shown in Figure 3. The proportion of does kidding of those mated ranged from 57 to 90% with an average of 79% for the 14 years (1984 to 1997).

Figure 3. Effect of age on body weight in Angora goats.

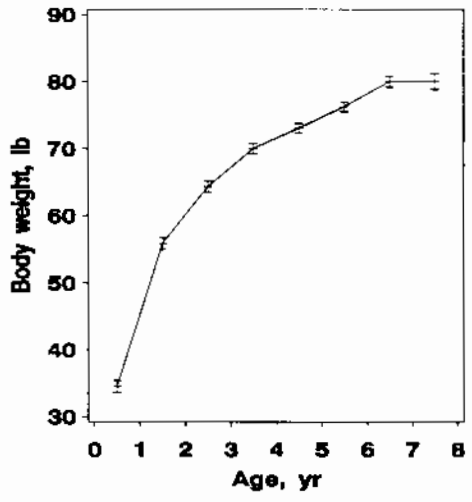
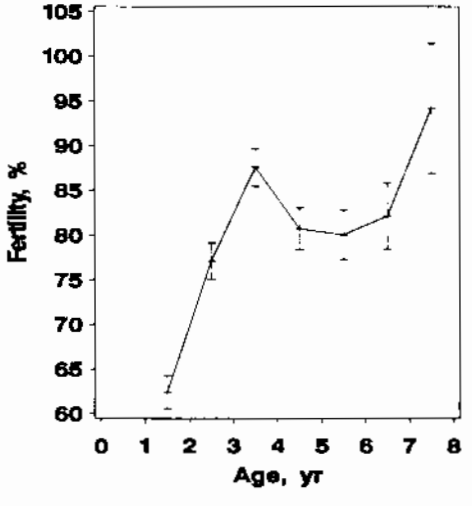


Figure 4. Effect of age at time of breeding on fertility in Angora goats.



Heritability Estimates

The heritability estimates of FW, FD, BW and fertility are shown in Table 5. Body weight and FD had the highest heritability estimates, and fertility had the lowest estimate. The heritability estimate of .15 for FW from the present study is between the estimates of .13 of Yalcin (1982) and .19 of Snyman and Olivier (1996). With 7,073 FW records, the present study had more FW observations than any previously reported in the literature. However, the present study did have repeated records on animals and some studies such as Snyman and Olivier (1996) and Gerstmayr et al. (1992) had larger numbers of animals with records. Reported heritability estimates for FW range from .06 (Gerstmayr et al., 1992 for yearling fleece in Turkey) to .45 (Gifford et al., 1991 for kid fleece at 6 mo of age in Australia). The three reports (Gifford et al., 1991; Nicoll et al., 1989; Shelton and Bassett, 1970) of high (from .36 to .45) heritability estimates of FW were derived from data sets with 30 or fewer sires represented. The wide range of environmental conditions in which Angora goats are raised probably contributes to some of the variation among heritability estimates.

The FD heritability estimate of the present study, .41, was higher than all but one (Nicoll et al., 1989) of the previously reported estimates for this trait. The only report of a heritability estimate of FD in Angora goats obtained from a larger data set was the .26 of Snyman and Olivier (1996) who used 6,195 FD records. Their data were all from 9 mo old animals, whereas the data from the present study were from a wider range of ages.

Table 5. Estimates of heritability[a], phenotypic and genetic correlations for fleece weight (FW), fiber diameter (FD), body weight (BW) and fertility (FERT) for Angora goats

Trait	FW	FD	BW	FERT[b]
FW	**.15**	.44	.35	.10
FD	.33	**.41**	.30	.11
BW	.29	.24	**.47**	.23
FERT	.35	.64	.88	**.02**

[a] Heritability on the diagonal, phenotypic correlations above diagonal, [b] genetic correlations below the diagonal.
Fertility was coded as 1 or 0.

A high estimate (.47) for the heritability of BW was obtained. The present study used BW from a range of ages (.5 to 7.5 yr of age), whereas most of the other reports used BW from younger ages only. The previous estimates of heritability of BW from Texas Angoras (Shelton and Bassett, 1970; Shelton and Snowder, 1983) were also higher than other estimates (.33 to .50 for Texas vs .13 to .29 for other locations). This suggests

that more genetic variation for BW may be present in the Texas Angora population.

The heritability of fertility was estimated to be .02. Reproductive traits typically have low heritability estimates (.05 to .15). The extremely low estimate from the present study suggests that improvements to fertility through selection will be limited. Therefore, improvements in fertility appear to be more likely to arise through environmental changes, such as improved nutrition. However, the high CV of fertility (Table 3) suggests that genetic selection for improved fertility should not be ignored.

Phenotypic and Genetic Correlations

The phenotypic and genetic correlation estimates between all traits were positive (Table 5). The undesirable phenotypic (.44) and genetic (.33) correlations between FW and FD indicate that progress from selection to simultaneously increase FW and decrease FD will be limited. The phenotypic and genetic correlation estimates between FW and BW were both favorable. These values indicate that selection for either increased FW or increased BW will lead to a favorable increase in the other.

The correlation estimates between FD and BW were .30 (r_p) and .24 (r_g), indicating that selection for decreased FD will lead to a correlated decrease in BW. Fertility had high genetic correlations with BW (r_g = .88) and FD (r_g = .64), but considerably lower phenotypic correlations (r_p = .23 for BW and r_p = .11 for FD). No other reports of correlation estimates of fertility were found.

The only phenotypic and genetic correlations that were unfavorable were those that included FD. A desirable decrease in FD due to single trait selection is expected to result in undesirable correlated changes in FW, BW and fertility. Therefore, multiple trait, index selection should be practiced in Angora goat breeding programs.

Differences among parameter estimates can be due to differences among the populations of goats, differences among the environments in which the goats were producing, and differences among variance component estimation procedures.

Predicted Selection Response

The predicted direct response to single trait selection for decreased FD and the correlated responses in FW, BW, and fertility are shown in Table 6 (assuming a standardized selection differential of 1.0). The correlated responses to the desirable decrease of 1.19 microns were predicted to be undesirable for each of the three other traits. It was predicted that, after one generation of selection, FW would decrease by .044 lb/6-mo shearing, BW would decrease by 1.04 lb and fertility would decrease by .5%.

Table 6. Predicted direct and correlated responses to one generation of single trait selection for decreased fiber diameter (assuming a selection differential of 1.0)

Trait	Direct Response	Correlated Response
Fiber diameter	-1.19 µm	-
Fleece weight	-	-.04 lb
Body weight	-	-1.03 lb
Fertility	-	-.5 %

Conclusion

The data used in this analysis represented a wider genetic base of the Texas Angora population compared to the data used in earlier analyses (Shelton and Bassett, 1970; Shelton and Snowder, 1983). The results show that the economically important traits, FW, FD, and BW are moderately to highly heritable in Texas Angora goats. However, the other economically important trait analyzed, fertility, is lowly heritable. It is also evident that age and type of birth (at the younger ages) have to be taken into consideration when comparing animal records for FW, FD, BW, and fertility. Season also has to be accounted for because it has been shown to affect FW and FD.

The moderate to high genetic correlations estimated between FW, FD, BW, and fertility for Texas Angora goats is a confirmation of a cause for concern with regard to implications for selecting for finer mohair. Of particular interest is the genetic correlation between FD and FW, which suggests that it will be difficult to select for heavier shearing animals with fine mohair, because selecting for a decreased FD will lead to an unwanted correlated decrease in FW. Due to the high genetic correlation between FD and fertility, selecting for decreased FD will also lead to an unwanted correlated decrease in fertility. It is therefore necessary for an economic evaluation to be done to estimate the relative economic values to be used to construct a selection index that can be used to improve profitability from Angora goats.

Implications

Because of the unfavorable correlations between FD and other economically important traits (FW, BW, and fertility) the relationships among these traits must be known in order to develop a selection index that will appropriately weight selection criteria. The parameter estimates of this study indicate that single trait selection for decreased FD will lead to undesirable decreases in FW, BW and fertility. The estimated phenotypic and

genetic parameters can be used in constructing selection indices for multiple trait breeding objectives.

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1997 Texas A&M Pasture to Packer Program

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ABSTRACT

Feedlot performance for the 1997 Texas A&M Pasture to Packer Program indicated that 35.5 % of the lambs gained less than .5 lb/d. Profitable lambs gained an average of .6 lb/d or more. Feed efficiency for the entire group was 6.84 lb of feed per lb of gain. In general, as frame size increased, lambs gained faster and were on feed fewer days. Crossbred lambs slightly out-gained finewool lambs; however, they were on feed the same number of days. In general, wether lambs slightly out-gained ewe lambs and were on feed one to two weeks less.

If the optimum carcass weight is assumed to be 65 lb, then 86 % of the lambs yielded lighter than optimum carcasses when slaughtered at a fat thickness of approximately .25 in. Average backfat and body wall thicknesses for the entire group were .29 and 1.34 in., respectively.

Price of carcasses was not influenced by carcass weight or fatness. Extremely high feeder lamb prices resulted in a loss for all but seven producer groups. Only 42.5 % of the lambs made money by feeding them rather than selling them as feeders. The average difference between initial value and the return to the producer was - $4.43. The differences for the 28 producer groups ranged from an average loss of $19.23/hd to an average profit of $8.41/hd. The profitable entries were characterized by rapid gains (.6 lb/d or greater), fewer days on feed (84 d) and heavy carcass weights. Implementation of a value based marketing system would provide an economic incentive for producers to improve the quality of lambs being produced.

Introduction

Finewool sheep are the backbone of the Texas sheep industry. Selection efforts to improve fleece characteristics have been successful. However, little selection pressure , other than for increased size, has been applied toward sheep to produce lean, fast-growing, muscular lambs. Selection for improved fleece characteristics tends to impede improving carcass merit. With the loss of the incentive program, a much smaller percentage of a producers' income comes from wool. If lamb is going to compete successfully for an ever-shrinking portion of the retail meat case and producers are to survive, several changes must be made. To that end, lamb producers should reevaluate the appropriate selection emphasis for fiber and carcass production in their enterprise.

Commercial, purebred and registered producers need to determine how their sheep fit the needs of the entire lamb production system. The Texas A&M Pasture to Packer Program was designed to 1) provide commercial lamb producers, purebred sheep breeders, stocker operators and lamb feeders the opportunity to determine the feedlot performance and carcass characteristics of lambs they are producing and the factors that influence value and 2) familiarize producers with lamb feeding and retained ownership as a possible alternative marketing method.

Materials and Methods

Four hundred forty lambs were delivered by 28 producer groups from 12 counties to the Denis Feedlot in Vancourt, Texas, on July 9 to 11, 1997. Stratification of lambs by breed and sex is given in Table 1. Upon arrival the lambs were ear tagged and weighed. Each lamb was assigned an initial value based on the San Angelo feeder lamb market during the delivery week. Feeder lamb prices used to determine value were: less than 60 lb - $1.08/lb, 60 to 89 lb - $0.98/lb and 90 lb and up - $0.84/lb. Lambs were assigned a frame score (small, medium or large) and were slaughtered at an appropriate weight to yield carcasses with .25 in. backfat or less. Target weights for the frame score groups were 105, 115 and 125 lb for the small (S), medium (M) and large (L) framed lambs, respectively. Within 1 wk after arrival at the feedlot, all lambs were vaccinated for enterotoxemia and dewormed. In terms of ration changes, illness, shearing, etc., lambs were managed like all other lambs in the feedlot. Lambs were weighed every 4 wk and were slaughtered at Strube Packing Company in Rowena and Ranchers Lamb of Texas in San Angelo. Carcass data collected included hot carcass weight, fat thickness, leg conformation score, body wall thickness, maturity score and quality grade. All expenses were deducted from carcass income, and the balance was sent to the owners along with a detailed performance, carcass and financial summary report. The difference between the initial value of the lambs (feeders) and the return to producer

(fats) was calculated to determine profit or loss for each producer.

Table 1. Stratification of lambs by breed and sex

Item	No. of Head	%
Finewool	293	66.6
Wethers	241	82.3
Ewes	52	17.7
Crossbred[a]	110	25.0
Wethers	42	38.2
Ewes	68	61.8
Cheviot/Finewool cross	15	3.4
Dorper/Finewool cross	10	2.3
Texel/Finewool cross	10	2.3
Medium wool[b]	2	0.4
Total	440	100

[a] Suffolk or Hampshire x finewool
[b] Suffolk or Hampshire

Results and Discussion

Performance Data

Feedlot performance data for individual lambs are given in Table 2. The average weight upon arrival at the feedlot was 73 lb with a range of 34 to 121 lb. Average slaughter weight was 119 lb and ranged from 66 to 159 lb. Several poor doing lambs (primarily rectal prolapses) were railed in an attempt to salvage some value for the producer. The four lambs that prolapsed during the study belonged to producers that raise club lambs that are short docked. Overall death loss was 2.6% (16 lambs) which is slightly higher than what most lamb feeders experience. Days on feed ranged from 61 to 112 with an average of 82 d. Total gain averaged 46 lb with a range of -14 to 79 lbs. Average daily gains ranged from -.23 to 1.05 lb/d with an average of .56 lb. Experiences in the Denis Feedlot indicate that in order for lambs to return a profit, they must gain at least .5 lb/d.. In this study, 35.5 % of the lambs gained less than .5 lb/d. Because all producer groups are combined, it is impossible to obtain feed efficiency information for individual producer groups; however, the entire group had a feed efficiency of 6.84 lb of feed/lb of gain. Feedlot performance data for the 28 producer groups are given in Table 3.

Table 2. Means and ranges for feedlot performance, carcass and financial data for all lambs

Item	Mean	Range
Initial weight, lb[a]	73.0	34 to 121
Final weight, lb[b]	119.0	66 to 159
Gain, lb[a]	46.0	-14 to 79
Average daily gain, lb[a]	.56	-.23 to 1.05
Days on feed[a]	82.0	61 to 112
Carcass weight, lb[a]	58.6	30.5 to 81.5
Leg score[a,b]	10.4	4 to 14
Backfat, in.[a]	.29	.03 to .60
Body wall, in.[a]	1.34	.5 to 2.2
Quality grade[a,c]	10.6	5 to 13
Initial value, $[d]	70.37	36.72 to 101.64
Ending value, $[d]	98.12	0 to 139.81
Total cost, $[d]	32.18	3.18 to 40.06
Return to producer, $[d]	65.94	-20.02 to 113.06
Difference, $[d]	-4.43	-105.32 to 24.99

[a] Includes only those lambs that were slaughtered (424 head).
[b] Leg conformation scores are equivalent to 8 = average good, 9 = high good, 10 = low choice, ... 15 = high prime.
[c] Quality grades are equivalent to 10 = low choice, 11 = average choice ... 14 = average prime.
[d] Includes all lambs (440 head).

Table 3. Means and ranges for feedlot performance, carcass and financial data for the 28 producer groups

Item	Mean	Range
Initial weight, lb[a]	71.6	40 to 94
Final weight, lb[a]	117.4	95 to 134
Gain, lb[a]	45.8	30 to 69
Average daily gain, lb[a]	.55	.38 to .70
Days on feed[a]	86.0	66 to 112
Carcass weight, lb[a]	58.0	49 to 66
Leg score[a,b]	10.5	9.8 to 11.7
Backfat, in.[a]	.28	.22 to .39
Body wall, in.[a]	1.33	1.2 to 1.6
Quality grade[a,c]	10.6	10.1 to 11.3
Initial value, $[d]	69.35	42.66 to 83.39
Ending value, $[d]	96.84	71.95 to 112.67
Total cost, $[d]	32.18	25.69 to 40.06
Return to producer, $[d]	64.65	42.54 to 83.61
Difference, $[d]	-4.65	-19.23 to 8.41

[a] Includes only those lambs that were slaughtered (424 head).
[b] Leg conformation scores are equivalent to 8 = average good, 9 = high good, 10 = low choice, ... 15 = high prime.
[c] Quality grades are equivalent to 10 = low choice, 11 = average choice ... 14 = average prime.
[d] Includes all lambs (440 head).

Table 4. Mean feedlot performance data by breed and sex group

Item	Finewool		Crossbred		Cheviot/	Dorper/	Texel/	Medium
	Ewe	Wether	Ewe	Wether	Finewool	Finewool	Finewool	Wool
Number of Lambs	52	232	64	41	15	9	10	2
Initial weight, lb	66	75	68	81	94	39	49	75
Final weight, lb	115	119	117	127	126	95	103	123
Gain, lb	49	44	49	46	32	56	54	48
ADG, lb	.52	.55	.57	.58	.49	.53	.61	.68
Days on feed	94	80	86	79	65	106	89	71

Mean feedlot performance data by breed and sex group are given in Table 4. Crossbred lambs out-gained finewool lambs by .03 lb/d; however, they were on feed the same number of days (83 d). Finewool wether lambs out-gained finewool ewe lambs by .03 lb/d and were on feed 14 d less. Crossbred wether lambs out-gained crossbred ewe lambs by .01 lb/d and were on feed 7 d less. There were some Cheviot x finewool lambs, Dorper x finewool lambs, Texel x finewool lambs and medium wool lambs on test. The feedlot performance data on these lambs is quite variable and few conclusions can be drawn due to the small numbers.

Mean feedlot performance data for finewool and crossbred lambs within small, medium and large frame groups are given in Table 5. In general, as frame size increased, lambs gained faster and were on feed fewer days. The only exception was that the small framed crossbred lambs out-gained the medium framed crossbred lambs. However, the low number of small framed crossbred lambs (7) was likely not typical of the frame class.

Table 5. Mean feedlot performance data for finewool and crossbred lambs within small, medium, and large frame groups

Item	Finewool			Crossbred		
	L	M	S	L	M	S
Number of lambs	30	240	14	10	88	7
Initial weight, lb	89	72	64	91	72	59
Final weight, lb	135	118	105	138	118	112
Gain, lb	46	46	41	47	46	53
ADG, lb	.64	.54	.47	.68	.56	.62
Days on feed	72	85	87	69	82	85

Carcass Data

Lambs were assigned a frame score (small, medium and large) and were slaughtered at an appropriate weight to yield carcasses with .25 in. backfat or less. Target weights for the small, medium and large framed lambs were 105, 115 and 125 lb, respectively. The lambs were sold on an individual carcass basis, but no price difference was assigned for carcasses of various weights and fatnesses. Means and ranges for carcass data for all lambs are given in Table 2. The average carcass weight for all lambs was 58.6 lb with a range of 30.5 to 81.5 lb. There were very few differences in leg score and quality grade except for a few outliers that are attributed to those prolapsed lambs that were slaughtered at very light weights. Average backfat and body wall thicknesses were .29 and 1.34 in., respectively. Backfat thickness was slightly higher than the target of .25 ins. As frame size increased, backfat thickness and body wall thickness increased slightly. This unexpected result was likely because the first slaughter date was delayed approximately 2 wk due to scheduling problems. Some of the lambs that were quite large coming onto the test got too big.

Financial Data

Means and ranges for financial data for all lambs are presented in Table 2. Means and ranges for financial data for the 28 producer groups are presented in Table 3. For all financial data it was assumed that all lambs were eating the same amount of feed since individual feed intake data were not available. It stands to reason that the range in profit and loss is somewhat exaggerated because the better performing lambs probably ate more feed and the poorer performing lambs probably ate less feed. Factors affecting income and expenses are presented in Table 6. Extremely high feeder lamb prices resulted in a negative return for all but seven producer groups. The average difference between initial value and the return to the producer was -$4.43 with a range of -$105.32 to $24.99. The differences for the 28 individual producer groups ranged from an average loss of $19.23/hd to an average profit of $8.41/hd.

Table 6. Factors affecting income and expenses

Income	
Carcass vlaue	$165.00/cwt
Drop credit (pelt & offal)	$4.50/hd
Wool Sales	$1.33/hd
Expenses	
Slaughter charge	$8.00/hd
Feedlot processing	$1.10/hd
Freight	$0.31/hd
TSGRA Commodity Board Check-off	$0.20/hd
Shearing	$0.96/hd
Feed	$0.225/hd/day
Miscellaneous	$0.036/hd/day
Yardage	
Interest	
Insurance	

Only 42.5 % (187 of 440) of the lambs returned a profit when fed rather than being sold as feeders. The characterization of these 187 profitable lambs by initial weight groups and prices is given in Table 7. It is interesting to note that 59, 37 and 51 % of the light lambs (less than 60 lb), middle weight lambs (60 to 89 lb) and heavy lambs (greater than or equal to 90 lb), respectively, were profitable with each returning an average of $6.21 to $7.08. All three groups gained .6 lb/d or more. The light weight lambs averaged 47.2 lb going on test, were on feed an average of 104.4 d and were slaughtered at an average weight of 110.2 lb. The middle weight lambs averaged 70.8 lb going on test, were on feed an average of 81.6 d and were slaughtered at an average weight of 124 lb. The heavy weight lambs averaged 97.6 lb going on test, were on feed an average of 62.3 d and were slaughtered at an average weight of 134.2 lb. The light weight profitable lambs consisted of 40 % small framed and 60 % medium framed lambs. The middle weight lambs consisted of 3 % small framed, 85 % medium framed and 12 % large framed lambs. The heavy weight group consisted of 47 % medium framed and 53 % large framed lambs. It is evident that the three weight groups parallel the three frame sizes which indicates that the larger framed lambs grew faster than smaller framed lambs before they were weaned.

Table 7. Characterization of profitable lambs by initial weight groups and prices

Trait	< 60 lb ($1.08/lb)	60 - 89 lb ($0.98/lb)	≥ 90 lb ($0.84/lb)
Number of profitable lambs	45	112	30
Percent of total group	59	37	51
Initial weight, lb	47.2	70.8	97.6
Final weight, lb	110.2	124	134.2
ADG, lb	.61	.66	.60
Days on feed	104.4	81.6	62.3
Profit, $	7.08	6.21	6.92
Frame size, %			
Small	40	3	0
Medium	60	85	47
Large	0	12	53

Acknowledgments

The authors wish to express their appreciation to Denis Feedlot, Strube Packing Company, Rancher's Lamb of Texas, Texas A&M Animal Science Department - Meat Science Section, Angelo State University students and County Agricultural Extension Agents who had producers involved in the program for their cooperation and assistance during the study.

Effects of Breed, Sex, and Ration Type on Production of Market Kid Goats

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ABSTRACT

A multi-year goat experiment was initiated in 1996 to generate data for developing a model to predict economic returns from various management/breeding options with changing prices of mohair and goat meat. Kids produced during the first year were combined with kids from other sources and used in a pen replicated 3 x 2 x 2 factorial experiment. Factors were breeding (Angora, meat, and Angora x meat), sex, and roughage level (12 and 30%). Weaning weights and growth rates in the feedlot were lower in Angoras compared with meat goats. Crossbred goats were intermediate in both response criteria but approached the meat goats in weaning weights and in feedlot gains when a low roughage ration was fed. These data will be used with data generated during the two remaining years of the study.

Introduction

The goat population in Texas is changing to adapt to new developments in the goat industry. With mohair demand depressed and goat meat demand on the rise, goat producers are looking to increase the profitability of their enterprises by selling more goats for meat. Because there is little difference in carcass value other than weight (Oman et al. 1996a, 1996b), decisions on breed of goat and management practices should be based on the efficiency of kid production and actual and opportunity costs associated with the different options. For example, producers with Angora flocks may have options to 1) maintain Angora breeding, 2) maintain an Angora female flock but crossbreed with a meat-type male when considered advantageous, or 3) convert to breeding meat-type goats. A study was initiated to compare reproductive rate, weaning weight, feedlot gain, and feed efficiency with female Angora and meat goats both bred to either Angora or meat goat males. The experiment will continue over a 3-yr period. Activities during the first year are reported herein.

Materials and Methods

During the first year (1996), breeding herds were assembled at the TAMU Agricultural Research and Extension Center at San Angelo from existing Angora flocks at San Angelo and the Winters Ranch at Brady and from offspring of the meat goat herd at Brady. Males included Angoras purchased from the Angora Goat Performance Test at the Texas Agricultural Experiment Station at Sonora and meat goat sires (⅝ Boer) from the local TAES breeding program. Breeding females were divided into two groups with one-half of the available Angora (51) and meat goat females (¼ to ⅞ Boer, 97) in each breeding group. One group was bred to Angora males and the other group to meat goat males during the first cycle beginning Oct. 1, 1996; the males were switched for the second cycle.

Although 1996-97 was intended to be a year to establish the breeding herds and reduce effects of disparity of age, kids produced from this first breeding were used in a feeding study during the fall of 1997. Kids from the described breeding were weaned in August, combined with similar Angora and Angora x meat crossbred goats, and fed together on a medium roughage diet for about one month. On Sept. 19, the goats were placed on a 3 x 2 x 2 factorial experiment with breed (Factor a; Angora, meat, and Angora x meat), sex (Factor b; castrated male and female), and roughage level (Factor c; 12 and 30%) with two pen replicates for each factor combination. The 24 pens included from four (male meat goats) to 10 (Angora or crossbred goats) goats per pen for a total of 196 kid goats in the feeding experiments.

The goats were fed, usually daily, the diet (Table 1) at a slightly higher level than consumption, and orts were collected and weighed two or three times per week. The kids were weighed at the beginning (Sept. 19) and end (Dec. 8) and at two intermediate points during the experiment. Two goats became morbid during the experiment, apparently from social disorder, and were removed.

Results and Discussion

The data (Table 2) indicate that meat kids were heavier at weaning, consumed more feed, and gained weight more rapidly and efficiently in the feedlot. The crossbred kids were intermediate in weaning weight (closer to meat kids) but similar to Angora kids in feedlot performance. Interestingly, females weighed less at weaning but gained as rapidly as males in the feedlot.

Table 1. Composition of diets fed to Angora, meat, and crossbred kid goats in a feedlot

	Diet	
Item	1	2
Ingredients	%	%
Cottonseed hulls	3	7.5
Peanut hulls	3	7.5
Dehydrated alfalfa	6	15
Sorghum grain	70	52.5
Cottonseed meal	11	11
Molasses	4	4
Ammonium chloride	.75	.75
Salt	.75	.5
Calcium carbonate	1	.75
Vitamin/mineral premix	.5	.5
Rumensin (20 mg/ton, active)	+	+
	100.0	100.0
Nutrient concentrations		
Crude protein	15	15
Total digestible nutrients	70	63
Calcium	.57	.60

Table 2. Weaning weights and feedlot performance of goats as affected by breed type, sex, and diet roughage level

Comparisons	No.	Weaning wt, lb	Feed Intake, lb/d	ADG, lb	Feed/ gain
Breed type					
Angora	80	31.3[a]	1.41	.14[a]	10.1
Meat	36	50.3[c]	2.19	.29[b]	7.6
Angora/meat	80	46.3[b]	1.70[b]	.17[a]	10.0
Sex					
Female	99	39.0[a]	1.70	.20	8.5
Male	97	46.2[b]	1.83	.19	9.6
Roughage level					
12%	98	43.1	1.70	.21	8.1
30%	98	42.2	1.82	.19	9.6

[a,b,c] Mean values within a grouping that do not share a common superscript differ ($P < .05$).

Roughage level had no effect on gain when the pooled data were considered. However, a breed x diet interaction ($P < .05$) suggested that kids of the different breed types did not respond the same to the different roughage levels. When analyzed separately (Table 3), the data indicate that gains and efficiency were more similar on the low roughage diet (diet 1) compared with the high roughage diet (diet 2). It appears that the meat goat kids are more tolerant of high roughage than the other goat types observed.

Table 3. Feedlot performance of kid goats of different breeding fed two diets containing different levels of roughage (12 and 30%, respectively)

Comparisons	No.	Feed intake, lb/d	ADG, lb/d	Feed/ gain
Diet 1				
Angora	40	1.32[a]	.15	8.8
Meat	17	2.10[b]	.28	7.5
Angora/meat	41	1.69[b]	.20	8.4
Diet 2				
Angora	40	1.49[a]	.13[a]	11.5
Meat	19	2.27[c]	.30[b]	7.6
Angora/meat	39	1.70[b]	.14[a]	12.1

[a,b,c] Mean values within a grouping that do not share a common superscript differ ($P < .05$).

Implication

Angora kids were smaller at weaning and gained at a slower rate compared with meat type kids under the conditions of this experiment. Angora x meat crossbred kids were intermediate but approached the meat-type kids in weaning weight and in growth rate when fed a low roughage diet. These data will be combined with data from the next two years to develop a model for predicting economic returns from various breeding and feeding programs, depending on prices of mohair and goat meat.

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Effects of Dietary Copper During Late Gestation on Thermometabolism in Newborn Lambs

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ABSTRACT

To determine the effects of prenatal dietary Cu level on thermometabolism in lambs, 12 twin-bearing ewes were assigned to low- or high-Cu treatments 3 mo prior to lambing. A basal diet containing 7 ppm Cu, 2 ppm Mo and .2% S was fed with 0 (low-Cu ewes) or 20 ppm supplemental Cu as Cu-lysine (high-Cu ewes). An oral drench of tetrathiomolybdate to impair Cu absorption was also administered to low-Cu ewes biweekly (avg 43 mg/d) beginning 2 mo prior to lambing. At birth, lambs were fed pooled bovine colostrum and placed in a chamber at 68 °F. To determine norepinephrine (NE) turnover rates in brown fat, one lamb within each twin pair was administered i.v. a tyrosine hydroxylase inhibitor, α-methyl-DL-tyrosine, at 6 (250 mg/kg BW) and 9 h of age (125 mg/kg BW), whereas the control twin lamb received saline. Lambs were killed at 12 h of age and perirenal brown adipose tissue (BAT) samples collected for NE analysis using HPLC. Reductions in BAT NE concentrations between methyl-DL-tyrosine (AMPT) and saline-infused lambs were used to estimate NE turnover rates. Blood samples were obtained at 2, 6 and 12 h of age and plasma analyzed for triiodothyronine (T_3) and thyroxine (T_4). Birth weights and BAT mass were not affected by prenatal Cu treatment and averaged 4.1 ± .2 kg and 20.5 ± 1.2 g, respectively. Low-Cu lambs had lower ($P < .01$) liver Cu levels than high-Cu lambs. Rectal temperatures were lower ($P < .05$) in low-Cu lambs at 2 h of age, but not at 6 and 12 h of age. Plasma T_4 concentrations were not affected by prenatal Cu treatment and averaged 7 ± .6 μg/dL. However, lambs born to low-Cu ewes had lower ($P < .01$) plasma T_3 concentrations (175 vs 271 ± 30 μg/dL, respectively) and lower ($P < .05$) BAT NE turnover rates (.16 vs .3 ± .04 ng/mg/h) than lambs born to high-Cu ewes. These data suggest that a maternal Cu deficiency may impair thermometabolism of newborn lambs by altering the endocrine control of BAT thermogenesis.

Introduction

Lamb mortality represents a major economic loss to the sheep industry, with conservative estimates of preweaning mortality losses ranging from 15 to 20%. Rook (1989) found that the vast majority of lamb deaths in Michigan flocks occurred within the first several days of life, and that 50% of postlambing deaths during the first week of life were due to starvation and(or) hypothermia. Thus, hypothermia is a major cause of death in newborn lambs and occurs when the rate of heat loss exceeds the rate of heat production. The abrupt increase in heat loss that newborn lambs encounter at birth is compounded by evaporation of fetal fluids and cold and(or) wet weather conditions at lambing. Newborn lambs attempting to avoid hypothermia during cold exposure are capable of increasing their rate of heat production by about 4 times the rate produced during thermoneutral metabolism. This cold-induced increase in heat production is derived from shivering thermogenesis in muscle tissue and nonshivering thermogenesis in brown adipose tissue (BAT).

Brown Adipose Tissue in Newborn Lambs

BAT is a specialized tissue found in all newborn ruminants. It has been shown that BAT thermogenesis contributes about half of the heat generated by newborn lambs exposed to cold temperatures. The ability of BAT to generate heat is due to the presence of an uncoupling protein that is found only in BAT mitochondria. When stimulated by cold exposure, this unique uncoupling protein acts to disconnect normal oxidative phosphorylation from fatty acid oxidation, thereby causing BAT mitochondria to generate heat rather than ATP (chemical energy). BAT is highly innervated by the sympathetic nervous system, which during cold exposure, releases norepinephrine (NE) to activate BAT thermogenesis. Norepinephrine activates BAT thermogenesis by stimulating fatty acid oxidation and uncoupling protein gene expression in mitochondria. Moreover, NE activates a deiodinase enzyme found in BAT that converts thyroxine (T_4) to the more active thyroid hormone triiodothyronine (T_3). Local synthesis of T_3 is also an important regulator of uncoupling protein gene expression. Thus, both NE and T_3 play a critical role in regulating BAT thermogenesis in newborn lambs.

The Potential Role of Copper in BAT Development

Eales et al. (1982) reported that newborn lambs presented with hypothermia (average rectal temperature of 85 °F) had low plasma Cu levels (.18 μg/mL) compared to normal values of .63 μg/mL reported in noncold-exposed newborn lambs. This observation

suggests that a maternal Cu deficiency may impair the cold tolerance of newborn lambs. Although experiments to date have not examined the impact of maternal Cu deficiency on BAT thermogenesis, there are several Cu-dependent enzyme systems that play critical roles in regulating BAT thermogenesis, including cytochrome c oxidase (electron transport system) and dopamine-ß-hydroxylase. The later enzyme regulates the synthesis of NE from dopamine in the sympathetic nervous system. Moreover, Cu deficiency has been shown to influence thyroid hormone status. In rats, Lukaski et al. (1995) found that Cu deficiency reduced plasma T_3 and T_4 concentrations, and reduced the activity of deiodinase in BAT resulting in hypothermia. With this background in mind, the objectives of this experiment were to examine the effects of maternal Cu deficiency on the endocrine control of BAT and thermometabolism in newborn lambs.

Materials and Methods

Experimental Design and Animals

Twelve multiparous twin bearing Rambouillet ewes (mean initial BW = 60 kg) were selected from a large flock using ultrasound examination during the first trimester of gestation and allotted to pens (two ewes/pen). Three months prior to lambing, ewes were randomly assigned to low- and high-Cu treatments. A basal diet (Table 1) containing 39% corn, 35% cottonseed hulls, 19% rice mill feed, 5% meat and bone meal, 1.5% cottonseed meal and .5% vitamin/mineral supplement was fed with 0 (low-Cu) or 20 ppm supplemental Cu (high-Cu) as Cu-lysine. Both treatment diets were supplemented with 2 ppm Mo as Na_2MoO_4 and .2% S as $CaSO_4$. Diets were fed once daily and feed intake adjusted biweekly based on average pen BW to meet or exceed all nutrient requirements of twin-bearing ewes with the exception of Cu (NRC, 1985). Additionally, an oral drench containing ammonium tetrathiomolybdate (Aldrich Chemical Co.) was administered to low-Cu ewes beginning 2 mo prior to lambing. The ammonium tetrathiomolybdate was dissolved in distilled water at 10 mg/mL and administered twice weekly to provide an average dose of 43 mg/h/d.

Table 1. Nutrient composition of the prenatal copper diets[a]

	Prenatal dietary copper treatment	
Nutrient	Low-Cu	High-Cu
Crude Protein, %	10.3	10.6
Calcium, %	.93	1.0
Phosphorus, %	59	.63
Sulfur[b], %	.37	.38
Molybdenum[c], ppm	2.1	2.9
Copper, ppm	7	26[d]
Zinc, ppm	60	58
Iron, ppm	93	98

[a]Analyses are expressed on a DM basis.
[b]Supplemental S in the form of $CaSO_4$.
[c]Supplemental Mo in the form of Na_2MoO_4.
[d]Supplemental Cu in the form of Cu-lysine.

NE Turnover Procedure

At lambing, lambs were weighed and immediately separated from their ewe to prevent nursing. Lambs were cleaned, placed in a small pen equipped with a heat lamp and at 2 h of age, lambs were fed pooled bovine colostrum at a rate of 30 mL/kg BW. At 4 h of age, lambs were placed in environmental chambers maintained at 68 °F. To assess the effects of prenatal Cu level on NE turnover rates in brown fat, one lamb within each twin pair was administered the tyrosine hydoxylase inhibitor, methyl-DL-tyrosine (AMPT) to effectively block NE synthesis, whereas the control lamb received physiological saline. The AMPT (Sigma Chemical Co., St. Louis, MO) was dissolved in physiological saline at a concentration of 100 mg/mL and administered i.v. at 6 h of age at a dose of 250 mg/kg BW, and repeated at 9 h of age at a dose of 125 mg/kg BW. The saline treated lambs received equal volumes of physiological saline i.v. at 6 and 9 h of age. Lambs were euthanized at 12 h of age and perirenal BAT samples were collected, weighed, quick frozen in liquid N_2, and stored at -112 °F for subsequent analysis of NE content using HPLC with electrochemical detection. Reductions in brown fat NE concentrations between AMPT and saline infused lambs were used to estimate NE turnover rates.

Blood and Liver Analysis

Ewe blood samples were collected via jugular vena puncture during the prenatal period at 2-wk intervals and at lambing. The ewes remained on their respective treatments until liver samples were collected using a Tru-Cut biopsy needle (Baxter Healthcare, Valencia, CA) at approximately 17 d postlambing. Lamb blood samples were collected at 2, 4, 6, 9 and 12 h of age. The 2-h blood samples were collected prior to colostrum feeding, and the 6- and 9-h blood samples were collected prior to AMPT or saline injections.

Lamb rectal temperatures were measured at each blood sampling time. Plasma was harvested and stored at -4 °F until analysis. Ceruloplasmin activity was measured by determining the oxidation rate of p-phenylenediamine by ceruloplasmin using colormetric procedures as previously described (Houchin, 1958). Plasma Cu concentration was determined by flame atomic absorption spectrophotometry (Model S 11, Thermo Jarrell Ash, Franklin, MA). Plasma T_3 and T_4 concentrations were determined by standard RIA procedures using assay kits. Liver mineral concentrations were determined by inductively coupled plasma-atomic emission spectroscopy with ultrasonic nebulization procedures (Braselton et al., 1997).

Statistical Analysis

The data were analyzed by the General Linear Models procedure of SAS (1989) for a randomized block design. Rectal temperature, T_3 and T_4 data were analyzed as a time series data set. Data collected at 2, 4 and 6 h of age were used to compare the high- and low Cu treatment groups. Data collected at 6, 9 and 12 h of age were used to assess the effects of AMPT treatment.

Results and Discussion

Copper Status

Duration of the treatment period and daily feed intake were not affected by prenatal Cu treatment and averaged 88 d and 3.34 kg/d, respectively. Low-Cu ewes had lower ($P < .01$) liver Cu concentrations and higher ($P < .01$) Mo concentrations compared to high-Cu ewes (Table 2). Reference values for adequate liver Cu concentrations in sheep range from 105 to 420 ppm Cu DM (Puls, 1994), suggesting that the liver Cu concentrations of low-Cu ewes were within the normal range and that liver Cu concentrations of high-Cu ewes exceeded adequate levels.

Prenatal Cu treatment had no effect on ewe plasma ceruloplasmin activity, although, ceruloplasmin activity increased ($P < .05$) during gestation and peaked at lambing. Plasma Cu concentrations were higher ($P < .05$) in low-Cu ewes compared to high-Cu ewes on days 28 and 14 prior to lambing. Gooneratne et al. (1981) also found that plasma Cu levels were elevated in sheep supplemented with Mo and S to induce a secondary Cu deficiency. Increased intakes of Mo and S are thought to increase mobilization of Cu from tissues and increase the circulating levels of insoluble Cu in blood. This further demonstrates that plasma Cu concentrations are a poor index of Cu status in ewes.

Liver Cu levels of lambs born to high-Cu ewes were 2.3 times the liver Cu levels found in the lambs born to low-Cu ewes (Table 2). Additionally, lambs born to low-Cu ewes had higher ($P < .01$) liver Mo levels than lambs born to high-Cu ewes. Prenatal Cu treatment had no effect on plasma Cu or ceruloplasmin activity in lambs.

Table 2. Effect of prenatal dietary copper treatments on liver mineral concentrations of the ewes and their lambs[a]

	Ewes			Lambs		
Mineral	Low-Cu	High-Cu	SEM	Low-Cu	High-Cu	SEM
Copper	173[b]	802[c]	133	132[b]	306[c]	35
Molybdenum	26.5[b]	4.7[c]	1.8	1.7[b]	.8[c]	.18
Zinc	126.5[b]	84.1[b]	16.6	493[b]	361[b]	79.9

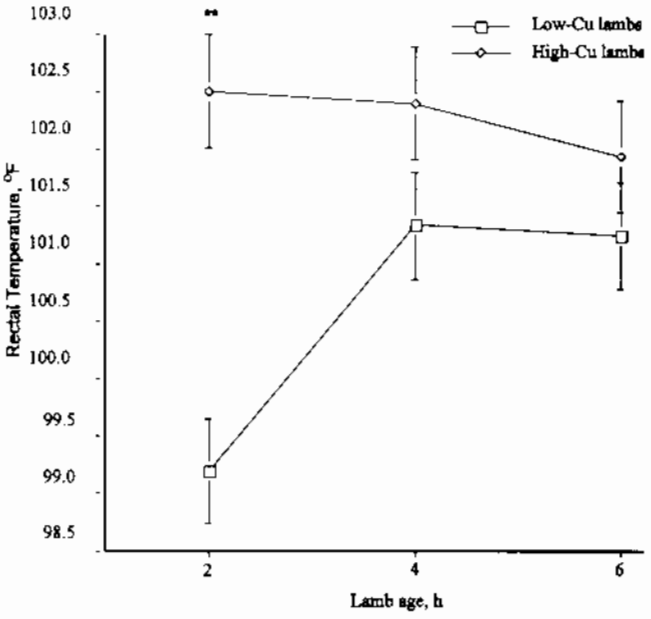
[a] Values are expressed as ppm DM.
[b,c] Values within a row and animal type without a common superscript differ ($P < .01$).

Rectal Temperatures and Birth

Prenatal Cu treatment had no effect on lamb birth weight and averaged 4.1 ± .2 kg. At 2 h of age, rectal temperatures of lambs born to high-Cu ewes were 3.3 °F higher ($P < .01$) than lambs born to low-Cu ewes. Rectal temperatures of high-Cu lambs remained numerically higher at 4 and 6 h of age (Figure 1). Average rectal temperatures during the first 6 h of life for the lambs born to low- and high-Cu ewes were 100.6 vs 102.3 ± .5 °F, respectively. During the first 6 h of life, the major event taking place in lambs is an excessive loss of heat with mild hypothermia cases occurring at rectal temperatures below 102 °F. When rectal temperature is at or below 99 °F for an extended period of time, death will occur without intervention.

In newborn lambs, approximately half of the heat generated during summit metabolism (maximal metabolic rate in response to cold) has been attributed to BAT metabolism (Alexander and Williams, 1968) demonstrating its importance in maintaining thermal balance. These data suggest that lambs born to low-Cu ewes were hypothermic due to impaired BAT metabolism. In support of this concept is that treatment with the NE blocker, AMPT, reduced ($P < .08$) rectal temperatures at 12 h of age compared to saline treated lambs (100.2 vs 100.9 ± .2 °F for the AMPT and saline treated, respectively).

Figure 1. Effect of prenatal Cu treatments on low- and high-Cu lamb rectal temperatures at 2, 4, and 6 h of age. **Treatment means differ (P < .01).



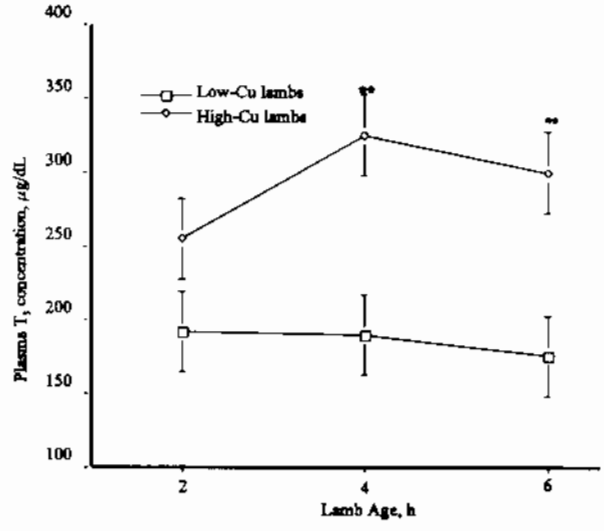
Hormone Concentrations and BAT NE Turnover Rate

Prenatal Cu treatment had no effect on the amount of BAT found in newborn lambs, or the activity of cytochrome c oxidase in BAT. However, lambs born to high-Cu ewes had higher ($P < .05$) BAT NE turnover rates compared to lambs born to low-Cu ewes (.3 vs .16 ± .04 ng/mg/h). These data suggests that lambs born to low-Cu ewes had decreased activity of the Cu-dependent enzyme, dopamine -β- hydroxylase, which is required for the conversion of dopamine to NE. Plasma T_3 concentrations were higher ($P < .01$) at 4 and 6 h of age in lambs born to high-Cu ewes compared to lambs born to low-Cu ewes (Figure 2), even though plasma T_4 concentrations were not altered by prenatal Cu treatment. Approximately 60% of circulating T_3 levels in newborn lambs are derived from the conversion of T_4 to active T_3 in peripheral tissues by the enzyme thyroxine 5' -deiodinase (Klein et al., 1980). The fact that lambs born to low-Cu ewes had lower plasma T_3 levels but similar T_4 levels suggests that deiodinase activity may have been suppressed as a result of decreased NE stimulation caused by the low-Cu treatment. In support of this idea, lambs treated with the NE blocker (AMPT) had lower ($P < .05$) plasma T_3 levels (172 vs 227 ± 17 μg/dL for the AMPT and saline-treated lambs, respectively) but similar plasma T_4 levels (5.9 vs 6.7 ± .3 μg/dL, respectively) compared to saline-treated lambs. Furthermore, Lukaski et al. (1995) have demonstrated that Cu deficient rats had reduced activity of thyronine 5' -deiodinase in brown fat and lower plasma T_3 concentrations.

Implications

For the newborn lamb to meet the high demand for Cu during the early postlambing period, it must receive adequate amounts of Cu from the ewe during late fetal development, because milk is a poor source of Cu. In this experiment, we have demonstrated that part of the newborn lamb's high demand for Cu is to support the Cu-dependent processes that regulate thermometabolism. Low-Cu lambs had lower NE turnover rates in BAT and lower plasma T_3 levels which likely contributed to lower rectal temperatures during the early postlambing period. Thermometabolism was compromised in low-Cu lambs even though the low-Cu ewes would not be classified as being Cu deficient. These results demonstrate that providing adequate dietary Cu levels during late gestation may help to prevent hypothermia, which is a major contributor to early lamb mortality.

Figure 2. Effect of prenatal Cu treatments on low- and high-Cu lamb T_3 concentrations at 2, 4, and 6 h of age. **Treatment means differ (P < .01).



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Effects of Gossypol on Thyroid Function in Young Lambs

S.W. Kuhlmann, M.C. Calhoun, J.E. Huston, B.C. Baldwin, Jr., and C.B. Calk

ABSTRACT

Thirty Rambouillet lambs (40.8 ± 3.1 lb) were used in a study to determine the effects of free and total gossypol intakes on circulating levels of triiodothyronine (T_3) and thyroxine (T_4) in sheep. Treatments were a control diet (without gossypol), three cottonseed meal diets (two expander solvent and one direct solvent) and a diet with cottonseed meats. Six lambs received each dietary treatment. Free gossypol intakes covered the range from 0 to 15.7 mg/lb LW/d and total gossypol intakes from 0 to 42.7 mg/lb LW/d. Feed intakes and live weight gains, averaged across all treatments, were 1.57 ± .13 and .25 ± .02 lb/d, respectively, and were not affected by treatment. Serum levels of triiodothyronine and thyroxine were not different for the control lambs and lambs fed the cottonseed meal diets and averaged 2.1 ± .15 ng/mL and 71 + 6.8 ng/mL, respectively. Lambs fed the cottonseed meats diet had lower serum concentrations of triiodothyronine (1.6 ± .15 ng/mL) and thyroxine (64 ± 6.8 ng/mL), than lambs fed the control or cottonseed meal diets, but these differences were not significant.

Introduction

Gossypol, a polyphenolic binaphthyl dialdehyde produced by the cotton plant and concentrated in cottonseed in discrete structures called pigment glands, is toxic to animals (Berardi and Goldblatt, 1980). The exact mechanism(s) by which gossypol exerts many of its effects are not clearly understood, but inappetance and weight loss are commonly observed in many species (Berardi and Goldblatt, 1980; Calhoun and Holmberg, 1991). Thyroxine (T_4) and triiodothyronine (T_3) are the primary thyroid hormones which regulate metabolism and growth. In recent studies with young male (Rikihisa and Lin, 1989) and female (Lin et al., 1990) rats and with young Brahman bulls (Randel et al., 1991) and 2 yr old Brangus heifers (Wyse and Randel, 1991) gossypol decreased circulating levels of thyroid hormones.

In the rat studies, the source of gossypol was gossypol acetic acid in phosphate buffer administered subcutaneously at levels of .45, 2.27 and 4.53 mg/lb live weight/d for 15 d. At 15 d, serum concentrations of T_3 and T_4 were decreased at the 2.27 and 4.53 mg/lb live weight/d levels of gossypol. In earlier work, Shi et al. (1981) reported oral gossypol at 10.89 mg/lb LW/d for three weeks had no effect on the thyroid gland of male rats, indicating gossypol was much more available when administered subcutaneously.

In a study with 6 mo old, weaned Brahman bulls, diets containing 20% cottonseed meal or 41% whole fuzzy cottonseed were fed for 35 wk. Free gossypol intakes were 1.8 and 19 g/d, respectively, for the cottonseed meal and whole cottonseed diets. Both sources of gossypol decreased serum concentrations of thyriod hormones. Cottonseed meal was as effective as whole cottonseed even though the free gossypol level in cottonseed meal was one tenth that of cottonseed (Randel et al., 1991). Similar results were not obtained in a study with female cattle. When postpubertal Brangus heifers were fed diets with either 25% solvent extracted cottonseed meal or 43% whole fuzzy cottonseed for 10 weeks, suppression in serum levels of T_3 and T_4 only occurred with the whole cottonseed. Free gossypol intakes were 5 and 15 g/d for the cottonseed meal and whole cottonseed diets, respectively (Wyse and Randel, 1991).

The purpose of this research was to assess the effects of gossypol on thyroid function in young lambs fed diets with different sources of gossypol that varied in free and total gossypol content.

Materials and Methods

Thirty Rambouillet lambs (40.8 ± 1.7 lb) were assigned at random to individual feeding pens and to five dietary treatments (six lambs/treatment). Treatments were a control diet (without gossypol), three cottonseed meal diets (two expander solvent and one direct solvent) and a diet with cottonseed meats. One expander solvent cottonseed meal (ES 1) contained .071% free and 1.02% total gossypol. The other (ES 2) contained .074% free and 1.43% total gossypol. These were selected for use in this study because they were similar in free gossypol content but very different in total gossypol, and consequently very different in bound gossypol, which is determined as the difference between free and total gossypol. This was done to examine the possibility that bound gossypol might be available and exert an effect on serum levels of thyroid hormones. The direct solvent cottonseed meal, which contained

.310% free and 1.18% total gossypol, was used to provide a cottonseed meal diet with a high free gossypol content. The cottonseed meats contained .979% free and 1.144% total gossypol, and were used to provide a diet with a very high level of free gossypol.

Diets were based on sorghum grain, dehydrated alfalfa, peanut hulls and cottonseed meal or meats and were formulated to be isocaloric and isonitrogenous (Table 1). Refined cottonseed oil and soybean meal were used to adjust fat and protein contents of the diets. Feed intake was restricted to 3.5% of live weight to ensure uniform feed intakes throughout the 56-d feeding period. Live weights were obtained initially and again at 56 d.

Table 1. Ingredient composition of the experimental diets[a]

Item	Control	CS meats[b]	CS meal[c]
Sorghum grain, milo	51.05	53.90	46.60
Alfalfa meal, dehydrated	12.50	12.50	12.50
Soybean meal, 48% CP	15.50	6.00	---
Cottonseed meal	---	---	20.00
Cottonseed meats[d]	---	10.70	---
Peanut hulls	10.00	10.00	10.00
Cottonseed oil	4.00	---	4.00
Molasses, cane	4.00	4.00	4.00
Calcium carbonate	1.00	1.40	1.40
Mono-dicalcium phosphate	.45	---	---
Ammonium chloride	.50	.50	.50
Vitamin-mineral premix[e]	1.00	1.00	1.00

[a] All diets contained 110 mg/kg thiamine mononitrate to control polioencephalomalacia.

[b] Cottonseed meats. The diet was formulated to provide 18.14 mg·lb LW^{-1}·d^{-1} free gossypol when consumed at 3.5% of live body weight.

[c] Cottonseed meal.

[d] Cottonseed meats were weighed out in the laboratory each day and mixed into the rations by hand to avoid changing the state of the free gossypol during the feed mixing process.

[e] The percentage ingredient composition of the premix was sodium chloride, 64.7; potassium chloride, 19.0; sulfur, 10.0; zinc oxide, 0.274; vitamin A (29.9 x 10^6 IU/kg), 0.73; vitamin D (29.9 x 10^6 IU/kg), 0.093; vitamin E (27.6 x 10^4 IU/kg), 0.72; chlortetracycline (110 mg/kg), 3.0; and molasses, 1.5.

Blood samples were collected via jugular venipuncture at day 56 of the study. Serum was obtained, stored frozen (–20 °C), and subsequently used for analysis of T_3 and T_4 at the Texas Veterinary Medical Diagnostic Laboratory in College Station. Total and free gossypol in the cottonseed meals and meats were determined by the official methods of the American Oil Chemists Society (AOCS, 1985a,b).

The analysis of variance for a completely random design with five treatments and equal replication was used in the statistical treatment of the data (SAS, 1985).

Results and Discussion

No clinical signs of gossypol toxicity were observed during the 56-d experimental period. There were no significant treatment effects for live weight gain, feed intake or feed requirements for gain. Across all treatments live weight gains, feed intakes and feed/gain averaged .25 ± .02 lb/d, 1.57 ± .13 lb/d and 6.6 ± .5 lb feed/lb gain, respectively (Table 2). The lack of an effect of treatments on lamb performance was not unexpected because diets were formulated isonitrogenous and isocaloric and the amount of feed offered was restricted to 3.5% of live weight/d for all treatments.

Free gossypol intakes covered the range from 0 to 15.7 mg/lb LW/d and total gossypol intakes from 0 to 42.7 mg/lb LW/d. Serum levels of triiodothyronine and thyroxine were not different for the control lambs and lambs fed the cottonseed meal diets, and averaged 2.1 ± .15 ng/mL and 71 ± 6.8 ng/mL, respectively. Lambs fed the cottonseed meats diet had lower serum concentrations of triiodothyronine (1.6 ± .15 ng/mL) and thyroxine (64 ± 6.8 ng/mL), than lambs fed the control or cottonseed meal diets, but these differences were not significant (Table 2).

Toxic effects of gossypol are related to the level and availability of gossypol consumed and duration of feeding. Although free gossypol in cottonseed meal is much more available than free gossypol in cottonseed, without a measurement of gossypol in plasma or liver, it is not possible to know how much of the gossypol consumed was actually absorbed into the body. This is more critical with cottonseed than with cottonseed meal and makes it difficult to compare the results of different studies. Based on the similar suppression of circulating levels of T_3 and T_4 when Brahman bulls were consuming 1.8 g/d of free gossypol from cottonseed meal and 19 g/d of free gossypol from cottonseed, the availability of free gossypol from cottonseed meal in the study of Randel et al. (1991) appeared to be 10-fold greater than for cottonseed. In contrast, When postpubertal Brangus heifers were fed diets with either 25% solvent extracted cottonseed meal or 43% whole fuzzy cottonseed for 10 wk, suppression in serum levels of T_3 and T_4 only occurred with whole cottonseed (Wyse and Randel, 1991). Free gossypol intakes were 5 and 15 g/d for the cottonseed meal and whole cottonseed diets, respectively, indicating a very different relationship for the relative availability of free gossypol from cottonseed meal and cottonseed in this study compared with the study of Randel et al. (1991).

The lack of an effect of the cottonseed meal diets on thyroid hormone levels in the lambs in this study agrees with the results of Wyse and Randel (1991). These

results indicate it is unlikely the use of cottonseed meal in practical production rations for lambs would adversely affect thyroid function for two reasons. One is the level of crude protein in these lamb diets (18.9% on a dry matter basis) far exceeds levels recommended by the National Research Council (NRC, 1985), even for rapidly growing early-weaned lambs (16.9%). Consequently, it is very unlikely a producer would use this much cottonseed meal in a lamb ration. The other is that direct solvent cottonseed meals with .310% free gossypol are no longer produced by the cottonseed oil mills in the U.S. Essentially all of the cottonseed meal currently is being produced by the expeller or the expander solvent process and free gossypol levels seldom exceed .20%.

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Table 2. Performance, gossypol intakes and serum triiodothyronine (T_3) and thyroxine (T_4) levels of lambs fed diets containing cottonseed meats and cottonseed meals from different processing methods

	Experimental diets					
		Cottonseed meal				
Criterion	Control	ES 1[a]	ES 2[b]	DS[c]	Meats[d]	SEM[e]
Animals, no.	6	6	6	6	6	
Initial live weight, lb	41.2	40.6	39.0	43.2	39.7	3.1
Live weight gain, lb/d	.24	.24	.22	.24	.29	.02
Feed intake, lb/d	1.57	1.56	1.48	1.65	1.57	.13
Feed/gain	6.8	6.3	6.9	7.3	5.8	.5
Gossypol intakes, mg/lb LW/d						
Total	0	30.3	42.7	35.6	18.1	.20
Free	0	2.1	2.2	9.3	15.7	.04
T_3, ng/mL	2.0	2.1	2.0	2.2	1.6	.15
T_4, ng/mL	71	73	70	70	64	6.8

[a] Expander solvent process cottonseed meal No. 1 (.017% free and 1.02% total gossypol).
[b] Expander solvent process cottonseed meal No. 2 (.074% free and 1.43% total gossypol).
[c] Direct solvent process cottonseed meal (.310% free and 1.18% total gossypol).
[d] Cottonseed meats (.979% free and 1.14% total gossypol).
[e] Standard error of the mean.

Effects of Monensin on the Availability of Gossypol in Cottonseed to Lambs

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ABSTRACT

Twenty-two Rambouillet ewe lambs (116 ± 2.7 lb) were used in a study to assess the possibility that monensin might alter the availability of gossypol in diets containing cottonseed. The lambs were maintained individually in pens at the Texas Agricultural Experiment Station (TAES) - San Angelo and fed 2.2 lb/d of a diet with10% cracked Pima cottonseed and either 0 or 30 g of monensin/ton. The cracked Pima seed contained 1.0% total gossypol. The (+) isomer was 46.9% and the ( ) isomer 53.1% of total gossypol. Calculated levels of total, (+)- and ( )-gossypol in the diet were 1,000, 469 and 531 ppm, respectively. There were no signs of gossypol poisoning, and no lambs died during the 28-d study. Although feed intake was restricted to ensure all feed offered would be consumed, lambs fed the diet with monensin ate 3.6% less feed ($P < .01$) and were selectively leaving mostly intact Pima seed. This is reflected in the greater reduction in gossypol intake (22.8%, $P < .01$) than in feed intake for these lambs. Plasma concentrations of total and (+)- and (−)-gossypol were lower in the lambs consuming the diet with monensin, reflecting their lower gossypol intakes; however, the proportion of isomers in plasma averaged 40.6 ± .82% (+) and 59.4 ± .82% (−) and was not affected by monensin. Gossypol availability, determined by calculating plasma gossypol response per unit of gossypol intake, was not affected by the addition of monensin to the diet for either total gossypol or the (+) and (−) isomers.

Introduction

Cottonseed , cottonseed meal, and cottonseed hulls are fed extensively to ruminants (cattle, sheep, and goats). All contain gossypol, a toxic polyphenolic dialdehyde. Although ruminants with a fully functional rumen are more tolerant of dietary gossypol than either young ruminants or monogastric animals because of the extensive detoxification of gossypol that occurs in the rumen, this protective mechanism can be overwhelmed (Lindsey et al., 1980; Calhoun and Holmberg, 1991; Calhoun, 1995). Decreased feed intake and animal performance are commonly reported in gossypol poisoning; however, sudden death in apparently healthy animals has also been a frequent observation. Gross lesions after death are primarily related to the effects of congestive heart failure. The most common and prominent change is increased fluid in the abdominal and thoracic cavities (Calhoun and Holmberg, 1991).

Gossypol binds to cell membranes and alters their physico-chemical properties. Increased osmotic fragility of red blood cells has been observed consistently in ruminants fed gossypol acetic acid and cotton by-products (Calhoun et al., 1990a,b). Changes in red blood cell fragility are very sensitive to gossypol intake and occur prior to changes in other blood constituents and before signs of gossypol toxicity are observed (Calhoun et al., 1990a).

Monensin, a carboxylic ionophore, also is used extensively in ruminant diets as an anticoccidial agent and for improvement in feed efficiency (Calhoun et al., 1979; Goodrich et al., 1984). Monensin alters the permeability of cell membranes (Dixon, 1990), and the pathology of monensin poisoning is similar to gossypol poisoning (Novilla, 1992). Because of this, it is important to examine the possibility that including monensin in ruminant diets might alter the availability and toxicity of gossypol.

Materials and Methods

Twenty-two replacement, Rambouillet ewe lambs (116 ± 2.7 lb) from the flock at the TAES - Barnhart Station were used in this study. During the study they were maintained and fed individually in pens at the TAES in San Angelo. Assignment to pens was at random. Prior to the study all lambs had been vaccinated with *Clostridium perfringens* (Types C and D) toxoid[1] and drenched with Tramisol®[2].

All lambs were fed 2.2 lb/d of a diet with10% cracked Pima cottonseed and containing either 0 or 30

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[1]*Clostridium perfringens* Types C and D toxoid, Anchor Laboratories, Inc., 2 mL per lamb injected subcutaneously in the neck.

[2]Levamisole hydrochloride, American Cyanamid Co., Tramisol ®, .25 g of levamisole hyrochloride was given to each lamb in 20 mL of water using an automatic drench gun.

g of monensin/ton[3] (Table 1). Eleven lambs were assigned at random to each treatment. Diets were fed daily and feed refusals recorded and discarded. Lambs were weighed at the beginning and at the end of the 28-d study and were checked daily for health problems.

Table 1. Percentage ingredient composition of the diet[a]

Item	%
Sorghum grain, milo	52.69
Alfalfa meal, dehydrated	11.25
Pima cottonseed, cracked	10.00
Peanut hulls	9.00
Soybean meal	10.08
Molasses, sugarcane	4.50
Ammonium chloride	0.45
Calcium carbonate	1.13
Vitamin-mineral premix[b]	0.90

[a] The monensin diet contained 30 g of monensin/ton.
[b] The percentage ingredient composition of the premix was as follows: sodium chloride, 66.68; potassium chloride, 19.02; sulfur, 4.92; manganese oxide, .56; zinc oxide, .54; vitamin A (13.6 x10^6 IU/lb), .81; vitamin D (13.6 x 10^6 IU/lb), .11; vitamin E (12.5 x 10^4 IU/lb), .40; chlortetracycline (50 g/lb), 2.96; and molasses, 1.98.

At 28 d, blood samples were collected by venipuncture, from the external jugular vein, into vacuum tubes containing sodium heparin as an anticoagulant. Plasma was separated, using a refrigerated centrifuge, and stored frozen (- 20 °C) until used for the determination of gossypol.

Total gossypol in the cottonseed was determined by the official method of the American Oil Chemists Society (AOCS, 1985). The (+) and (-) isomers of gossypol in the cottonseed were determined by high performance liquid chromatography after pre-column derivitization with a chiral amine [(R)-(-)-2-amino-1-propanol)] (Hron et al., 1995). Total and (+)- and (-)-gossypol in lyophilized plasma were determined by high performance liquid chromatography as described by Kim and Calhoun (1995).

A t-test was used to test for differences between treatment means (Steel and Torrie, 1960).

Results and Discussion

The cracked Pima seed contained 1.0% total gossypol on a whole seed, as fed basis. The (+) isomer was 46.9% and the (-) isomer 53.1% of total gossypol. Calculated levels of total, (+)- and (-)-gossypol in the diet were 1,000, 469 and 531 ppm, respectively. There were no signs of gossypol poisoning, and no lambs died during the 28-d study.

Although feed intake was restricted to ensure all feed offered would be consumed, lambs fed the diet with monensin ate 3.6% less feed ($P < .01$) and were selectively leaving fairly intact Pima seed. This is reflected in the greater reduction in gossypol intake (22.8%, $P < .01$) than in feed intake for these lambs (Table 2). The Pima seed were cracked using a roller mill, resulting in the seed coat actually being cracked for most of the seed, but 25.7% were not broken apart and still appeared to be intact seed. Why lambs on the diet without monensin ate all these seed, whereas lambs on the diet with monensin did not is not known, but may be related to the fact that feeds containing monensin are less palatable.

Table 2. Live weight, feed intake and gossypol intakes of lambs fed a diet containing 10% cracked Pima cottonseed, with and without monensin

	Treatment			
Item	No Monensin	Monensin[a]	SEM	P <
Live wt., lb	115	117	2.66	N.S.
Feed intake	2.20	2.12	.010	.01
Gossypol intake				
Total, g/d	.976	.753	.014	.01
Total, mg/lb LW/d	8.54	6.45	.235	.01
(+), g/d	.459	.354	.007	.01
(+), mg/lb LW/d	4.01	3.03	.110	.01
(-), g/d	.517	.399	.008	.01
(-), mg/lb LW/d	4.53	3.42	.124	.01

[a] The monensin diet contained 30 g of monensin/ton.

Plasma concentrations of total and (+)- and (-)-gossypol were lower in the lambs consuming the diet with monensin, reflecting their lower gossypol intakes; however, the proportion of isomers in plasma averaged 40.6 ± .82% (+) and 59.4 ± .82% (-) and was not affected by monensin (Table 3). Gossypol availability, determined by calculating plasma gossypol response per unit of gossypol intake, was not affected by the addition of monensin to the diet for either total gossypol or the (+) and (-) isomers (Table 3).

[3] Monensin sodium, Elanco Products Co., Rumensin$_{80}$®, containing 80 g of monensin sodium/lb.

Table 3. Plasma gossypol and plasma gossypol responses of lambs fed a diet containing 10% cracked Pima cottonseed with and without monensin

	Treatment			
Item	No Monensin	Monensin	SEM	P<
Plasma gossypol				
Total, ug/ml	5.94	4.65	.326	.01
(+), ug/ml	2.42	1.90	.141	.05
( ), ug/ml	3.53	2.75	.193	.01
(+), % of total	40.8	40.5	.824	N.S.
( ), % of total	59.2	59.5	.824	N.S.
Plasma gossypol response[a]				
Total	.701	.727	.047	N.S.
(+)	.608	.633	.045	N.S.
( )	.786	.811	.052	N.S.

[a] Plasma gossypol response = $\frac{\text{Plasma gossypol, µg/ml.}}{\text{Gossypol intake, mg/lb LW/day}}$

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Effects of Supplementation with Ferrous Sulfate, Lysine, and Vitamin E on Performance and Erythrocyte Fragility of Lambs Fed a Diet Containing Cottonseed Meal

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ABSTRACT

Eighty Rambouillet lambs (80.7 ± 1.8 lb) were randomly assigned to 16 pens (two ewes and three wethers/pen) and given ad libitum access to four dietary treatments (four pens/treatment) for 56 d. The treatments were 1) basal diet, 2) basal diet + .33% $FeSO_4$-H_2O, 3) basal diet + 1% lysine and 4) basal diet + 38.6 IU vitamin E/lb. The basal diet was based on dry-rolled sorghum grain (milo), dehydrated alfalfa hay, peanut hulls and 20% expander solvent cottonseed meal (.184% free gossypol and 1.336% total gossypol). Animals were weighed and heparinized blood was collected at 0, 28 and 56 d from three randomly selected lambs in each pen. Osmotic fragility of erythrocytes was determined by measuring the percentage of erythrocytes hemolyzed in a .75% (pH 7.4) saline solution. Live weight gains were higher ($P < .05$) for lambs fed the lysine (.363 lb/d) and vitamin E (.372 lb/d) treatments than for lambs fed the control (.295 lb/d) and ferrous sulfate (.293 lb/d) treatments. Feed intake was lower ($P < .05$) for control lambs compared to vitamin E-treated lambs (2.78 vs 3.11 lb/d), but feed intakes for these lambs were not different from lambs receiving the diets with either added iron (2.84 lb/d) or lysine (3.09 lb/d). Feed efficiency, free gossypol (FG) intakes and total gossypol (TG) intakes were not significantly different between treatments, and averaged 9.1 ± .55 lb feed/lb gain, 5.5 ± .16 mg FG/lb LW/d and 39.8 ± 1.1 mg TG/lb LW/d across all treatments. Initial erythrocyte fragility averaged 14.1 ± 2.8% hemolysis. Neither lysine nor vitamin E protected lambs against the effects of gossypol on erythrocyte fragility. At 56 d the values were 35.1, 41.8 and 44.1% hemolysis for the control, lysine and vitamin E diets, respectively. In contrast, there was not a significant increase in erythrocyte hemolysis during the 56-d period for lambs fed ferrous sulfate at a level that provided a 2.9:1 weight to weight ratio of iron to free gossypol in the diet.

Introduction

Numerous studies with poultry and swine have demonstrated the effectiveness of adding ferrous iron to the diet for reducing gossypol availability (Phelps, 1966; Tanksley and Knabe, 1981; Waldrup, 1981). However, research with ruminants is limited. Cummins and Hawkins (1982) reported that the addition of 400 ppm of iron from ferrous sulfate to a calf starter diet containing 43% whole cottonseed, fed during the period when calves were from 2 to 8 wk of age, counteracted the toxic effects of gossypol, but apparently not by decreasing gossypol absorption or sparing blood hemoglobin.

Barraza et al. (1991) conducted two studies to assess the effects of adding 500 ppm of iron from ferrous sulfate to cattle diets containing cottonseed and cottonseed meal. In one study, a diet containing 15% whole cottonseed and 15% cottonseed meal was fed to lactating dairy cattle, with and without 500 ppm of iron for 4 wk. Although cows were ingesting 23 g of free gossypol per day, there was no evidence of gossypol poisoning in cows receiving either of the diets; therefore, it was not possible to assess the value of added iron. Because the diet without added iron contained 351 ppm iron, the high level of iron in the ingredients used may have provided some protection. In the other study, male Holstein calves were fed a pelleted starter diet from 3 to 16 wk of age that contained 50.0% cottonseed, 9.0% cottonseed meal and 6.2% cottonseed hulls. Although these calves were consuming 3 g of free gossypol per day, feed intakes and gains were not different from control calves consuming a diet in which soybean meal was used as the protein source. The lack of a toxic effect of gossypol was attributed to extensive binding of gossypol when the diet was pelleted. However, since gossypol poisoning was not observed in any of the calves on this study, the value of iron was not determined.

In the studies by Cummins and Hawkins (1982) and Barraza et al. (1991) animal performance and blood measurements were used as indicators of gossypol poisoning. However, they did not determine

erythrocyte fragility. Erythrocytes of cattle, sheep and goats fed gossypol exhibit decreased resistance to osmotic stress in buffered (pH 7.4), hypotonic saline solutions (Calhoun et al., 1990a,b,c). Changes in erythrocyte osmotic fragility are very sensitive to gossypol intake and occur prior to changes in other blood constituents and before signs of gossypol toxicity are observed (Calhoun et al., 1990a,b,c). Lipid peroxidation may be a factor in the altered fragility of erythrocyte membranes of animals consuming gossypol (Kuhlmann et al., 1998). If this is the case, vitamin E (a natural antioxidant) may be beneficial in reducing the effects of gossypol on erythrocyte fragility. The binding that takes place in the rumen between the free aldehyde groups of gossypol and free epsilon amino groups of lysine is believed to be the mechanism protecting ruminants from gossypol poisoning (Riser and Fu, 1962).

The objectives of this research were to determine if dietary iron, lysine or vitamin E would 1) prevent the increase in erythrocyte hemolysis associated with gossypol consumption and 2) affect the performance of Rambouillet lambs consuming a diet containing cottonseed meal.

Materials and Methods

Eighty Rambouillet lambs (36.6 ± .81 kg) were randomly assigned to 16 pens (two ewes and three wethers/pen) and given ad libitum access to four dietary treatments (four pens/treatment) for 56 d. The treatments were 1) basal diet, 2) basal diet + .33% $FeSO_4$-H_2O, 3) basal diet + 1% lysine and 4) basal diet + 38.6 IU vitamin E/lb. The basal diet was based on dry-rolled sorghum grain (milo), dehydrated alfalfa hay, peanut hulls and 20% expander solvent cottonseed meal (Table 1). Animals were weighed and heparinized blood was collected by puncture of the exterior jugular vein at 0, 28 and 56 d from three randomly selected lambs in each pen. Osmotic fragility of erythrocytes was determined by measuring the percentage of erythrocytes hemolyzed in a .75% (pH 7.4) saline solution (Nelson, 1979). The official methods of the American Oil Chemists Society were used for the determinations of free (AOCS, 1985a) and total (AOCS, 1985b) gossypol.

The General Linear Models Procedure of the Statistical Analysis System (SAS, 1985) was used in the statistical treatment of the data. Duncan's Multiple Range Test was used to test for differences between treatments means. Differences were considered significant when $P < .05$.

Table 1. Percent ingredient composition of the experimental diets

Ingredient	Diet			
	Basal	Fe	Lysine	Vit. E
Sorghum, grain	50.60	50.27	49.35	50.60
Alfalfa, dehy	12.50	12.50	12.50	12.50
Peanut hulls	10.00	10.00	10.00	10.00
Cottonseed meal	20.00	20.00	20.00	20.00
Molasses	4.00	4.00	4.00	4.00
Calcium carbonate	1.40	1.40	1.40	1.40
Ammonium chloride	.50	.50	.50	.50
Premix[a]	1.00	1.00	1.00	1.00
$FeSO_4$[b]	---	.33	---	---
Lysine hydrochloride	---	---	1.25	---
Vitamin E[c], g	6.8	6.8	6.8	45.4

[a] The percentage ingredient composition of the premix was as follows: sodium chloride, 66.68; potassium chloride, 19.02; sulfur, 4.92; manganese oxide, 0.56; zinc oxide, 0.54; vitamin A (13.6×10^6 IU/lb), 0.81; vitamin D (13.6×10^6 IU/lb), 0.11; vitamin E (12.5×10^4 IU/lb), 0.40; chlortetracycline (50 gm/lb), 2.96; and molasses, 1.98.

[b] $FeSO_4$-$1H_2O$, .33% added to the basal diet.

[c] Vitamin E, 38.6 IU/lb of d,l-α-tocopheryl acetate added to the basal diet.

Results and Discussion

The expander solvent cottonseed meal used in this study contained .184% free and 1.336% total gossypol. Concentrations in the basal diet were 368 ppm free and 2672 ppm total gossypol. There were no signs of gossypol poisoning in any of the lambs during this study. These results are consistent with previous studies in which weaned lambs were fed diets containing 400 ppm of free gossypol from cottonseed meals for 56 d without signs of gossypol toxicity (Calhoun, et al., 1990a,b).

Initial live weight of all lambs averaged 80.6 ± 1.79 lb. Live weight gains were higher ($P < .05$) for lambs fed the lysine (.364 lb/d) and vitamin E (.373 lb/d) treatments than for lambs fed the control (.295 lb/d) and ferrous sulfate (.293 lb/d) treatments. Feed intake was lower ($P < .05$) for control lambs compared to vitamin E-treated lambs (2.78 vs 3.11 lb/d), but feed intakes for these lambs were not different from lambs receiving the diets with either added iron (2.84 lb/d) or lysine (3.09 lb/d). Feed efficiency, free gossypol intakes and total gossypol intakes were not significantly different among treatments, and averaged 9.1 ± .55 lb feed/lb gain, 5.5 ± .16 mg FG/lb LW/d and 39.8 ± 1.1 mg TG/lb LW/d across all treatments (Table 2).

Initial erythrocyte fragility averaged 14.1 ± 2.8% hemolysis. Neither lysine nor vitamin E added to the

basal diet protected lambs against the effects of gossypol on erythrocyte fragility. At 56 d the values were 35.1, 41.8 and 44.1% hemolysis for the control, lysine and vitamin E diets, respectively. In contrast, erythrocyte hemolysis was lower ($P < .05$) during the 56-day period for lambs fed ferrous sulfate at a level to provide a 2.9:1 weight to weight ratio of added iron to free gossypol in the diet (Table 2). The lack of an effect of added lysine on erythrocyte fragility is consistent with previous reports showing that gossypol poisoning was not decreased when lysine was added to the diets of poultry and swine (Phelps, 1966; Berardi and Goldblatt, 1980). The level of vitamin E added to the diet in this study was probably too low to produce a response, but results have not been consistent in studies where much higher levels of vitamin E (2,000 and 4,000 IU/d) were fed to cattle consuming diets that contained cottonseed meal (Velasquez-Pereira, 1995).

Based on the ability of ferrous iron to prevent the rise in osmotic fragility caused by gossypol in this study, it appears ferrous sulfate might be useful in helping to prevent gossypol poisoning problems when ruminants are fed diets containing cottonseed and/or cottonseed meal for extended periods.

Table 2. Effects of supplementation with iron sulfate, lysine or vitamin E on performance and erythrocyte fragility in lambs

	Diets				
Criterion	Basal	$FeSO_4$[a]	Lysine[b]	Vit. E[c]	SEM[d]
Initial live wt., lb	79.4	80.2	81.4	81.6	.813
Live wt. gain, lb/d	.295[g]	.293[g]	.364[f]	.373[f]	.010
Feed intake, lb/hd/d	2.78[g]	2.84[fg]	3.09[fg]	3.11[f]	.046
Feed/gain	9.56	9.81	8.48	8.43	.553
Gossypol intake, mg/lbLW/d					
Free	5.26	5.35	4.62	5.67	.346
Total	38.33	38.87	40.87	41.10	2.51
RBC hemolysis, %					
Initial	14.6	14.6	12.9	14.4	2.82
28-day[e]	22.6[fg]	17.6[g]	26.2[f]	24.3[fg]	2.40
56 day[e]	35.1[f]	18.3[g]	41.8[f]	44.1[f]	2.80

[a] $FeSO_4 \cdot H_2O$, .33% added to the basal diet
[b] Lysine-HCl, 1.0% lysine equivalent added to the basal diet.
[c] Vitamin E, 38.6 IU/lb of d,l-α-tocopheryl acetate added to the basal diet.
[d] Standard error of the mean.
[e] Values are least squares means adjusted by covariance for initial values.
[f,g] Means in the same row without a common superscript are significantly different ($P < .05$).

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Influence of Zinc and Manganese on Performance and Fiber Production of Rambouillet Sheep and Angora Goats

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ABSTRACT

Nine experiments are summarized in which the effects of dietary or injected zinc (and in some cases manganese) on live weight gain, fiber production, and fiber quality were established for sheep and Angora goats under a variety of conditions. Some evidence indicated that Zn and/or Mn supplementation may increase growth rate in Angora kids on range and rapidly growing kids in the feedlot. None of the situations tested indicated that Zn or Mn ions were deficient in the diets of sheep.

Introduction and Literature Review

Zinc (Zn) is an essential element that is required for normal growth, development, and function of ruminants (Mills et al., 1967). A severe deficiency of zinc can lead to death. Lesser deficiencies are most apparent in cells and tissues that grow rapidly, e.g. skin and follicles.

Zinc and sheep

The most striking clinical signs of zinc deficiency in ram lambs are impaired growth of testes and cessation of spermatogenesis. Other signs of deficiency in sheep include loss of wool, swelling and lesions around the hooves, skin lesions, excessive salivation, anorexia, a tendency to eat wool, general listlessness, and reduced growth (NRC, 1985). Zinc levels of 19 to 26 mg/kg DM appear to be adequate for growth in lambs, but a higher level (32 mg/kg DM) is required for maximum testicular development and function in rams. Zinc requirements for pregnancy and lactation have not been established. Specific requirements for Zn are hard to pinpoint because exact needs depend on the chemical form and numerous mineral interrelationships. Egan (1972) reported that providing supplemental Zn (and Mn) to grazing ewes in South Australia improved reproduction even when the Zn content of the forage appeared adequate (17 to 28 mg/kg DM). Masters and Fels (1980) also observed a 14% increase in number of lambs born and increased lamb survival when Zn was supplemented from mating, through pregnancy and lactation. Later experiments (Masters and Fels, 1985) failed to provide consistent results. Wool grown under Zn-deficient conditions tends to be brittle with less crimp than usual or no crimp at all, and the wool is finer than that grown with adequate Zn in the diet. Zinc must be supplied continuously because very little is stored in the body. Some is stored in the liver as a metallothionin. A typical concentration range for Zn in the liver is 150 to 200 mg/kg (dry weight). A decline in plasma Zn can be detected within 36 h of feeding a Zn-deficient diet (Mills *et al.*, 1967). Plasma Zn levels below .3 µg/mL are considered low. Zinc deficiency has also been associated with reduced immunity to diseases (Kegley and Spears, 1995) including footrot.

Ruminants can also get too much Zn. One gram of Zn in 1 kg of feed results in reduced feed consumption and gain in lambs (Ott *et al.*, 1966).

Manganese and sheep

Manganese (Mn) is necessary for skeletal development. The minimum requirements of sheep for Mn are not known. Mn deficiency results in impaired growth, skeletal abnormalities, and ataxia of the newborn, and depressed or disturbed reproductive functions. An adequate amount in the diet is considered to be 20 to 50 mg/kg of DM. However, symptoms of Mn deficiency have been reported when sheep were consuming diets containing 40 to 50 mg/kg of DM. A level of 1,000 mg/kg of dietary Mn is the maximum tolerable level for sheep.

Zinc and goats

Zinc deficiency in Angora goats produces hardening of the skin (parakeratinosis), hair loss (alopecia), and changes in the structure of horns and feet. Other symptoms are stiff joints, excessive salivation, swelling of feet, atrophy of testes, low libido, and reduced feed intake with subsequent weight loss (NRC, 1981). Symptoms of deficiency are developed when goats consume feed containing 4 to 7 ppm Zn. A level of 1,000 ppm Zn is toxic to goats. A minimum requirement for goats is probably 10 ppm.

Manganese and goats

Deficiency of Mn in the diet of goats produces general lethargy, a reluctance to walk, deformity in the forelegs, and reduced reproductive efficiency. Symptoms of deficiency have developed at 5.5 ppm but not at 90 ppm. Mn deficiency also results in delay in the outset of estrus in young females and in abortion and reduced kid birth weights for mature nannies. Manganese content of the hair produced by goats is the best indicator of manganese status of the animal.

Zinc (and Mn) have been introduced into sheep and goats in several different ways. Most commonly, inorganic salts and organic chelates have been mixed with feedstuffs. In experimental work, drenching has been used to provide specific quantities of aqueous solutions into sheep. However, the absorption of Zn and Mn ions from solutions and feeds introduced through the mouth into the body is low and negatively influenced by high Ca concentrations in either the feed (e.g., alfalfa hay or dormant forages) or the drinking water. Phytates in grain-based feeds, amino acids, and proteins are also capable of tying up Zn and Mn ions thus making them less available for essential processes. Most recently, subcutaneous injections of Zn and Mn chelates were used to introduce relatively small quantities into the animal's body.

Zinc, in at least four forms, has been used to alleviate or prevent deficiencies. These forms include the metallic element; simple inorganic compounds such as ZnO, $ZnCl_2$, and $ZnSO_4$; organo-zinc compounds such as Zinpro 40 (zinc methionine); and most recently, a Zn/Mn injectable chelate known as Multimin[1] or Jecta-min[1]. This last product combines Zn and Mn because conditions prevailing where deficiencies occur or could be expected are similar for Zn and Mn. Additional claims made for this injectable product, when deficiencies actually exist, include increased fiber production and production of longer, finer fibers particularly when animals are being fed with a high protein (> 16%) diet.

Over the years, researchers at this unit and their graduate students (at Texas A&M University and Angelo State University) have conducted several experiments involving the manipulation of Zn alone or a Zn/Mn mixture in the diets of sheep and Angora goats. This progress report is composed of a summary of each of these experiments conducted from 1991 to 1997. Zinpro 40® is zinc methionine containing 4% Zn and 8% methionine and is manufactured by Zinpro Corporation, Edina, Minnesota. Each milliliter of Multimin contains 20 mg Zn ions and 20 mg Mn ions in solution. It is available through Logos Agvet, Halfway House, South Africa. It may become available in the U.S. under the trade name Jecta-Min, the licensor being Technology Commercialization Transfer Ltd., Carson City, Nevada.

[1]Mention of tradenames or proprietary products does not constitute a guarantee, warranty, or recommendation of the product by the Texas Agricultural Experiment Station and does not imply its approval to the exclusion of other products that also may be suitable.

Production conditions and productivity in general are extremely variable in western Texas. Proving that a specific problem is due to a Zn or Mn deficiency would be very difficult. An alternative and reliable method of confirming mineral deficiencies is the response derived from specific mineral supplementation. This has been our general approach in the following experiments.

Procedures

Experiment 1, 1991

Two hundred and fifty-two Rambouillet wether lambs (average body weight = 68 lb) were fed for 68 d in a 3 x 3 factorial arrangement of treatments (random design, four replicates; one rep = one pen of lambs, seven lambs/pen) to establish the effects of different Zinpro 40 concentrations (0, .125, and .250%) and sources of cottonseed meal (three) in the diet on feedlot performance, carcass characteristics, and wool production and quality. Actual intakes of Zn due to the Zinpro 40 achieved in the experiment were 0, 80 and 160 mg/d.

Experiment 2, 1992-93

Six-month-old male and female Angora kid goats (28) were fed in a 112-d study to assess the effects of Zn supplementation on live weights and the quality and quantity of mohair produced. Treatments were 1) basal diet (17 ppm Zn); 2) basal diet + .125% ZnMet (50 ppm Zn); 3) basal diet + .250% ZnMet (100 ppm Zn); and 4) basal diet + Zn/Mn injection (20 mg Zn + 20 mg Mn every 28 d).

Experiment 3, 1993-94

Thirty-nine six-month-old Angora male kids were group fed in drylot in a replicated 2 x 2 factorial design to determine the effects of injectable chelated Zn/Mn solution and protein on mohair growth and quality and live weight gains. Protein treatments consisting of basal rations supplemented with either cottonseed meal alone (CSM) or cottonseed meal plus fish meal (CSM/FM) were provided to create two levels of body weight gain and mohair growth. One-half of each group was injected every 28 d with one mL of solution containing 20 mg Zn and 20 mg of Mn in chelated form. The animals were shorn prior to and following a 112-d trial. Animals were weighed every 28 d throughout the study, and blood samples were obtained prior to injection of the chelated Zn/Mn solution. Shorn fleeces were analyzed for grease fleece weight, yield, fiber diameter, staple length, and medullation. Blood samples were analyzed for Zn concentration.

Experiment 4, 1993-94 (Bohnert, 1994)

Sixty Rambouillet ram lambs (approximately 9 mo of age and 116 lb body weight) and 30 Angora male kids (approximately 7 mo of age and 55 lb body weight)

were fed *ad libitum* for 112 d in drylot to compare the effects of inorganic (ZnO) and organic (Zinpro 40) sources of zinc in the diet. The ZnO added 35.7 mg/kg of Zn to the diet while Zinpro 40 added 40 mg/kg of Zn and 80 mg/kg of methionine. Animals were shorn and weighed at the start of the study, and assigned to pens randomly (three animals/pen) after blocking on body weight. The animals were weighed every 28 d and shorn at the end of the study. Fleeces were analyzed for fiber growth per 28-d period, fleece weight, yield, fiber diameter, and medullated fiber content (in the case of mohair).

Experiment 5, 1995-96

Forty-three nursing Angora kids (male and female, 2 to 3 mo old. 17.5 ±3.6 lb) were maintained on rangeland with their dams for 128 d (March to August). The kids were assigned to two groups (treated and control) that were blocked by body weight and sex. The treated group was injected subcutaneously initially and every 28 d with 1 mL of a chelated Zn/Mn solution containing 20 mg Zn and 20 mg Mn. Animals were shorn and weighed at theend of the trial; and fleeces were analyzed for average staple length, clean yield, clean fleece weight, average fiber diameter, and medullation.

Experiment 6, 1995-96

Nineteen weaned Angora male kids (6 to 7 mo old) were fed for 112 d in drylot with a ration comparable to that described in Experiment 3 (low protein diet). The kids were assigned to two treatment groups (control and treated) that were blocked by body weight. The treated group was injected initially and every 28 d with 1 mL of a chelated Zn/Mn solution containing 20 mg Zn and 20 mg of Mn. The goats were weighed every 28 d throughout the study.

Experiment 7, 1995-96

One hundred sixty-three mature breeding Rambouillet ewes were maintained on rangeland for one production year. The ewes were assigned to two treatment groups (control and treated) that were blocked by age. Ewes in the treated group were injected initially in August and every 28 d thereafter with 1 mL of a chelated Zn/Mn solution containing 20 mg Zn and 20 mg of Mn. The ewes were weighed and then bred in September/October to lamb in March and April. Grease fleece and shorn body weights and lamb data were obtained from March to June.

Experiment 8, 1995

Forty-five female Rambouillet lambs (about 60 d old, 54 ± 11.3 lb) born in the fall of 1994 were weaned and sheared in April, 1995. Subsequently, the lambs were maintained on rangeland for 128 d. During this time they were fed free choice with a mixed ration. The lambs were assigned to two treatment groups (control and treated) that were blocked by weight. The treated group was injected initially and every 28 d with 1 mL of a chelated Zn/Mn solution containing 20 mg Zn and 20 mg Mn. The lambs were weighed at 28-d intervals throughout the study. At termination of the trial, the lambs were weighed and sheared again, and the fleeces were analyzed for greasy and clean weights of wool, staple length, and fiber diameter.

Experiment 9, 1996-97

A 3 x 2 x 2 factorial experiment was conducted with weaned Angora kid goats (6 mo; 35 lb) with three or four kids in each of two reps for a total of 78 kids in the experiment. Treatments were 0, 20, and 40 mg injections of the Zn/Mn chelate at 28-d intervals (Factor 1). Two rations (Factor 2) considered low and medium quality were fed to male and female goats (Factor 3) in confinement for 165 d. The kids were weighed and shorn at the beginning and end of the feed trial. Traits considered in the analysis were live body weight change, clean fleece growth rate, fiber diameter, lab scoured yield, staple length, med, and kemp.

Experimental Diets

Experimental diets (other than grazed forage) used in the nine experiments are described in Tables 1 through 6.

Table 1. Percentage ingredient composition of the diet used in Experiment 1

	Diet[a]	
Ingredient	Starter	Finishing
Sorghum grain, milo	27.75	67.5
Alfalfa meal, dehydrated	12.5	10.0
Cottonseed hulls	40.0	10.0
Cottonseed meal	13.5	5.0
Sugarcane molasses	6.0	5.0
Calcium carbonate	.75	1.0
Sodium chloride	.50	.50
Vitamin and mineral premix[b]	1.0	1.0

[a] The composition was changed from the starter to the finishing diet during a 2-wk adaptation period.

[b] The percentage ingredient composition of the premix was as follows: sodium chloride, 66.68; potassium chloride, 19.02; sulfur, 4.92; manganese oxide, .56; zinc oxide, .54; vitamin A (13.6×10^6 IU/lb), .81; vitamin D (13.6×10^6 IU/lb), .11; vitamin E (12.5×10^4 IU/lb), .40; chlortetracycline (50 gm/lb), 2.96; and molasses, 1.98.

Table 2. Percentage ingredient composition of the basal diet used in Experiment 2

Ingredient	%
Alfalfa meal, dehydrated	20
Sorghum grain, milo	63
Peanut hulls	10
Sugarcane molasses	5
Calcium carbonate	.5
Sodium chloride	.5
Urea	1

Table 3. Percentage ingredient composition of the diet used in Experiments 3 and 6

	Diet	
Ingredient	Low protein	High protein
Cottonseed hulls	20	20
Alfalfa hay, dehydrated	8	10
Sorghum grain, milo	60.3	54.4
Cottonseed meal	4.6	4
Fish meal	0	5.8
Sugarcane molasses	4	4
Mono-dicalcium phosphate	7	0
Calcium carbonate	1.4	.8
Salt	.5	.5
Ammonium chloride	.5	.5

Table 4. Percentage ingredient composition of the diet used in Experiment 4

	Diet	
	Zinc oxide	Zinc
Alfalfa meal, dehydrated	29.0	29.0
Sugarcane molasses	5.0	5.0
Corn	24.7	24.7
Cottonseed hulls	24.0	24.0
Cottonseed meal, 41%	7.5	7.5
Soybean meal, 47%	7.5	7.5
Ammonium chloride	.50	.50
Calcium carbonate	.50	.50
Mineral premix[a]	1.0	1.0
Vitamin premix[b]	.05	.05
Aurofac-10[c]	.15	.15
Zinpro 40[d]	0	10
Zinc oxide[e]	.10	0

[a] Premix added to the diet: 2 mg/lb of I, 13.5 mg/lb of Mn, 9.3 mg/lb of Fe, and .26 mg/lb of Co.
[b] Premix added to the diet: 2000 IU/lb of vitamin A, 1000 IU/lb of vitamin D, and 1 mg/lb of vitamin E.
[c] A product of American Cyanamid Company containing 10 g chlortetracycline per pound.
[d] The Zinpro 40 contained 18 g/lb of Zn and 36 g/lb of methionine.
[e] The zinc oxide contained 16.2 g/lb of Zn.

Table 5. Percentage ingredient composition of the diet used in Experiment 8

Ingredient	%
Alfalfa meal, dehydrated	10
Sorghum grain, milo	60
Cottonseed meal	20
Fish meal	2
Corn gluten meal	2
Sugarcane molasses	4
Mono-dicalcium phosphate	1
Vitamin/mineral premix[a]	1

[a] The percentage ingredient composition of the premix was as follows: sodium chloride, 66.68; potassium chloride, 19.02; sulfur, 4.92; manganese oxide, .56; zinc oxide, .54; vitamin A (13.6×10^6 IU/lb), .81, vitamin D (13.6×10^6 IU/lb), .11; vitamin E (12.5×10^4 IU/lb), .40; chlortetracycline (50 gm/lb), 2.96; and molasses, 1.98.

Table 6. Percentage ingredient composition of diet used in Experiment 9

	Diet[a]	
Ingredient	Low quality	Medium
Peanut hulls	12.5	12.5
Wheat straw	12.5	12.5
Sorghum grain, milo	66.5	61.0
Soybean meal	0	5.0
Sugarcane molasses	5.0	5.0
Ammonium chloride	1.0	1.0
Urea	.5	1.0
Calcium carbonate	1.0	1.0
Salt	1.0	1.0

[a] 5,000 IU of vitamin A and 10 mg of monensin sodium (Rumensin)/lb of diet.

Results

Experiment 1

No feedlot performance, carcass, or fleece traits (except clean fleece weight) were affected by level of Zinpro. The probable reason was that there was no Zn deficiency in the diet.

Experiment 2

Live weight, average daily gain, mohair production, yield, fiber diameter, staple length, and medullation were unaffected by treatments. During the study, live weight gain averaged only .07 lb/d. High variations among animals were present in all the measured traits.

Experiment 3

Results are summarized in Table 7. Injections of Zn/Mn produced higher (P = .04) daily body weight gains and tended to increase clean fleece weight (P = .13) and percentage of kemp fibers (P = .10). Although kemp fiber contents tended to be higher in the goats injected with Zn/Mn, they were within the normal range. The goats consuming CSM/FM diet produced more mohair (P = .04) and tended to have higher daily body weight gains (P = .18) and coarser mohair fibers (P = .18). No differences (P > .4) were observed between feed treatments for staple length, med, and kemp. The treatment x Zn/Mn interaction was not significant (P > .25) for most of the traits measured, the exceptions being clean yield (P = .06) and med fibers (P = .10). Content of Zn in the blood serum of injected goats was not different than in untreated animals (.97 vs .95 ppm) and was within the normal range. These results indicate that this low level of injectable chelated Zn/Mn solution had an effect on the anabolic processes of these rapidly growing goats even when fed rations adequate in Zn and Mn (41 to 48 and 66 to 72 ppm, respectively).

Table 7. Main effects of protein source and an injectable zinc/mangqanese (Zn/Mn) preparation on performance, fleece production and fiber characteristics of Angora goats in Experiment 3

	Diet[a]			Zn/Mn		
Item	CSM	CSM/FM	P	Control	Injected	P
Animals, No.	21	18	--	19	20	--
Initial weight, lb	67.2	68.3	.39	68.1	69.2	.73
Final weight, lb	99.3	106.6	.13	98.9	107.0	.09
Daily gain, lb/d	.27	.31	.18	.26	.32	.04
GFW[b], lb	5.0	5.7	.04	5.1	5.6	.13
Clean yield, %	78.1	75.7	.10	77.3	76.4	.54
CFW[c], lb	3.9	4.3	.05	4.0	4.3	.13
Fiber diam., μm	30.4	31.1	.18	30.5	31.0	.35
Staple length, in	4.2	4.2	.76	4.2	4.2	.71
Med fibers, %	.41	.38	.87	.44	.34	.29
Kemp fibers, %	.09	.14	.39	.07	.15	.10

[a] CSM = cottonseed meal and CSM/FM = cottonseed meal/fish meal diets.
[b] Grease fleece weight.
[c] Clean fleece weight.

Experiment 4

Zinc source did not affect live weight gain, feed intake, or feed/gain in either the sheep or the goats. Fleece production and quality were not affected by zinc source. This study did confirm that Angora billie kids are more than twice as efficient at converting feed to fiber compared to Rambouillet ram lambs.

Experiment 5

Kids in the treated group exhibited a higher average daily gain than control animals (.21 vs .19 lb/d, P = .02), and males gained at a faster rate than females (.22 vs .17 lb/d, P < .0001). Treatment did not affect fiber production or any of the measured properties (P > .15). Male kids grew more clean mohair than females (2.0 vs 1.7 lb, P = .02).

Experiment 6

Goats in the treated group tended to gain at a faster rate than the control animals (.22 vs 19 lb/d, P = .16). This level of significance does not give a clear indication that the Zn/Mn injections actually made a difference.

Experiment 7

The results of this experiment are summarized in Table 8. The Zn/Mn chelate injections apparently had no effect on any of the properties measured. Unfortunately, another problem occurred during this experiment; only a fraction (61%) of the ewes were bred. Even this percentage was unaffected by treatment. These results indicate that deficiencies in Zn and Mn did not exist at the Barnhart, Texas ranch location in the 1995-96 production year.

Table 8. Lamb and wool production of mature Rambouillet ewes given an injectable zinc/manganese preparation every 28 days for one production year (Experiment 7) August 1995 to June 1996

	Treatment	
Item	Control	Zn/Mn
Number of ewes shorn	77	86
Number of ewes lambing	49	51
Number of lambs weaned		
Per ewe in flock	0.66	0.60
Per ewe lambing	1.04	1.02
Pounds of lamb		
Per ewe in flock	35.6	28.8
Per ewe lambing	56.0	48.6
Pounds of wool		
Per ewe	9.86	10.05

Experiment 8

Treatment did not affect rate of body weight gain, final weight, or any of the fleece properties of these lambs. However, several of the lambs periodically escaped the experimental pasture during the study and did not consume the feed consistently. This reduced the overall average gain of the lambs and moreover, disproportionally reduced the gain and increased variation in gain in the Zn/Mn group.

Experiment 9

The results of this experiment are summarized in Table 9. Neither the mineral injections nor the rations resulted in any measurable effects on the rates and traits measured. Male kids gained weight at a faster rate than females and produced higher yielding fleeces (P < .05). These results confirmed previous observations (Experiment 2) that, when diet quality and(or) intake is low, a Zn/Mn chelate injected at 28-d intervals does not affect either growth rate or mohair characteristics in Angora goats. Consequently, injections of this product cannot be recommended for improving the performance of Angora kid goats under the conditions of this experiment.

Discussion

It is well established that both Zn and Mn are required elements for mammalian animals. Presence of these elements in the proper range is necessary for normal enzyme activities. However, the low requirement levels, variability in content of these elements in forages and feed ingredients, and inherent animal differences in response to nutritional treatments cause difficulty in determining efficacy of either dietary or injected supplemental supplies of these elements. In some cases (Experiments 3, 5, and 6), the injected

chelates seemed to cause increases in growth rate. In most of the studies, the treated animals showed no advantage in the response criteria (growth rate, fleece growth and characteristics, and reproduction). There was a general trend that responses were observed when performance was high (ADG > .20 lb/d in Experiments 3, 5, and 6) but not observed when performance was low (ADG < .10 lb/d in Experiments 2 and 9). Also, there was no indication that either Zn or Mn was below requirements level in any of the experiments. Therefore, recommendations for general use of the supplemental Zn/Mn sources used in these studies to enhance production seem inappropriate. Circumstances may exist such that animals will be more productive when these products are used.

Implications

The use of supplements (dietary or injected) of Zn/Mn likely will cause increases in performance of animals consuming diets deficient in these elements and providing adequate nutrition to support high performance. Animals fed low-quality diets did not respond to these treatments. However, these elements were not low in the diets provided and are not likely to be low in the region in which these studies were conducted. A general recommendation that these elements be supplementally provided seems inappropriate. However, high-performing animals may respond to elevated Zn/Mn supplies, especially if these elements are marginal in the diet.

Table 9. Main effects of chelated zinc/manganese injections at 28-day intervals, ration type, and sex on live body weight change and mohair growth rate and characteristics in Angora kid goats (Experiment 9)

	Zn/Mn, mg			Diet		Sex		
Item	0	20	40	Low	Medium	Male	Female	SEM
No. of animals	26	26	25	39	38	42	35	--
Avg. daily gain, lb/d	.06	.05	.05	05	.06	.07[a]	.04[b]	.01
Clean fleece growth, g/d	8.1	8.9	8.8	8.4	8.8	8.6	8.6	.76
Fiber diameter, μm	26.6	26.6	26.4	26 6	26.5	26.3	26.8	.87
Lab scoured yield, %	74.1	73.3	75.9	74.4	74.4	76.3[a]	72.6[b]	1.30
Staple length, in	5.3	5.0	5.2	5.1	5.2	5.0	5.4	.30
Med fibers, %	.55	.49	.56	.61	.46	.48	.58	.35
Kemp, %	.20	.18	.11	.16	.16	10	.22	.26

[a,b] Means within a row with different superscripts differ ($P < .05$).

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Nutritive Value of Guajillo (*Acacia berlandieri)* as a Component of Goats' Diets

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ABSTRACT

Four Angora male goats were used in a latin square experimental design to determine the nutritive value of guajillo (*Acacica berlandieri*) as a component of goats' diets. Dried guajillo leaves and alfalfa hay were chopped and mixed to prepare four diets. The experimental treatments (diets) contained 0, 25, 50 and 75% of dried guajillo leaves. The feeding regime consisted of 10 d of adaptation period and 7-d collection period. Feeds were offered twice daily and water was offered three times per day. Samples of diets and feces were analyzed for DM, OM, N, ADF, NDF, lignin, cellulose, gross energy, and tannins. Urine samples were analyzed for N and gross energy. Dietary level of guajillo had no effect ($p > 0.05$) on DM and OM intakes. However, water intake and urine output decreased ($P < .05$) with increasing level of guajillo in the diets. The digestibility of all the nutrients decreased ($P < .05$) with increasing level of guajillo. Energy balance and nitrogen balance expressed as percent intake were negatively affected by increasing level of guajillo. The lower availability of N can be explained mainly by the increasing ADF-N and BSA (bovine serum albumin) precipitation with increasing level of guajillo in the diets.

Introduction

Rangelands are the major source of feed for both domestic and wild ruminants. On a worldwide basis, rangelands contribute about 70% of the feed needs of domestic ruminants and over 95% of the feed needs of wild ruminants. Rangelands in the United States provide domestic ruminants with up to 65% of their total feed needs (Holechek et al., 1995). *Acacia* species cover large areas throughout southern and southwestern Texas. Guajillo (*Acacia berlandieri* Benth) occurs on more than 2.4 million ha in Southern Texas (Fulbright et al., 1991). This species may constitute up to 37% of a herbivore's diet (Barnes et al., 1991). Moreover, in the region of guajillo occurrence, some areas may be completely dominated by the shrub, making it the only source of forage on the range.

Proximate analysis (Barnes et al., 1991) suggests that the nitrogen content of *Acacia berlandieri* is high. However, *Acacia berlandieri* is known to contain a number of allelochemicals (Clement et al., 1997). The nutritive value of forage depends on the intake of feed, and the extent to which the quantity eaten by the animal supplies dietary energy, proteins, minerals and vitamins. Although some is known about the effects of phenolic amines on endocrine function and reproductive performance (Forbes et al., 1993; Forbes et al., 1994a; Forbes et al., 1994b; Carpenter et al., 1994; Vera-Avila et al., 1996), little is known about the nutritive value of *Acacia berlandieri* leaves as a component of livestock diet. This information void makes it difficult to plan grazing for goats on guajillo range when the animals are used for production purposes. The objectives of this study are to analyze the effects of dietary level of *Acacia berlandieri* on the voluntary intake, digestibility of nutrients and metabolism of nitrogen using goats as a model.

Materials and Methods

Diets were prepared with dried guajillo leaves and alfalfa hay. Both alfalfa hay and guajillo leaves were chopped through a 1-cm screen to reduce sorting by the animals when fed. A metabolism trial was conducted for mixed diets with different levels of dried guajillo leaves and alfalfa hay. Four complete mixed diets were prepared: 1) 0% guajillo; 2) 25% guajillo; 3) 50% guajillo; 4) 75% guajillo. Four Angora male goats were used in a latin square design experiment. The feeding regime consisted of 10 d of adaptation period and 7 d collection period. Feeds were offered twice daily, and water was offered three times per day. The animals had free access to mineral blocks. Refusals were collected daily. Total feces and urine outputs were collected daily. A 10% aliquot of feces was pooled by animal, sub sampled at the end of each collection period, dried at 55 °C and ground for chemical analyses. Total urine was collected in containers containing 100 ml of 0.1 N HCl. A 10% aliquot was composited by animal and frozen for chemical analyses. Samples of diets and feces were analyzed for DM, OM, N, ADF, NDF, lignin, cellulose, gross energy, and tannins. Urine samples were analyzed for N and gross energy. Data were analyzed as latin square experimental design using GLM procedure of SAS (1988).

Results and Discussion

Characteristics of the diets

The characteristics of the four diets fed to goats during the trial are presented in Table 1. Cellulose and N content decreased with increasing levels of guajillo in the diet. Organic matter, NDF, ADF, ADF-N, lignin and energy increased with increasing levels of guajillo in the diets.

Table 1. Characteristics of the diets fed to goats in the metabolism trial

	Diet			
Item	0%	25%	50%	75%
Ingredient (% as-fed)				
Alfalfa hay	100	75	50	25
Guajillo leaves	0	25	50	75
Analysis (% DM)				
DM	89.5	89.7	90.0	90.4
OM	88.3	89.6	90.6	91.7
N	3.5	3.4	3.2	3.0
NDF	40.8	41.9	43.4	43.5
ADF	26.4	27.6	28.1	31.9
ADF-N	0.46	0.62	0.83	0.90
Cellulose	19.4	18.9	17.9	17.4
Lignin	5.6	6.2	6.7	7.3
Energy (cal/g DM)	4315.8	4414.5	4607.4	4731.9

Intakes

Intakes of DM, OM and of water are presented in Table 2. DM and OM intakes were not affected ($P > .05$) by the level of guajillo in the diets. However, water intake and urine output were affected ($P < .05$) by the level of guajillo fed.

Table 2. Intake of goats (g/kg BW) and urine output (g/day) as affected by the levels of guajillo in the diets

	Diets			
Item	0%	25%	50%	75%
DM	28.6a	30.0a	28.6a	29.4a
OM	25.3a	26.9a	25.9a	26.9a
Water	2262.7a	1974.6ab	1767.6ab	1413.6b
Urine	1513.2a	1172.5a,b	1000.9b	756.4b

a,b Least squares means. Means in the same row followed by different letters are significantly different ($P < 0.05$)

Digestibility of nutrients

The coefficient of digestibility (COD) of DM, OM, N, energy, NDF and ADF decreased as guajillo level in the diet increased (Table 3). Dry matter digestibility of guajillo leaves fed to white-tailed deer varied from 35.2 to 48.1% (Barnes et al., 1991). Dry matter digestibility of guajillo obtained in this study by regression is 36.1% ($n = 16$; $P = 0.0001$, $R^2 = 0.9168$). Intake is a multi-functional event and cannot be predicted from digestibility studies alone. Several studies indicate that dry matter digestibility (DMD) is not a guide to intake. For example DMD was not a guide to intake of *Albizia lebbeck*, where sheep consumed more fallen leaves of DMD of 43% than fresh leaves of DMD of 64%. Also, goats consumed similar amounts of *Leucaena* (35.5 g/kg BW) and *Gliricidia* (32.6 g/kg BW) despite large differences in digestibility, 68.0 vs 56.3%, respectively (Kaitho et al., 1997).

Table 3. Digestibiligy of nutrient (%) in the four diets fed to goats in the metabolism trial

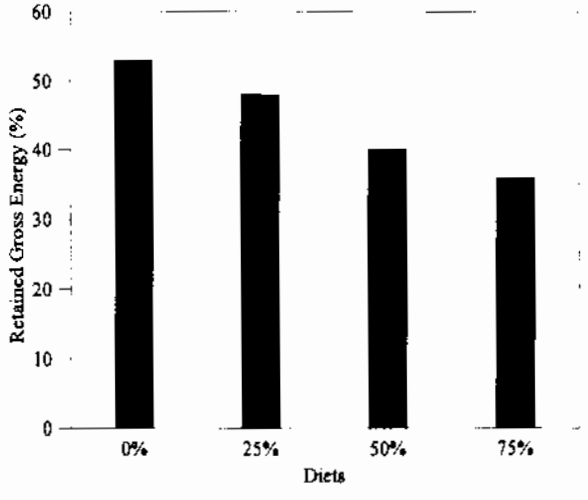
	Diets			
Items	0%	25%	50%	75%
DM	59.3a	54.0b	48.3c	41.6d
OM	61.9a	56.3b	50.3c	43.8d
N	73.1a	63.9b	54.3c	42.8d
Energy	57.9a	52.2b	45.9c	40.8d
NDF	46.5a	32.0b	20.4c	5.6d
ADF	43.1a	23.7b	6.7c	0.0d

a,b,c,d Least squares means. Means in the same row followed by different letters are significantly different ($P < .05$).

Gross energy balance

Gross energy (GE) balance is presented in Figure 1. When retained GE was expressed as a % of intake, guajillo level in the diet negatively affected ($p < 0.05$) retained energy. Retained GE was higher for goats eating 0 or 25% guajillo and lower for goats eating 50 or 75% guajillo.

Figure 1. Gross energy retained (% of gross energy intake).



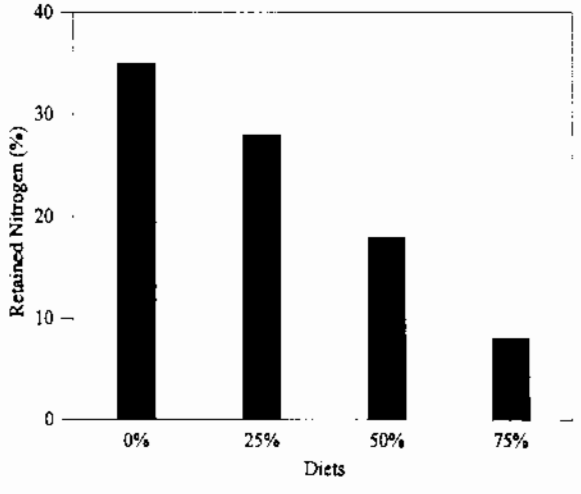
Total output of GE was affected by level of guajillo in the diets. Goats assigned diets of 0 or 25% guajillo in the diets had lower total output of GE. Feces is the major source of output for GE. Fecal GE output was lower for goats fed 0% guajillo diet when expressed as % of total GE output.

Nitrogen balance

Nitrogen balance is presented in Figure 2. Nitrogen retained was affected ($P < .05$) by the level of guajillo in the diet. N retained decreased with increasing levels of guajillo in the diet. Retained N, expressed as a % of intake was higher for goats eating 0 or 25% guajillo diets, intermediate for goats eating 25 or 50% guajillo diets and lower for goats eating 50 or 75% guajillo diets.

Total N output expressed as a % of intake was lower for goats eating 0 or 25% guajillo diets, intermediate for goats eating 25 or 50% guajillo diets and higher for goats eating 50 or 75% guajillo diets. Fecal N output increased with increasing levels of guajillo in the diets while urinary N output decreased with increasing levels of guajillo in the diets indicating that most N compounds in guajillo are eliminated through the feces.

Figure 2. Retained nitrogen (% of nitrogen intake).



ADF-N and BSA precipitation

The content of ADF-N and the BSA precipitation of each diet is presented in Table 4. Both ADF-N and BSA precipitation increased ($P < .05$) with increasing level of guajillo in the diets. Available N is a function of plant N content, the amount of nondigestible fiber-bound N, and the extent of N precipitation by tannins. Therefore, dietary level of guajillo decreased the availability of N by increasing ADF-N and BSA precipitation.

Table 4. ADF-N and BSA (bovine serum albumin) precipitation of the four diets fed to goats in the metabolism trial

	Item	
Diets	ADF-N (%)	mg BSA precipitated/mg diet
0 %	13.0 a	0.14 a
25 %	18.2 b	0.18 a
50 %	22.0 b	0.45 b
75 %	30.2 c	0.87 c

[a,b,c] Least squares means. Means in the same row followed by different letters are significantly different ($P < .05$).

Conclusion

Dried guajillo leaves as a component of goats' diets had no effect on DM or OM intake. However, the digestibility of the nutrients (DM, OM, N, energy, NDF and ADF) are negatively affected by the level of guajillo leaves in the diets. Energy balance and nitrogen balance (expressed as percentage of intake) are both negatively affected by the level of guajillo in the diets. Increases in ADF-N and BSA precipitation with increasing guajillo in the diets will reduce N availability. As the nutritive value of forage depends not only on the intake, but also the extent to which the quantity eaten by the animal supplies dietary energy, proteins, minerals and vitamins, improving the digestibility of the nutrients would improve animal production.

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Reproductive Performance of Rambouillet Rams Supplemented with Cottonseed Meal

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ABSTRACT

Twenty yearling Rambouillet rams (203 ± 13.2 lb) were fed diets containing soybean meal (SOM), expander solvent (ES) or direct solvent (DS) cottonseed meal (CSM) for 6 or 16 wk to assess the effects of gossypol intake and duration of feeding on reproductive performance of rams. Diets were formulated to be isocaloric and isonitrogenous. Four rams received each of the treatments, which were SOM continuously, SOM for 10 wk and ES CSM for 6 wk (ES6), ES CSM for 16 wk (ES16), SOM for 10 wk and DS CSM for 6 wk (DS6) and DS CSM for 16 wk (DS16). Cottonseed meal diets were fed for 3 and 13 wk prior to breeding and for the first 3 wk of the breeding season. Free (FG) and total (TG) gossypol levels in the ES and DS CSM were .131, 1.123 and .284, 1.142% (as fed basis), respectively. During the period (either 6 or 16 wk) that CSM was in the diets, FG and TG intakes were 0, 0; .57, 4.86; .59, 5.07; 1.12, 4.50 and 1.33, 5.35 g/d for the SOM, ES6, ES16, DS6 and DS16 treatments, respectively. Red blood cell (RBC) osmotic fragility was increased ($P < .01$) by treatments. At 12 wk, RBC hemolysis values were 12.1 (SOM), 26.7 (ES6), 34.6 (ES16), 17.9 (DS6) and 41.8% (DS16). Differences between ES and DS CSM were not significant, but duration of feeding CSM affected RBC hemolysis (ES6 vs ES16, $P < .05$; DS6 vs DS16, $P < .01$). At the beginning of wk 14, two rams from each treatment were fitted with a marking harness and each ram was placed with a breeding group of ten ewes for 6 wk. In semen collected by electroejaculation at 14 and 20 wk, there were no effects of CSM treatments on sperm concentration and motility. Libido was not affected by CSM treatments. Pregnancy rate (no. ewes pregnant/no. ewes exposed) based on ultrasound measurements at approximately 60d post-breeding were 18/20 (SOM), 17/19 (ES6), 20/20 (ES16), 19/20 (DS6) and 18/20 (DS16). Although the level of CSM used in these diets greatly exceeded the amount required to meet the protein requirements of yearling rams, there was no evidence of an adverse effect of CSM/gossypol on reproductive performance.

Introduction

Since the original observation over 30 yr ago that gossypol intake was associated with infertility in men in China there has been considerable interest in the possibility that gossypol might be valuable as a male contraceptive agent (Xue, 1985). Subsequent research has stimulated concerns about the safety of feeding large amounts of direct solvent cottonseed meal and/or cottonseed to breeding cattle or sheep (Randel et al., 1992). Evidence to support these concerns is based largely on observed changes in laboratory measurements of female and male reproductive functions and histopathologic changes in reproductive tissues. Only limited information is available to determine the practical relevance of the observed gossypol-induced changes because the laboratory studies generally have involved very high levels of gossypol to ensure an effect and usually have not been accompanied by attempts to use the gossypol-treated animals for breeding (Calhoun and Holmberg, 1991). Regardless of this limitation, there are numerous references in the literature suggesting the need for caution when feeding gossypol-containing cottonseed products to breeding animals. This study was conducted to determine the effects of feeding diets containing a high free gossypol direct solvent cottonseed meal and a low free gossypol expander solvent cottonseed meal prior to and during the breeding season on the reproductive performance of Rambouillet rams.

Materials and Methods

Animals and Feeding

Twenty yearling Rambouillet rams (203 ± 13.2 lb LW), maintained and fed in individual pens (10' x 20'), were assigned at random to five dietary treatments (four rams/treatment). The dietary treatments were (1) soybean meal(SOM), (2) expander solvent (ES) cottonseed meal(CSM) for 6 wk (ES6), (3) direct solvent(DS) CSM for 6 wk (DS6), (4) ES CSM for 16 wk (ES16) and (5) DS CSM for 16 wk (DS16). All diets were formulated to contain 17.5% crude protein (Table 1).

Table 1. Percentage ingredient composition of the experimental diets

	Diet			
Ingredient	SOM[a]	ES[b]	DS[c]	Ewe[d]
Sorghum grain	31.50	32.60	32.60	39.00
Dehydrated alfalfa meal	15.00	15.00	15.00	20.00
Peanut hulls	29.50	25.00	25.00	30.00
Soybean meal, 47.5% CP	15.00			3.00
ES cottonseed meal[b]		18.40		
DS cottonseed meal[c]			18.40	
Molasses	6.00	6.00	6.00	6.00
Calcium carbonate	.90	1.50	1.50	
Mono-dical phosphate	.60			.50
Vitamin-mineral premix[e]	1.00	1.00	1.00	1.00
Ammonium chloride	.50	.50	.50	.50

[a] Soybean meal
[b] Expander solvent cottonseed meal
[c] Direct solvent cottonseed meal.
[d] Diet fed to the ewes
[e] The percentage ingredient composition of the premix was as follows: sodium chloride, 66.68; potassium chloride, 19.02; sulfur, 4.92; manganese oxide, 0.56; zinc oxide, 0.54; vitamin A (13.6 x10^6 IU/lb), 0.81; vitamin D (13.6 x 10^6 IU/lb), 0.11; vitamin E (12.5 x10^4 IU/lb), 0.40; chlortetracycline (50 gm/lb), 2.96; and molasses, 1.98.

Rams were placed into their pens and the experiment was started thirteen weeks prior to the fall breeding season. The control Rams were fed the SOM diet for 16 wk. Rams assigned to the ES6 and DS6 treatments were fed the SOM control diet for 10 wk and then switched to their respective cottonseed meal diets for 6 wk. Rams assigned to the ES16 and DS16 treatments were fed these diets for 16 wk.

One hundred yearling Rambouillet ewes were randomly distributed into 10 pens (10' x 30') with 10 ewes/pen. At the end of the 13th week two rams from each treatment were fitted with marking harnesses and each ram was then placed with a group of ten ewes for a six week breeding period. During the breeding period, the ewes were provided with free choice access to the ewe diet given in Table 1. The first 3 wk of the breeding period rams continued to receive their respective cottonseed meal treatments. Consequently, they were separated from the ewes at feeding time. For the last 3 wk of the breeding period, ewes and rams were fed together and had free choice access to the ewe diet.

Upon completion of the breeding period, the ewes were removed from the pens and placed on native pasture. At the beginning of the breeding period, ten rams were taken to a commercial lamb slaughter facility and the testicles were collected after the rams were killed. Because of the size of the rams it was difficult to do this without slowing down plant operations, consequently the remaining 10 rams that had been used for breeding were castrated at a local veterinary clinic at the end of the breeding period.

Observations and Analysis

All animals were weighed initially and at 28-d intervals during the study. Dietary treatments were weighed and fed daily and feed not eaten was collected and weighed weekly. All animals were observed daily for signs of illness. When necessary a veterinarian was consulted and appropriate treatments administered.

Heparinized whole blood samples were collected from the rams by puncture of the external jugular vein initially and at 28-d intervals during the study. These samples were used for the determination of red blood cell (RBC) osmotic fragility in buffered (pH 7.4) hypotonic (.75%) saline solution (Nelson, 1979).

Scrotal circumference was measured at 28-d intervals during the study. However, an additional measurement was taken when the rams were placed with the ewes on d 91. Semen was collected by electroejaculation from all 20 rams at 91d and from the 10 rams used for breeding at 140 d for a qualitative assessment of semen quality (sperm motility and concentration). Testicles obtained from the experimental animals were measured, weighed and inspected for gross abnormalities. The epididymis were removed and inspected for gross changes. Two sections from the right and two from the left testicle were fixed in Bouin's solution for 24 h and then maintained in 70% ethanol until processed for histology. These tissues were subsequently embedded in paraffin and five micron sections were cut and stained with hematoxylin and eosin.

Slides were evaluated for changes in the tunica albuginea, the interstitium (connective tissue, Leydig cells, blood vessels) and seminiferous tubules (basement membrane, germinal epithelium, lumen). The slides were evaluated without previous knowledge of the experimental treatments. Results were checked by a second blind reading of the same slides after several days.

Ovulation rates were determined by laparoscopic examination approximately 7 d after the ewes were bred (Seeger et al., 1980). Pregnancy rates were determined by real-time ultrasound imaging at 60 to 75 d after breeding. Birth rates were calculated as lambs/ewe exposed and lambs/ewe lambing, and birth weights were determined for all lambs.

Free and total gossypol in cottonseed meal were determined by the official methods of the American Oil Chemists Society (AOCS, 1985a,b).

The General Linear Models Procedure (GLM) of the Statistical Analysis System (SAS, 1985) was used in the statistical treatment of the data. The experimental

design for this study was completely random. Single degree of freedom orthogonal contrasts were used to separate out and test treatment effects for the live weight and RBC fragility measurements. Treatment comparisons were: (1) control vs all CSM treatments, (2) ES CSM vs DS CSM, (3) ES CSM 6 wk vs ES CSM 16 wk and (4) DS CSM 6 wk vs DS CSM 16 wk. Initial RBC fragility was used as a covariant for the subsequent fragility measurements. Chi-square analysis was used to test for treatment effects on ovulation rates, pregnancy rates and lambing rates.

Results

Health of the rams during this study was excellent. There were no signs of gossypol poisoning. The health of the yearling ewes also appeared to be excellent, however one ewe was removed from the ES6 treatment because a fluid filled cyst was found during laparoscopic examination.

Free and total gossypol in the ES CSM and DS CSM and the calculated values for the diets are presented in Table 2. All values are reported on an as fed basis. Free gossypol in the DS CSM was slighty more than double the value for the ES CSM (.284 vs .131%), but total gossypol was similar for the two meals. Free and total gossypol intakes (Table 3) reflect the differences in the gossypol concentrations in the diets and the length of time each was fed. Live weight gains and feed intakes were similar across all treatments for the entire feeding period (data not shown).

Table 2. Free and total gossypol in cottonseed meals and diets

	Expander solvent		Direct solvent	
Item	Meal	Diet[a]	Meal	Diet[a]
Free gossypol[b]				
%	.131	.024	.284	.052
ppm	1,310	240	2,840	520
Total gossypol[c]				
%	1.123	.207	1.142	.210
ppm	11,230	2,070	11,420	2,100

[a] Calculated values.
[b] Determined by the Official Method of the American Oil Chemists Society (AOCS, 1985a).
[c] Determined by the Official Method of the American Oil Chemists Society (AOCS, 1985b).

Values for the percent hemolysis of RBC incubated in a buffered (pH 7.4) saline solution (.75% NaCl equivalent) are summarized in Table 4. Values for the control rams decreased throughout the study from 22.1% initially to 12.5% at 140 d. Values remained fairly constant throughout the study for rams fed the ES CSM diet for 6 wk. These rams were not switched from the control diet to the ES CSM diet until d 56 of the study. Rams fed the DS CSM for 6 wk were also switched from the control diet to the DS CSM diet on d 56, but RBC hemolysis values were increased for this group at 112 and 140 d.

Table 3. Free and total gossypol intakes of Rambouillet rams fed diets containing expander solvent (ES) and direct solvent (DS) cottonseed meal (CSM) for either six or sixteen weeks[a]

	ES CSM		DS CSM	
Item	6 wk	16 wk	6 wk	16 wk
Rams, no.	4	4	4	4
Gossypol intake, g[b]				
Free	21.8	64.3	43.1	144.4
Total	187.1	550.8	173.1	580.2
Gossypol intake, g/d[c]				
Free	.57	.59	1.21	1.33
Total	4.86	5.07	4.50	5.35
Gossypol intake, mg/lb I.W/d[c]				
Free	1.13	1.25	2.46	2.87
Total	9.71	10.70	9.89	11.52

[a] Cottonseed meal diets were fed for 3 and 13 wk prior to breeding and for the first 3 wk of the breeding season.
[b] The total amount of gossypol consumed for the entire period cottonseed meal was fed.
[c] Daily gossypol intakes during the period when cottonseed meal was fed.

Table 4. Red blood cell hemolysis in a buffered (pH 7.4) saline solution (.75% NaCl equivalent) of Rambouillet rams fed a control diet with soybean meal (SOM) and diets containing either expander solvent (ES) or direct solvent (DS) cottonseed meal (CSM) for either six or sixteen weeks[a]

		ES CSM		DS CSM		
Item	SOM	6 wk	16 wk	6 wk	16	SEM
RBC hemolysis, %						
Initial	22.1	28.1	22.0	23.2	24.6	6.8
28-d	14.6	24.8	19.6	19.3	18.0	2.3
56-d	15.2	29.8	34.6	21.0	33.3	4.3
84 -d	12.1	26.7	34.6	17.9	41.8	3.8
112-d[b]	12.3	21.5	43.5	27.9	30.9	1.6
140-d[b]	12.5	25.1	29.8	35.2	23.5	1.7

[a] Cottonseed meal diets were fed for 3 and 13 wk prior to breeding and for the first 3 wk of the breeding season.
[b] Values for 112 days and 140 days are for only the two rams used for breeding.

A statistical summary for the treatment comparisons are presented in Table 5. Red blood cell hemolysis values for animals on the CSM diets were significantly higher than those for the control animals at 56, 84, 112 and 140 d. No differences in RBC hemolysis were

observed for the ES vs. DS CSM diets. At d 56 and 84, RBC hemolysis values were significantly higher for both the ES16 and DS16 treatments vs the ES6 and DS6 treatments. Red blood cell hemolysis values for the last two sampling dates (112 and 140 d) are for only the two rams used for breeding. This possibly explains the inconsistent responses observed for these sampling times.

Table 5. Treatment comparisons for RBC hemolysis[a,b]

Comparison	Initial	28 d	56 d	84 d	112 d[c]	140 d[c]
SOM vs CSM	NS[d]	NS	P < .05	P < .01	P < .01	P < .01
DS vs ES	NS	NS	NS	NS	NS	NS
DS_6 vs DS_{16}	NS	NS	P < .10	P < .01	NS	P < .05
ES_6 vs ES_{16}	NS	NS	P < .10	P < .05	P < .01	NS

[a] SOM = soybean meal, CSM = Cottonseed meal, DS = direct solvent cottonseed meal and ES = expander solvent cottonseed meal.
[b] Cottonseed meal diets were fed for 3 and 13 wk prior to breeding and for the first 3 wk of the breeding season.
[c] Comparisons in this column includes only values for the two rams used for breeding.
[d] NS = no significant difference between the treatments compared.

Scrotal circumference values are presented in Table 6. There were no significant differences between treatments at anytime during the experiment. However, the average scrotal circumference of the rams on all treatments decreased with time during the 6-wk breeding period. There were no significant treatment effects on sperm motility and concentration for semen collected by electroejaculation from all 20 rams at 91d and from the 10 rams used for breeding at 140 d (data not shown).

Table 6. Scrotal circumference of Rambouillet rams fed a control diet with soybean meal (SOM) and diets containing either expander solvent (ES) or direct solvent (DS) cottonseed meal (CSM) for either six or sixteen weeks[a]

		ES CSM		DS CSM		
		wk		wk		
Item	SOM	6	16	6	16	SEM
Scrotal circumference, cm						
28-d	35.6	34.6	34.8	35.8	35.0	1.05
56-d	35.7	35.6	35.8	36.0	35.6	1.05
84-d	34.6	35.1	35.4	35.0	34.9	.95
Start of breeding	35.4	34.8	36.0	35.7	36.3	.88
112-d[b]	33.0	34.0	33.2	34.0	32.0	.71
140-d[b]	31.8	32.4	32.9	31.6	33.0	.86

[a] Cottonseed meal diets were fed for 3 and 13 wk prior to breeding and for the first 3 wk of the breeding season
[b] Values for 112 days and 140 days are for only the two rams used for breeding.

Upon gross examination of the testes, one ram on the control diet had unilateral chronic epididymitis and testicular atrophy. This finding was unrelated to experimental treatment and most likely the result of *Brucella ovis*, *Histophilus ovis* or other organisms from the *Haemophillus*, *Actinobacillus*, or *Corynebacterium* groups. On histopathologic examination of the tunica albuginea, the interstitium (connective tissue, Leydig cells, blood vessels) and seminiferous tubules (basement membrane, germinal epithelium, lumen) only a few cases presented abnormalities, but in most cases these were incidental findings and not related to treatments. However, one ram fed the DS CSM diet for 16 wk had unilaterial mild atrophy of the seminiferous tubules and one ram fed the DS CSM diet for 6 wk had bilaterial mild atrophy of the seminiferous tubules. These were the only significant findings of an effect of gossypol/CSM treatment on the testes.

A summary of breeding and lambing data is presented in Table 7. Ovulation rates were similar across all treatments and indicated all ewes were cycling. Because of this it was assumed that any differences observed in reproductive performance of the ewes would be due to the rams. Pregnancy rates (ewes pregnant/ewes bred) were 18/20, 17/19, 20/20, 19/20 and 18/20 for the SOM, ES6, ES16, DS6 and DS16 treatments, respectively. No significant differences between treatments were observed in pregnancy rate, number of ewes lambing, number of lambs born and birth weight of the lambs.

Discussion

Diets used in this study contained 1.8 times more crude protein than recommended for yearling rams by the National Research Council (NRC, 1985). The recommended level in diets for growing replacement rams weighing 176 to 220 lb is 8.6%, on an as fed basis; whereas, these diets contained 15.8%. Since many of the feeds (grains, hays, pastures) commonly fed to sheep contain at least 8.6% crude protein it is apparent very little supplemental protein is needed for yearling rams in practical production situations. It is important to keep this in mind, not only to place the results of this study in proper perspective, but to objectively assess the practical significance of the numerous studies with cattle and sheep that have reported adverse effects of gossypol on reproduction in males.

The increase in RBC hemolysis for rams fed the CSM diets in this study is consistent with previous reports. Increased hemolysis of RBC incubated in hypotonic saline solutions has been observed in cattle, sheep and goats fed diets containing cotton by products. (Lindsey et al., 1980; Calhoun et al., 1990a,b,c; Calhoun et al.,

1991; Calhoun and Holmberg, 1991; Chenowith et al., 1994). The effect of gossypol on the osmotic fragility of RBC is very sensitive and precedes other known physiologic and pathologic changes caused by gossypol (Calhoun et al., 1990a,b). Increases in RBC hemolysis of the magnitude observed in this study do not appear to be detrimental to the animal (Lindsey et al., 1980; Calhoun et al., 1990a,b,c). However, serum levels of malondialdehyde, an indicator of lipid peroxidation, was positively associated with RBC hemolysis in sheep fed cottonseed meal (Kuhlmann et al., 1998) and decreases in sperm motility and the percentage of normal spermatozoa accompanied increased RBC hemolysis in mature Brahman bulls fed CSM (Risco et al., 1993).

Although RBC hemolysis increased during the period CSM was fed, RBC hemolysis values were not significantly different for the ES CSM and DS CSM at any sampling time. Since free gossypol intakes of rams receiving the diet with DS CSM were more than double those of rams fed the ES CSM diet (1.27 vs .58 g/d), it appears free gossypol content of the CSM did not reflect the amount of gossypol that was available to the rams. This lack of correlation between free gossypol intake and RBC hemolysis is consistent with results of previous studies with sheep (Calhoun et al., 1990a,b; Calhoun et al., 1991) and indicates free gossypol content of cotton by-products may be of limited value in making decisions about levels of cotton by-products that can be fed safely to ruminants.

The lack of an effect of cottonseed meal processing method and duration of feeding on scrotal circumference in rams in this study is consistent with previous reports. Dietary consumption of FG from WCS did not affect scrotal circumference, testicular or epididymal weights and measurements in ram lambs (Kramer et al., 1991) or young bulls (Chase et al., 1994; Smith et al., 1991). Scrotal and testicular measurements in bulls also were unaffected by FG from CSM (Chase et al., 1994; Chenoweth et al., 1994). In addition, Chase et al (1994) observed no changes in serum testosterone levels associated with feeding either WCS or CSM.

Feeding cottonseed meal did not adversely affect sperm motility and concentration in this study; however, Chenoweth et al (1994) reported a reduction in sperm motility and the number of normal sperm in bulls receiving 7.4 mg FG/lb LW/d from a direct solvent CSM, and the occurrence of sperm mid-piece abnormalities was increased for these same animals. In contrast to these findings, semen and sperm characteristics of bulls were not affected by consumption of FG (29 to 37 mg/lb LW/d) from WCS (Chase et al., 1994; Smith et al., 1991) or in ram lambs consuming 20 mg FG/lb LW/d (Kramer et al, 1991).

Chase et al. (1994) observed a thickening of the lumen of the seminiferous tubules and a reduction in the layers of germinal epithelium in bulls fed CS and CSM. The only histopathologic change in testicular tissue in this study was a mild atrophy of the seminiferous tubules of two rams fed the DS CSM. Although increases in RBC hemolysis and changes in the seminiferous tubules were observed in the rams fed CSM in this study, these changes were not accompanied by a reduction in breeding performance. Libido, pregnancy rates and lambing rates were not significantly different for rams fed the soybean meal and cottonseed meal diets.

Implications

Cottonseed meal can be used to provide supplemental protein in diets of mature rams without adversely affecting reproductive performance. However, caution should be used when feeding high levels of cottonseed meal in diets of rapidly growing young rams.

Acknowledgements

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Table 7. Ovulation, conception and lambing rates and average birth weights of lambs for ewes bred by Rambouillet rams fed a control diet with soybean meal (SOM) and diets containing either expander solvent (ES) or direct solvent (DS) cottonseed meal (CSM) for either six or sixteen weeks[a]

		ES CSM		DS CSM		
Item	SOM	6	16	6	16	SEM
Ewes, no.	20	19	20	20	20	
Times bred[b]	1.3	1.1	1.2	1.4	1.2	.055
Ovulation rate[c]	1.8	1.6	1.7	1.5	1.6	.066
Pregnancy rate[d]	18	17	20	19	18	
Ewes lambing, no	17	16	19	18	19	
Ewes open, no	3	3	1	2	1	
Total lambs born, no.	25	22	29	27	27	
Lambs born as singles, no.	9	8	10	9	11	
Lambs born as twins, no.	16	14	16	18	16	
Lambs born as triplets, no.	0	0	3	0	0	
Lambs/ewe exposed, no.	1.25	1.21	1.45	1.35	1.35	.15
Lambs/ewe lambing, no.	1.47	1.58	1.52	1.50	1.42	.14
Avg. birth weight, lb	9.13	9.28	9.40	8.97	8.86	.41

[a] Cottonseed meal diets were fed for 3 and 13 wk prior to breeding and for the first 3 wk of the breeding season.
[b] Rams were fitted with a marking harness in order to determine the number of times a ewe was bred.
[c] Ovulation rates were determined by laparoscopy.
[d] Pregnancy rates were determined by ultrasound.

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Supplemental Feeding Interval for Adult Ewes

J.E. Huston, B.S. Engdahl, and K.W. Bales

ABSTRACT

One range trial (42 ewes) and a confinement trial (36 ewes) were conducted to determine effects of supplementing adult Rambouillet ewes at 1-, 2- (or 4-), and 7-d intervals. In the range trial, pregnant ewes were assigned to three pasture groups and within each pasture group to four feed treatments. Feed treatments were control (Control; no supplemental feed), cottonseed meal (CSM; 25% of protein requirements), energy equivalent (Low; one-half protein and equal energy with CSM), and protein equivalent (High; equal protein and twice energy with CSM). The three pasture groups were penned either at 1-, 4- or 7-d intervals and individually fed for a period of 73 d during which parturition occurred. The pasture groups were rotated among pastures at 3-wk intervals to minimize pasture effects. Data collected included initial and final weights. A confinement trial (49 d) was conducted with 36 adult, nonpregnant ewes fed oat hay free-choice and .23 kg/hd (as fed) daily equivalents of cottonseed meal (CSM) at 0, 1-, 2-, and 7-d intervals to determine patterns of serum urea nitrogen (SUN; indicating efficiency of protein utilization), feed intake, and live body weight change. In the range trial, statistical contrasts indicated that all feed treatments reduced ($P < .0001$) weight loss compared with Control when feeding was daily. The High feed treatment appeared less effective when fed at less frequent intervals. The 4-d interval appeared the most effective feeding interval, especially when CSM and Low were the feed treatments. In the confinement trial the SUN levels in ewes fed at 7-d intervals remained higher ($P = .04$) than those in the Control until d 5 and not lower ($P = .17$) than 1-d until d 6 after the feeding event. These data show that sheep, like cattle, can be fed a protein supplement effectively as infrequently as one time per week.

Introduction

Range sheep obtain nutrients primarily as they consume various plants and plant parts from the range landscape. These plants differ in season of growth, length of growth and dormancy periods, and in presentation (low growing, herbaceous, shrubs, etc). The proportion of plant types in a particular location is determined by climate, site, and current and previous use. These factors shape the range vegetation to provide diet quality and quantity that may exceed or fail to meet the animal's requirements for desired productivity. Supplemental feeding is a means of providing limiting nutrients during deficient periods to promote productivity.

Supplements can be provided as meals, pellets, blocks, liquids, or gels. The form of feed and the delivery system of choice depend on the nutritional value of the feed, price, and convenience. Whereas certain feeds are designed for self-feeding using physical form or added ingredients to limit consumption, other feeds are "hand fed" to provide the desired amounts. Although in some instances hand-fed supplements are of greater value to the animal, the expense and inconvenience of delivery often eliminate them as alternatives. Cattle can be fed supplements as infrequently as once per week with good results thereby reducing the costs of distribution of hand-fed supplements (Huston et al., 1997). Similar results were reported for fall-lambing ewes (Huston et al., 1994). This study reports on follow-up studies conducted with winter-lambing ewes on range and adult, nonpregnant ewes in confinement to clarify the effects of interval of supplemental feeding in ewes.

Materials and Methods

One range trial and one confinement trial were conducted to determine the feasibility of feeding supplements to ewes on low-quality roughage diets at intervals less frequent than daily. The rangeland at the Texas A&M University Agricultural Research & Extension Center at San Angelo is represented by Angelo and Mereta clay loam soils with 0 to 1% slope. The vegetation of the area is primarily perennial, warm-season grasses with smaller amounts of cool-season and succulent species. The range trial (Trial 1) was conducted with adult Rambouillet ewes (ages = 1 to 4 yr) that were subjected to breeding between August 27 and October 6. Only ewes with breeding marks were included in the study.

Trial 1

The ewes were assigned to 12 groups of 9 ewes/group equalized for age, beginning live body weight, and breeding date. Four groups were assigned to each of three pastures. The four groups in each pasture were designated as control (Control; no supplemental feed), cottonseed meal [CSM; .25 lb/hd/d = 25% of crude protein (CP) requirements], a low level of a 65:35 mixture of sorghum grain:cottonseed meal [Low; equal digestible energy (DE) with CSM but lower CP], and a high level of the above mixture (High; equal CP with CSM with approximately twice the DE supply). Between January 4 and March 18 the three pastures were gathered either daily (1-d), every 4 d (4-d), or every 7 d (7-d), and treatments were applied on an individual animal basis using individual feeding stalls. Those in the 4-d and 7-d groups were fed 4 and 7 times the daily equivalent at each feeding event. The pasture groups were rotated among pastures to minimize the pasture effects. A Control group was included in each pasture to correct for pasture and other non-treatment effects. In comparing feeding frequency, average weight losses of Control ewes in each pasture were adjusted to the average of the three control groups. Within each pasture, weight losses of the fed ewes were adjusted by the same percentage as the average Control adjustment. Lambing occurred beginning January 20. Beginning and final ewe weights were taken. Only ewes with live lambs at the termination date (March 18) were included in the data.

Trial 2

Thirty-six, nonpregnant ewes were divided into 12 groups to receive four treatments in three replications (three ewes per replication) to study the effects of feeding cottonseed meal at different intervals on serum urea nitrogen (SUN; an indicator of efficiency of protein utilization), feed intake, and live body weight change. The groups were equalized for ewe weight and age. The ewes were fed wheat straw (approximately 3.5% CP and 1.4 Mcal/kg DE) free choice for 22 d then were fed oat hay (approximately 8% CP and 2.2 Mcal/kg DE) for 21 d before CSM treatments were applied in addition to free choice feeding of the oat hay for 28 d. The four treatments included a control group (Control; no CSM), CSM daily (1-d; .5 lb/ewe of CSM fed daily), CSM fed every 2 d (2-d), and CSM fed every 7 d (7-d). Feeding levels for 2-d and 7-d were two and seven times the 1-d level, respectively. During the first week of treatment, blood samples were drawn by venipuncture at 0800 on days 0, 1, 2, . . ., 7 in regard to first feeding. Serum was removed and frozen until analysis for urea nitrogen at a later date using a modification of the method of Chaney and Marback (1962). Daily forage consumption was measured during the 21 d before treatment and during the 28-d treatment period. The cottonseed meal was fed at 0800 in a separate feed trough that was large enough to accommodate concurrent feeding by all of the ewes in the group. Ewe weights were recorded prior to feeding of wheat straw, at the beginning of feeding of oat hay, at beginning of treatment, and at termination.

Statistical analysis

The weight data for Trial 1 was analyzed using the General Linear Model (GLM; SAS, 1991) with feed treatment and feeding interval as main effects and a feed treatment x feeding interval interaction. The means and contrasts are reported for the main effect of feed treatment across all pastures (Table 1) but not for feeding frequency. After a significant interaction was detected, a condensed analysis was conducted within each feeding interval for each treatment. For the condensed analysis, the data were corrected for pastures using the Control ewes and relative values for the ewes on other treatments to Control ewes within those pastures. Also, the weight change data for the condensed analysis were corrected for initial body weight. Because the feeding treatments were individually applied, the individual ewe was considered the experimental unit. Data from Trial 2 were analyzed using GLM with feeding interval (weight and intake data) and both feeding interval and day (SUN data) as main effects. Rep (pen) within feeding interval was used as error term. Contrasts were used to compare individual or groups of means as indicated in footnotes to the tables.

Results and Discussion

Results of Trial 1 are shown in Tables 1 and 2. Data from many of the ewes that were assigned to treatments in the range trials were deleted from the data because they either were not pregnant, lost their lamb(s), or did not adjust to the feeding routine (would not eat in the individual feeding stalls). Fed ewes lost less live body weight than Control, but losses did not differ among fed groups (Table 1). When all groups were pooled (including Control), those that were gathered at 7-d intervals lost more weight than the 1-d and 4-d groups. However, because the Control groups were not fed, (not considered a feeding frequency) and because a

treatment x frequency interaction was detected, only the condensed data for feeding frequency are shown (Table 2). When the data are expressed to show the effects of feeding at each feeding frequency, three inferences are indicated. Feeding reduced live body weight loss irrespective of feeding frequency. The low-protein supplement fed at a high level appeared less effective when fed at weekly intervals, which agrees with our previous report (Huston et al., 1994). Feeding at 4-d intervals appeared the most effective feeding frequency. In our previous study, the 4-d interval was more effective only when CSM was fed.

Winter-lambing ewes had higher initial live body weights but lost more body weight while on the feeding regime compared with fall-lambing ewes in the previous report (Huston et al., 1994). This was not surprising because range ewes in the region in which the experiment was conducted commonly consume a higher quality diet during fall compared with either summer or winter. This higher quality diet during fall would lower weight loss in ewes that lambed and increase live body weight in ewes in early to mid pregnancy. Therefore, fall-lambing ewes would weigh less in late summer while approaching late pregnancy but maintain weight better during early lactation compared with winter-lambing ewes. Those ewes bred for winter lambing would be heavier (carry more fat) during mid to late pregnancy but lose weight quickly after parturition when requirements would exceed the nutritional value of the diet.

Results of Trial 2 (Tables 3 and 4) indicate that infrequent feeding altered the serum urea nitrogen concentration (SUN) from the relatively uniform pattern for daily feeding. All feeding intervals elevated the SUN above control levels. The 2-d feeding resulted in an every-other-day pattern of higher and lower SUN. Ewes supplemented at 7-d intervals showed very high SUN values on d 1 and 2 following feeding then a slow decline in SUN back to prefeeding levels on about d 5. Differences in live body weight changes were not detected, possibly because of the short experimental period. However, it appeared that every-other-day feeding depressed the voluntary intake of hay.

Table 1. Effects of supplemental feeding and feed type/level on changes in live body weight of ewes on rangeland

	Feed treatment					Contrasts[a]		
Item	Control	CSM	Low	High	SE	1	2	3
Number of ewes	6	10	11	15				
Weight change, lb	-31.5	-21.1	-22.2	-19.4	1.65	.0001	.86	.21

[a] Contrasts: 1) Control vs fed groups; 2) CSM vs Low, High; 3) Low vs High.

Table 2. Effects of feed treatment and feeding interval on changes in live body weights (lb) of ewes bred to lamb during winter (data corrected to std. initial weight and control treatment)

	Feed treatments					Contrasts[a]		
Item	Control	CSM	Low	High	SE	1	2	3
Number of ewes	6	10	11	15				
Feeding interval								
Daily	-31.5	-24.9	-25.8	-17.8	1.87	.01	.40	.005
4-day	-31.5	-13.9	-16.7	-17.4	3.23	.008	.43	.90
7-day	-31.5	-24.9	-24.2	-22.9	3.08	.13	.70	.75
SE		2.49	2.62	2.73				
Contrasts[b]								
1		.29	.14	.49				
2		.0085	.11	.20				

[a] Contrasts: 1) Control vs fed groups; 2) CSM vs lower protein feed; 3) Low vs high level of low protein feed.
[b] Contrasts: 1) Daily vs less frequent; 2) 4-day vs 7-day feeding frequency.

Table 3. Serum urea nitrogen concentrations (mg/100 ml) in ewes fed hay and supplemented with CSM at increasing intervals (Trial 2)

	Treatments					Contrasts[b]		
Day	Control	Daily	2-d	7-d	SE[a]	1	2	3
0	14.9	12.1	15.9	13.5	2.64	.52	.52	.50
1	16.8	18.2	24.9	36.5	3.99	.001	.0001	.0001
2	14.6	19.1	19.8	26.2	4.19	.02	.06	.03
3	13.0	18.1	24.9	19.5	2.66	.0002	.52	.007
4	13.3	17.0	18.3	17.2	2.19	.009	.95	.04
5	13.6	18.7	22.6	15.5	2.77	.008	.17	.42
6	15.3	20.1	20.1	14.5	2.35	.07	.008	.70
7	15.2	20.7	22.1	13.3	2.29	.03	.0006	.32
SE[a]	1.82	1.78	4.41	2.33				
Contrasts[c]								
1	.21	.001	.02	.0001				
2	.80	.001	.28	.0001				
3	.20	.001	.01	.002				
4	.28	.001	.50	.06				
5	.38	.001	.07	.29				
6	.82	.001	.24	.58				
7	.84	.001	.09	.94				

[a] Standard errors.
[b] Contrasts: 1) Control vs fed groups; 2) Daily vs 7-day; 3) Control vs 7-day.
[c] Contrasts: Day 0 vs each of days 1 through 7.

Table 4. Body weights and intake in ewes fed hay and CSM at increasing intervals

	Treatments					Contrasts[a]			
Item	Control	Daily	2-d	7-d	SE	1	2	3	4
Live body weight, lb									
Initial weight	134.1	139.2	140.3	141.2	8.35				
Final weight	141.6	145.8	144.5	149.3	8.57				
Weight change	7.5	6.6	4.4	8.6	3.46	.62	.26	.53	.78
Intake, lb/day									
Hay	4.14	4.12	3.48	3.99	.13	.006	.001	.25	.24
CSM	.00	.51	.51	.51	.00				
Total	4.14	4.63	3.99	4.49	.13	.01	.17	.25	.002

[a] Contrasts: 1) Control vs fed groups; 2) Daily vs 2-d; 3) Daily vs 7-d; 4) Control vs 7-d.

Implications

These data, along with those previously reported, indicate that sheep, like cattle, can be fed as infrequently as one time per week without a major reduction in performance. However, caution is necessary to avoid overeating by individual ewes (bully effect) and toxicity caused by certain ingredients (e.g., urea) that may be toxic when consumed in high amounts.

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The Effects of Nutrition, Shearing, and Environment on Angora and Cashmere Goat Production

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ABSTRACT

Cashmere and Angora (approximately 60 each) females were utilized in a 3-yr study to determine the effects of body condition and natural cover (trees and shrub canopy) on survival, kidding rate, and fiber production of Angora and Cashmere goats sheared either early or late winter over three years. The treatments included feeding a 14% pelleted ration at two different feed levels (full feed for half of the goats and 1.5% of body weight for the other half) to create High and Low body conditions. Half of the animals on each feed treatment were then either shorn in mid January or mid February. Fleeces were individually sacked and analyzed for fiber quality. After shearing, the goats were placed either into an open pasture (canopy cover < 1%) or into a brush pasture (canopy cover > 25%). For yr 1 and 2, goats were scanned with a sonagram to determine the number of fetuses/doe. For yr 3, goats were scanned with a sonagram to determine if they were pregnant or open. Does were monitored to record abortions and early births. Kids were paired with their dams to determine reproductive losses. Over the 3-yr study, Angora and Cashmere goats in the High condition body treatment gained 30.7 and 28.3 lb/hd, respectively, whereas weights of those in the Low body condition treatment did not change. For yr 1and 2, Angora does averaged 1.06 fetuses per doe and raised 0.78 kids compared to 1.42 fetuses for Cashmere does which raised 1.36 kids each, which represents a reproductive loss of 26 and 4%, respectively. For yr 3, 81% of the Angora does were bred and raised 0.56 kids per doe compared to 100% of the Cashmere does being bred and raising 1.4 kids per doe. For Cashmere does, body condition, natural cover, and shearing date appeared to have no direct effect on kid production. The Angora does in the High body condition raised 0.76 kids/doe compared to 0.64 kids/doe for the Low body condition. Shearing date and cover appeared to have an effect on kid production for the Angora does. For yr 1, a possible breed x body condition interaction was observed for survival of adult goats after shearing. Six of seven (86%) of the adult Cashmere goats that died were in the Low body condition group, and only one Angora adult died. Three goats died (one Cashmere and two Angora) in yr 2 and only one Cashmere goat in yr 3. Cashmere grease fleece weight and clean fleece weight were significantly greater for the January shearing date than the February shearing date (.71 and .67 lb/hd for January and .55 and .52 lb/hd for February, respectively). Mohair fleeces were individually analyzed for grease fleece weight, lab scoured yield, clean fleece weight, fiber diameter, staple length, med fibers, kemp fibers and total medullation. Angora goats in the "High body condition, February shearing" produced the most grease and clean fleece weights followed by "High body condition, January shearing," "Low body condition, February shearing;" and "Low body condition, January shearing." Fiber diameter and total medullation were greater for the High body condition goats than the Low body condition goats.

Introduction

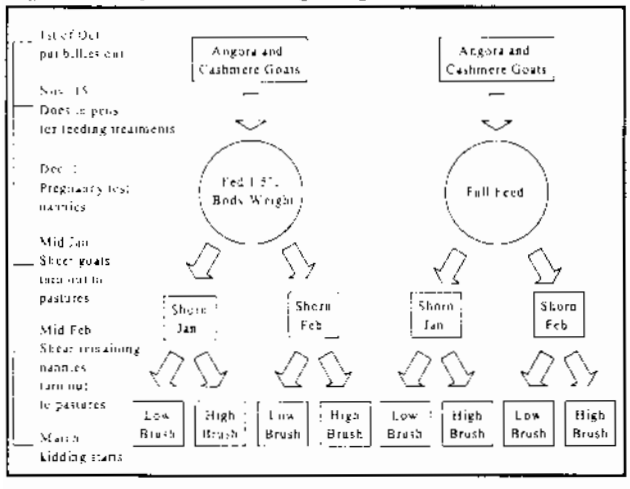
Goats in Texas vary in appearance and genetic potential and are perceived to differ in hardiness and resistance to various types of stress. Angora goats have a high genetic potential for fiber production, resulting in high nutritional requirements. Also, because forage is frequently of low quality, Angora goats in the Edwards Plateau region of Texas are generally undernourished throughout most of their lives unless they are provided supplemental feed. Being undernourished results in reduced reproduction, size, and fleece weight, and increased susceptibility to death from hypothermia immediately after shearing (Shelton, 1993). Cashmere goats produce significantly less fiber than Angora goats and apparently have lower nutritional requirements on a body weight basis. However, a relatively lower nutritional requirement does not necessarily reduce the shearing loss potential in Cashmere goats as compared to Angoras. Factors such as body condition and protection from harsh environments may be as important to Cashmere goats as they are to Angora goats. A 3-yr study was initiated to determine the interaction of management and the environment on Angora and Cashmere goat production and survival. Fiber data are reported for yr 1 only.

Materials and Methods

A flock of 60 Cashmere does (mixed aged) and 60 Angora does (21 mo old for yr 1and mixed aged for yr

2 and 3) were assigned randomly across various treatment groups to study how the effects of nutrition and shearing interact with environmental conditions to affect goat production (Figure 1). Breeding season for the does started around the first of October and continued until the middle of November for each year. After breeding and to establish High and Low body conditions. the does were assigned to 20 pens (six goats per pen based on body weight and breed) and fed a 14% pelleted ration at either 1.5% of body weight or *ad libitum* for 60 d. All goats were scanned each year around December 1 with a sonagram to determine the number of fetuses/doe. One half of the study goats were shorn in mid January and placed either into a 42-acre pasture with less than 1% brush canopy cover (open pasture) or into an 80- acre pasture with greater than 25% brush canopy cover (brush pasture)and a south facing slope. The remaining goats were maintained in pens until they were shorn in mid February and then evenly divided into the two pasture treatments. Goats were fed a supplement in both pastures to maintain body condition. Fleece characteristics of both breeds of goats were quantified to assess the treatment effects. Does were monitored so that abortions and early births could be recorded. Kids surviving to 6 wk of age were considered to be successfully raised.

Figure 1. Experimental design of goat research.

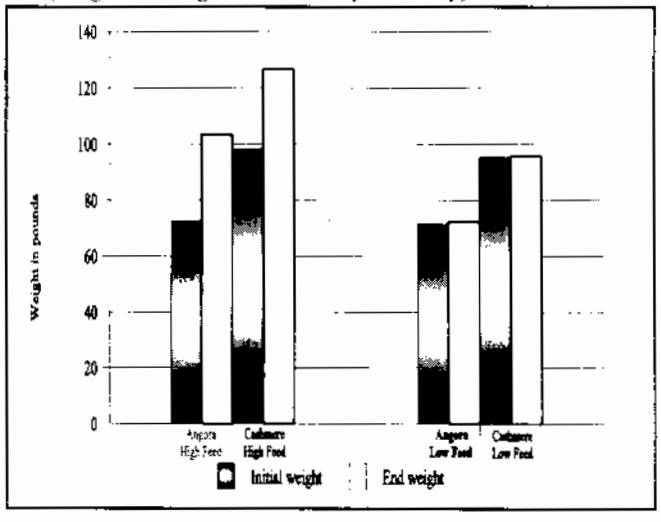


The Statistical Analysis System (SAS, 1985) General Linear Models procedures were used to analyze the data generated in this study. Duncan's Multiple Range Test was used to identify significant differences between mean values.

Results and Discussion

The feeding treatment was used to create a High and Low body condition. Goats in the High body condition gained more weight than goats in the Low body condition ($P < .01$). At the beginning of the study, the average body weight of the Angora goats for the 3-yr study was 72.2 lb compared to 97 lb for the Cashmere goats ($P = .01$). The average live body weight of the Angora goats in High body condition changed from an initial weight of 72.7 lb in October to 103.4 lb in mid November (gain = 30.7 lb over approximately 45 d), whereas the average live weight of those in Low body condition remained the same ($P = .45$; Figure 2). Body weights of Cashmere goats in High body condition changed from an initial average weight of 98.5 lb in October to 126.8 lb in mid November (gain = 28.3 lb). Those in Low body condition remained the same.

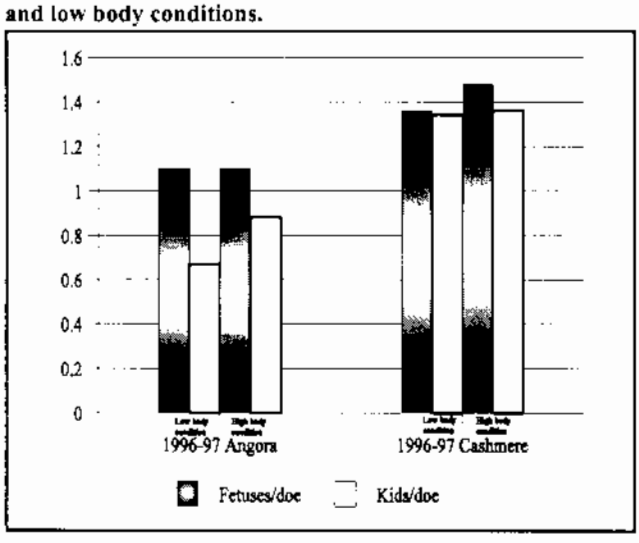
Figure 2 Weight changes of goats during feeding portion of test (weights averaged over three year study).



For 1996 and 1997, Angora does averaged 1.06 fetuses per doe compared to 1.42 per Cashmere doe ($P < .01$). Angora does raised fewer ($P < .01$) kids than Cashmere does to 6 wk of age (.78 vs 1.36 per doe) reflecting a 26 and 4% kid loss for the two breeds, respectively (Figure 3). Angora does in the Low body condition had a greater kid loss than does in High body condition (.67 kids weaned/doe vs .88 kids weaned/doe, respectively). For yr 3, 81% of the Angora does were bred and raised .56 kids per doe compared to 100% of the Cashmere does being bred and raising 1.4 kids per doe. Angora does in the High body condition raised more kids than Angora does in the Low body condition (.76 and .64 kids/doe, respectively; $P = .10$). Cashmere does raised similar kid crops regardless of body condition (1.37 for High and 1.39 kids/doe for Low

body condition). Both the shearing treatment effect and pasture treatments appeared to have no effect on subsequent kid production (P > .10). There were no significant breed x shearing or pasture treatment interactions.

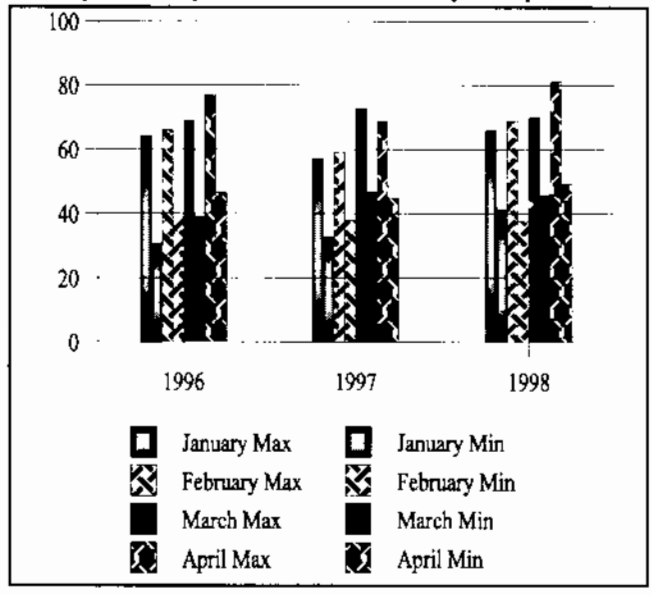
Figure 3. Average (1996-1997) fetuses and kids/doe for high and low body conditions.



In 1996 death losses of does were greater for the Cashmere than the Angora goats. A total of seven Cashmere goats died compared to only one Angora goat. Six of the dead Cashmere goats were from the Low body condition treatment. Of those that died, five were from the February shearing date, and four from the brush pasture. Cold dry weather occurred throughout most of the year (Figure 4). Freezing weather occurred 4 d in a row (Jan 18 to 21) soon after the first shearing date (Jan 15). No rain fell during January, and February precipitation was below normal. March had similar temperatures as February but .28 in. of precipitation was received; April had two consecutive days of cold wet weather. In 1997 three goats died (one Cashmere goat from the High body condition treatment and two Angora goats, one from the High and one from the Low body condition treatments). 1997 had more severe weather than the other 2 yr of the study. Freezing weather occurred 10 d in the month of January following the first shearing. The winter of 1997 was also represented by larger amounts of precipitation (6.9" vs 4.7" for 1998 and 1.2" for 1996). Cold wet weather followed both shearing dates; however, adult goat loss was minimal. Some Angora does appeared to abort after both shearing dates. No abortions were observed for Cashmere does.

In 1998 one Cashmere goat died from the Low body condition treatment. 1988 had the warmest winter of the 3-yr study. Warm, mild weather followed both shearing dates; however, Angora kid survival was low (kid crop at 6 wk = 56%). Because of the fairly mild winters, results from this study may not accurately predict goat response to winter shearing. However, of the total treatments applied to the goats, body condition appeared to be more important to adult goat survival. Cashmere goats may be slightly more susceptible to hypothermia than Angora does but Angora reproductive loss was significantly greater than from Cashmere does. Angora reproductive loss was less for the High body condition compared to the Low body condition.

Figure 4. Average maximum and minimum temperatures for January, February, March, and first 15 days of April.



Cashmere fleeces were individually analyzed for grease fleece weight, lab scoured yield, clean fleece weight, cashmere yield, cashmere down diameter, cashmere staple length, and guard hair staple length (Table 1). Mohair fleeces were individually analyzed for grease fleece weight, lab scoured yield, clean fleece weight, fiber diameter, staple length, med fibers, kemp fibers, and total medullation. Cashmere grease and clean fleece weights were greater for the January shearing date than the February shearing date (.71 and .67 lb/hd for January compared to .55 and .52 lb/hd for February, respectively). Cashmere goats started shedding fiber before the February shearing. Body condition had no effect on cashmere production (P = .56); however, mohair grease and clean fleece weights were greater for the High body condition Angora goats compared to the Low body condition goats (5.7 vs 4.1 lb/hd, respectively; P = .02). The "High body condition, February shearing" treatment produced the greatest grease and clean fleece weights (6.6 and 4.9 lb/hd, respectively) and had greater staple length, fiber

diameter and total medullation. February-shorn goats produced more mohair than January-shorn goats.

Table 1. Fiber measurements of Cashmere and Angora does on different feed and shearing treatments

	Cashmere Does						
TRT	GFW (lb)	LSY (%)	CFW (lb)	CY (%)	MFD (μm)	CSL (in)	GHSL (in)
HB-FS	.50[b]	91.7	.46[b]	16.5	18.2	1.8	2.3
HB-JS	.71[a]	93.5	.67[a]	24.8	18.8	1.9	2.0
LB-FS	.62[b]	95.9	.59[b]	22.2	18.9	1.9	2.2
LB-JS	.72[a]	94.2	.67[a]	21.9	18.8	2.1	1.9

	Angora Does						
TRT	GFW (lb)	LSY (%)	CFW (lb)	FD (μm)	MF (%)	KF (%)	TM (%)
HB-FS	6.7[a]	74.3[a]	4.9[a]	32.3[a]	.59[ab]	.52	.48[a]
HB-JS	4.6[b]	81.2[a]	3.7[b]	32.3[a]	.43[c]	.48	.24[b]
LB-FS	4.3[b]	79.8[a]	3.4[bc]	30.0[b]	.66[a]	.44	.16[b]
LB-JS	3.9[b]	79.4[b]	3.1[c]	29.9[b]	.47[bc]	.32	.14[b]

[a,b,c] Means within columns with different subscripts differ (P<0.05). GFW=grease fleece weight, LSY=lab scoured yield, CFW=clean fleece weight, CY=cashmere yield, MFD=cashmere fiber diameter, CSL=cashmere staple length, GHSL=guard hair staple length, FD=fiber diameter, MF=medullated fibers, KF=kemp fibers, TM=total medullation.

Implications

Management required for optimal fiber and kid production for these two breeds of goats are quite different. Angora goats responded to optimal feed levels in terms of reproductive efficiency and fiber production while cashmere goat production appeared to be neutral. Early shearing for Cashmere goats is important to reduce the loss of fiber due to shedding. Both Angora and Cashmere goats are susceptible to hypothermia after shearing; however, because Cashmere fiber grows more slowly than mohair fiber,cashmere goats may be more vulnerable. Brush canopy cover appeared to have no effect on kid production or adult goat survival.

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Using Nutrition Management To Reduce Fatness in Slaughter Lambs

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Excessive fatness is recognized as a major problem in lambs fed high-energy rations in the feedlot to achieve desired carcass weights. Some reports indicate that the body muscle mass can be maintained or continue to grow in lambs fed an energy deficient diet with adequate protein (Orskov, 1992). Presumably, energy to metabolize the protein and stimulate muscle growth is derived from body fat thereby reducing the unwanted fat while growing additional protein.

An abbreviated study was conducted to determine the feasibility of developing a nutritional management system to reduce the fatness of over-fat lambs. Thirty-six Rambouillet wether lambs were fed on a typical high-energy finishing ration until they appeared extremely fat. Based on body weights, the lambs were separated into three categories, small, medium or large with two groups of six lambs each, representing each category. One of the two groups for each body size category continued to receive the conventional finishing ration (control) while the other was fed wheat straw (free-choice) and 1 lb/head/d of a 32% protein concentrate for 34 d. The results (Table 1) indicate that the larger lambs were fatter initially and lost more weight and body condition (fatness) on the wheat straw diet compared with the smaller lambs. Although these data do not clearly indicate whether body muscle mass was maintained (or increased), they are sufficiently encouraging to justify another study including carcass measures.

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Table 1. Changes in live body weight and body condition (BC) score in overfat lambs continued on a high-energy finishing ration or a low-energy, protein adequate diet

		Group		
Body size	Item	Control	Wheat-straw	P
Small	Number of lambs	6	6	
	Initial wt, lb	100.7	99.5	.77
	Final wt, lb	108.5	93.2	.006
	Wt change, lb	7.8	-6.3	.0001
	Initial BC score	3.58	3.21	.03
	Final BC score	4.50	3.33	.0006
	BC score change	.92	.12	.005
Medium	Number of lambs	5	6	
	Initial wt, lb	108.8	109.3	.89
	Final wt, lb	110.0	101.8	.02
	Wt change, lb	1.2	-7.5	.02
	Initial BC score	3.40	3.50	.62
	Final BC score	4.05	3.38	.09
	BC score change	.65	-.12	.02
Large	Number of lambs	6	6	
	Initial wt, lb	124.5	129.3	.54
	Final wt, lb	136.5	118.3	.006
	Wt change, lb	12.0	-11.0	.0003
	Initial BC score	4.12	3.75	.25
	Final BC score	4.25	3.42	.006
	BC score change	.13	-.33	.16

Effect of Sodium Molybdate and Sulfate Supplementation in the Diet of Sheep Chronically Intoxicated with Copper

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ABSTRACT

An outbreak of chronic copper poisoning occurred during the 1997-1998 Texas Agricultural Experiment Station Ram Performance Test (TAES-RPT). Feed analysis revealed that several lots of the ram test feed contained levels of copper above the safe range for sheep.

To determine the effects of molybdenum and sulfate on sheep chronically intoxicated with copper, 28 rams from the RPT that belonged to TAES were selected. At the beginning of the experiment, four rams were killed to establish base line values of liver and kidney copper levels. The remaining 24 rams were randomly allocated into two experimental groups. Group 1 (molybdenum/sulfate, n = 12), was put on a diet that contained 5 lb of 2% sodium molybdate (Na_2MoO_4) and 5 lb of ground gypsum (calcium sulfate, $CaSO_4$) per ton of feed for 3 wk. Group 2 (control), received the same diet but without added molybdenum and sulfate.

Elevated levels of several serum enzymes were evidence that all animals had liver damage at the beginning of the molybdenum/sulfate feeding trial. The average body weight at wk 1, 2 and 3 were significantly higher in the molybdenum/sulfate-treated group. Average daily feed intake was also higher in this group. Six rams in the control group died during the experiment or shortly after, but none of the rams in the molybdenum/sulfate-treated group has died (as of the writing of this manuscript). These findings suggest that the addition of molybdate and sulfate to the diet had a beneficial effect on chronic copper poisoning in sheep. However, results of the evaluation of liver and kidney functions and of serum and tissue copper concentrations did not reveal a significant improvement after treatment. To better understand the mechanisms by which molybdenum/sulfate protect sheep with copper toxicosis, further tests are presently being analyzed and a more detailed report will be published subsequently.

Introduction

Copper is an essential trace mineral required for many biological processes of domestic animals. However, the requirements for copper intake vary widely among different species. Both excess and deficient copper levels may result in disease (Kelly, 1985). There is a very complex relationship between copper, molybdenum and sulfate and the toxicity/nutrient status of animals. Sheep as a species are most prone to copper poisoning, with some breeds being more susceptible than others (Britt and Yeoman, 1985). The basis for chronic copper poisoning in sheep is the unique affinity between liver and copper, coupled with the very limited rate at which this species can excrete the element in the bile. Chronic copper poisoning of sheep may occur because of increased ingestion, due to pasture or feed contamination, or due to increased availability of dietary copper when dietary levels of molybdenum are unusually low (Kerr and McGavin, 1991; Seaman, 1985; Kelly, 1985).

The liver plays an important role in copper metabolism. During copper poisoning, most of the copper is accumulated in liver cells. As the concentration of copper in the liver rises, evidence of liver damage begins to appear, cells swell and their nuclei become vesicular. Affected sheep may remain clinically normal, as long as new liver cells are produced. However, when the loss of cells in the liver exceeds the replacement rate, the plasma copper levels begin to rise (Kumaratilake and Howell, 1989; Kelly, 1985). Eventually, the blood copper concentration in plasma is high enough to cause red blood cell damage and hemolysis. At this point, animals show depression, anorexia, weakness, hemoglobinemia, hemoglobinuria, anemia, and death within 1 to 2 d. Yellow discoloration of mucous membranes may be noted in sheep surviving for longer periods (Kelly, 1985). There is evidence that stress may precipitate these hemolytic crises in susceptible sheep.

Determination of serum levels of the liver enzymes aspartate aminotransferase (AST) and gamma glutamyltransferase (GGT) is useful in the evaluation of chronic liver damage. These values can be used to predict the clinical outcome of copper poisoning (Lewis et al., 1997). In addition, copper levels in serum can be used to infer the amount of copper in tissues of intoxicated animals. Because hemoglobin released from red blood cells during acute hemolytic crises can result in damage of the kidney, assessing the levels of creatine phosphokinase (CK) in the serum may be a useful indicator of the clinical stage and extent of kidney damage in intoxicated animals (Lewis et al., 1997).

During the 1997-1998 Texas Agricultural Experiment Station Ram Performance Test (TAES-RPT) an outbreak of chronic copper poisoning occurred as a result of contaminated feed. Feed analyses revealed that several lots of the basic ram test feed contained levels of copper above the safe range for sheep. Previous reports indicate that the administration of sodium molybdate alone or in combination with sulfate or other chelators may result in a substantial reduction in liver copper content and in reduction of liver damage (Botha et al., 1995; Gooneratne et al., 1989; Humpries et al., 1988; Humpries et al., 1986; Gooneratne and Christensen, 1997). However, because of great variation in experimental designs and in the parameters used to evaluate the effects of each treatment, many questions still remain. The objectives of the present project were to determine the effects of administering sodium molybdate and sulfate in the diet of sheep chronically intoxicated with copper and to assess tissue damage in these animals by measuring AST, GGT, CK and copper levels in serum.

Materials and Methods

Twenty-eight yearling rams that were part of the 1997-1998 RPT and that belonged to TAES were selected for this experiment. From September 15 through February 2, rams received a ration that averaged 68 ppm copper and ranged from 133 to 17 ppm (Figure 1). At the beginning of the experiment (February 3), four rams were selected and killed to establish base line values of liver and kidney copper levels. The remaining 24 rams were randomly allocated into two experimental groups. Group 1 (Molybdenum/sulfate, n = 12), was put on a diet that contained 5 lb of 2% sodium molybdate (Na_2MoO_4) and 5 lb of ground gypsum (calcium sulfate, $CaSO_4$) per ton of feed for 3 wk. Group 2 (control), received the same diet but without added molybdenum and sulfate. The ingredient composition of the basal diet is shown in Table 1.

Figure 1. Copper levels fed to rams on Sonora Ram test 1997-1998

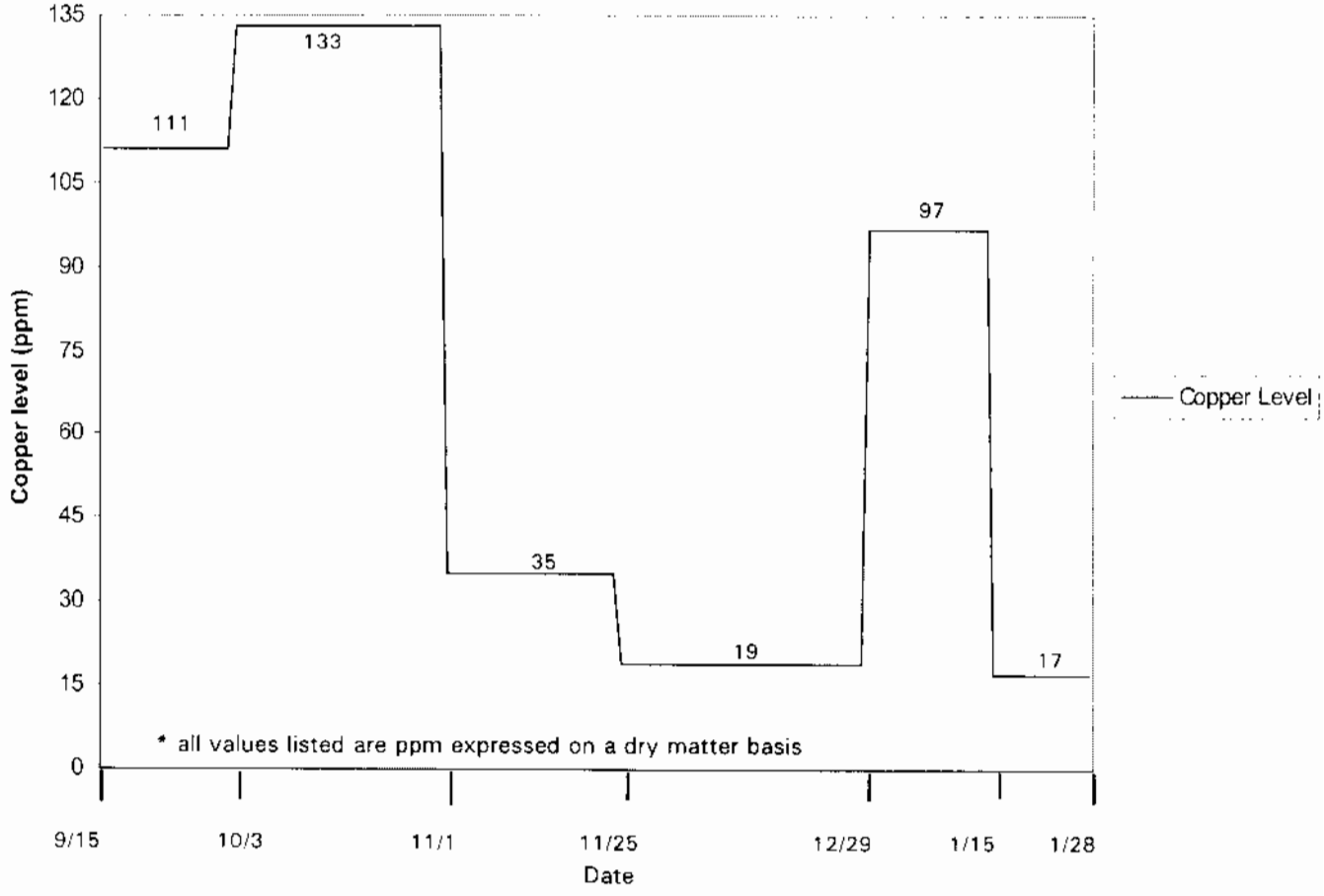


Table 1. Ingredient composition of the ram test feed

Ration ingredients	Percent (as fed)
Cottonseed hulls	23.37
Alfalfa, dehy., 17% CP	28.24
Grain sorghum, milo	24.34
Cottonseed meal, 41% CP	7.30
Soybean meal, 44% CP	7.30
Molasses, cane sugar	4.87
Binder	2.43
Salt, plain mixing	0.92
Trace mineral[a]	0.05
Calcium carbonate	0.49
Ammonium chloride	0.49
Aurofac 10[b]	0.15
Vitamin A	0.05
TOTAL	100.00

[a] Animal Science Products, Inc. Nacogdoches, TX. Guaranteed to contain the following minimum percentages: calcium, 12.00 as calcium carbonate; cobalt, 0.22 as cobalt carbonate; iodine, 0.25 as ethylenediamine dihydroiodide; iron, 6.60 as ferrous carbonate; manganese, 4.40 as manganous oxide and zinc, 12.00 as zinc oxide

[b] Aurofac 10, American Cyanamid. It contains 10 g of chlortetracycline per lb of product. Three pounds/ton would give 30 g of chlortetracycline/ton of feed.

Live body weights and average feed intakes were recorded weekly. Scrotal circumference was measured at the beginning and at the end of the experiment. Serum samples were collected at wk 0, 1, 2 and 3 and submitted to the Texas Veterinary Medical Diagnostic Laboratory for determination of AST, GGT, CK and copper levels. At the end of the 3-wk period, four animals in each group were randomly selected and killed. Complete necropsies were performed and liver and kidney copper levels were determined.

The significance of differences between means for the molybdenum/sulfate and control groups was determined by t-test (StatMost 2.5 for Windows, Datamost Corporation, Salt Lake City, UT).

Results

A total of 211 rams started the RPT at the TAES Sonora Station in September 1997. The feed for the ram test was formulated by TAES scientists and obtained from one supplier for the duration of the test. A statement was attached to the formulation submitted for bids that no copper should be added. Feed was usually delivered in truckloads of approximately 20 tons. The rams were delivered to the Sonora Station on September 15th and 16th, 1997. The graph in Figure 1 shows the copper levels as reported by the Northeast DHIA Forage Analysis Laboratory (Ithaca, NY) for a sample from each truckload of feed. Samples were taken when the truckloads were delivered, but the analyses were conducted only after the rams showed evidence of copper toxicosis. The first load of feed had 111 ppm copper and was fed for approximately 18 d. The rams began consuming the next load of feed (133 ppm copper) on October 3. The third truckload of feed (35 ppm copper) was fed from November 1 through November 25. The fourth truckload of feed (19 ppm copper) was fed from November 25 through December 29. The first deaths that were diagnosed as due to copper toxicosis occurred in December when the feed being consumed at the time was lower in copper than what had been consumed in the previous three truckloads. The fifth truckload of feed was high in copper (97 ppm). Results from the first feed samples analyzed were received the day after the fifth truckload of feed was delivered. During December 1997 and January 1998, 14 rams died from copper toxicosis. Four more rams died between February and March. All remaining rams, excluding those used in the trial, at the Sonora Station were fed the same molybdenum/sulfate diet described above for 3 wk starting on January 28 and were then dismissed from the test and taken back to their respective places of origin between March 23 and 30. Additional rams died after being removed from the test, but a precise count or confirmation of the cause of death was not established.

From the group of 24 rams selected to evaluate the effects of molybdenum/sulfate on copper poisoning, two rams from the control group died during the 3-wk experiment. Four additional rams in this group died after the end of the experiment. Of these six rams, four died with clear clinical signs of acute hemolysis secondary to copper poisoning within 2 wk of the end of the experiment. Subsequently one ram died from acute pneumonic Pasteurellosis and another died 3 mo after the end of the experiment with signs of hemolytic crisis and secondary bronchopneumonia. On the other hand, all the rams in the molybdenum/sulfate group were alive at the time of writing this manuscript (23 wk after the end of the experiment).

Table 2 presents the live body weights, the average daily gains, the average feed intake, the feed/gain ratio and the scrotal circumference measurements for the molybdenum/sulfate-treated and the control rams. No significant differences in body weight were observed between the molybdenum/sulfate and the control groups at wk 0 of the experiment ($P = .162$). Weekly average daily gains were variable between the two groups and among the individual rams within the groups. For the 3-wk period, rams in the molybdenum/sulfate-treated group tended to have a higher ($P = .085$) average daily gain compared to the control group, and resulted in the

molybdenum/sulfate group being heavier (P = .0009) at the end. Average daily feed intake was also higher (P = .0007) in the molybdenum/sulfate-treated group. Differences in feed/gain ratio and scrotal circumferences were not significant between groups.

Table 2. Performance data for copper-poisoned rams fed a diet containing ammonium molybdate and calcium sulfate or a control diet

Item	Control	Molybdenum	P-value
Live body weights, lb			
Week 0	224.9	233.1	0.162
Week 1	224.9	237.6	0.023
Week 2	227.6	245.4	0.044
Week 3	232.4	248.0	0.0009
Average daily gains, lb/d			
Week 1	0.00	0.64	0.063
Week 2	0.38	1.12	0.193
Week 3	0.69	0.37	0.684
3-weeks	0.36	0.71	0.085
Average feed intake, lb/d			
	7.3	11.1	0.0007
Feed/gain	25.4	16.1	0.300
Scrotal circumference, cm			
Initial	33.4	33.8	0.768
Final	33.1	34.5	0.542
Change	-0.07	0.73	0.339

Rams 112 and 117, both in the Control treatment, died during the experiment and were excluded from these data.

At wk 0 of the experiment, all 28 rams in the experiment had GGT serum levels above the normal range. Twenty-six of them also had AST serum levels above normal (data not shown). Weekly average serum values of these two liver enzymes (AST and GGT) for each of the two experimental groups are presented in Figures 2 and 3, respectively. Average weekly AST values were higher (P < .05) in the control group than in the molybdenum/sulfate group at wk 0, 1 and 3, and average weekly values for GGT were higher (P < .05) throughout the experiment. Average weekly CK serum values were within the normal range throughout the experiment with exception of wk 2 in the control group (Figure 4). The average CK values were not significantly different between the two experimental groups at anytime in this study. However, some individual animals had elevated CK values on one or more occasions.

Figure 2. Levels of aspartate amino transferase in serum (Normal range 53-153 U/L)

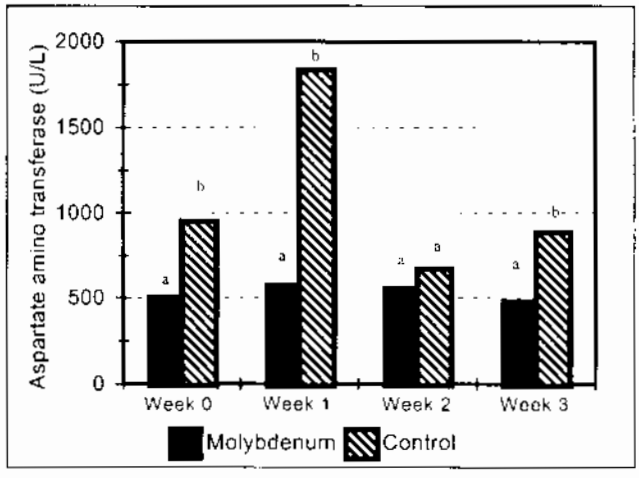


Figure 3. Levels of gamma glutamyl transferase in serum (Normal range 0-50 IU/L)

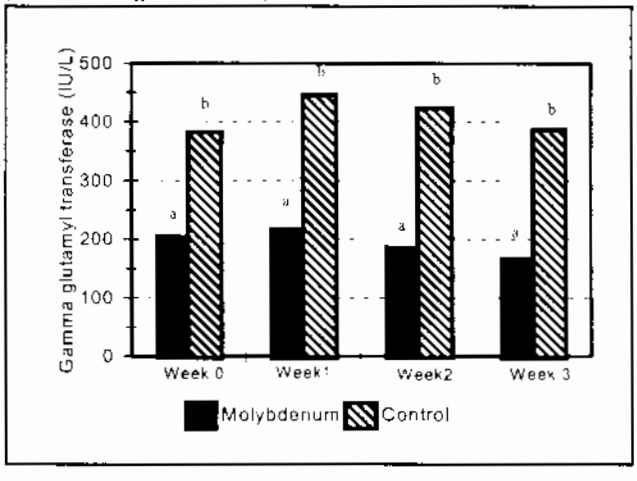
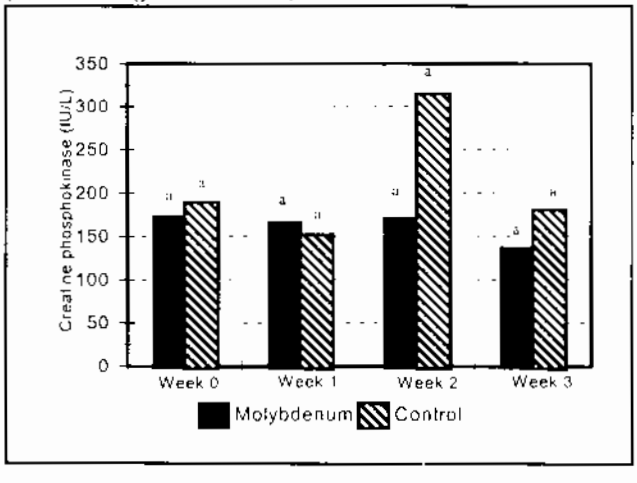


Figure 4. Levels of creatine phosphokinase in serum (Normal range 69-182 IU/L)



At wk 0, average serum copper levels were above the normal range (0.7 to 1.2 ppm) in the control group but

not in the molybdenum/sulfate-treated group (Figure 5). However, copper levels in serum increased to above the normal range in the molybdenum/sulfate-treated group for the remaining of the experiment, while in the control group they were elevated only at wk one. In the last 2 wk of the experiment, serum copper values in the control group were lower ($P < .05$) than those of the molybdenum/sulfate group.

Figure 5. Levels of copper in serum (Normal range 0.7-1.2 ppm)

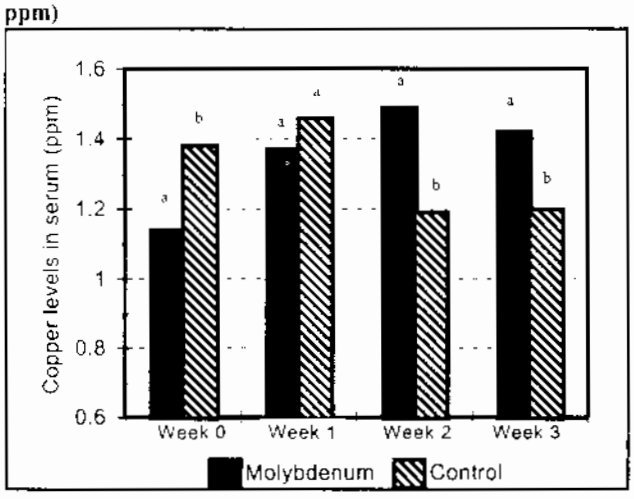
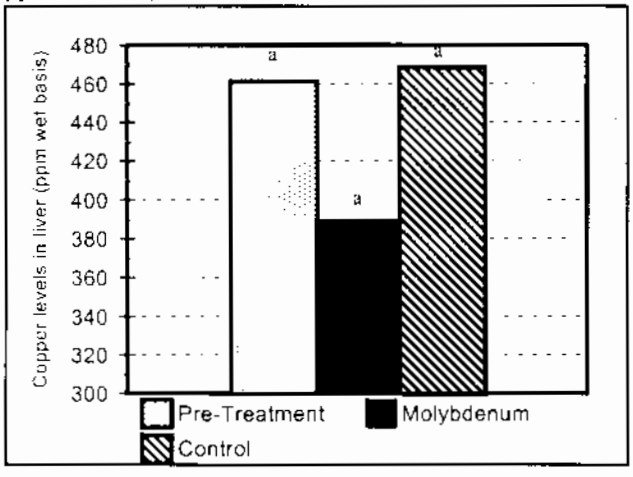
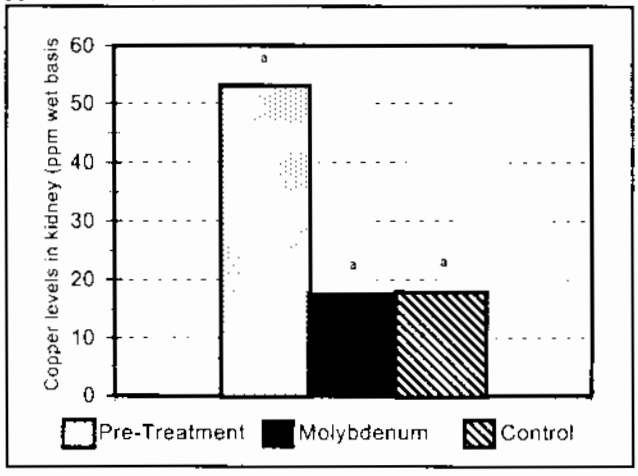


Figure 6. Levels of copper in liver (Normal range 25-100 ppm wet basis)



Average copper levels in the liver and kidney (Figures 6 and 7, respectively) of the four animals killed at the beginning of the experiment were above the normal range (normal copper levels are 25 to 100 ppm and 3 to 5 ppm in liver and kidney, respectively). Although average copper levels in the livers of the four animals treated with molybdenum/sulfate and killed at the end of the experiment were lower than in the control group and in the pre-treatment killed animals, the differences were not significant. Average copper levels in the kidney of the pre-treatment killed, the molybdenum/sulfate-treated and the control animals were above the normal range; however, differences among the three groups were not significant.

Figure 7. Levels of copper in kidney (Normal range 3-5 ppm wet basis)



Discussion

Sources of copper that have been responsible for toxicosis in sheep include wrongly formulated trace mineral supplements, rations containing excess poultry or swine waste, diets richly supplemented with palm oil by-products, pasture fertilized with chicken litter, forages from orchard pastures contaminated with copper sulfate fungicides, some parasiticides for gastrointestinal helminths, copper sulfate foot baths, fungicide-treated fence posts, corroded overhead cables, copper treated seed grains, and therapeutic parentally administered copper salts used for treatment of copper deficiency (Carlson and George, 1990). In the outbreak at the RPT, the source of copper was traced to the feed.

Evaluation of liver function has been used to predict the extent of liver damage and the clinical outcome of sheep chronically intoxicated with copper (Lewis et al., 1997; MacPherson and Hemingway, 1969). In the present experiment, AST and GGT levels in the serum of 24 rams indicated that all animals had severe liver damage before the beginning of the experiment, thus suggesting that all animals in the RPT most likely suffered from various degrees of copper-induced liver damage.

Several synthetic chelators have been used by investigators to treat copper toxicosis in animals (Botha et al., 1995; Gooneratne et al., 1989; Humpries et al., 1988; Humpries et al., 1986; Gooneratne and Christensen, 1997; van Ryssen, 1994; Ledoux et al.,

1996; Hidiroglou et al., 1984). Intravenous administration of tetrathiomolybdate is believed to lower body copper concentrations with variable success (Gooneratne and Christensen, 1997). However, intravenous treatment may be impractical when a large number of animals are involved. In the present study of effects of feeding molybdate and sulfate, a total of six animals in the control group died during the experiment or shortly after, whereas all of the molybdenum/sulfate-treated sheep survived. Live body weights were significantly higher in the molybdenum/sulfate-treated group than in the controls. These findings suggest that the addition of sodium molybdate and sulfate in the diet has a beneficial effect on copper poisoning in sheep. However, because the average feed intake was also higher in the molybdenum/sulfate-treated group, these data alone do not rule out the possibility that the increased feed intake and higher body weights were due to increased palatability of the molybdenum/sulfate diet.

Because the liver is the main target organ in copper toxicity, concentrations of liver enzymes in serum have been used to assess the extent of liver damage (MacPherson and Hemingway, 1969). A previous study reported that levels of liver enzymes were valuable aids for monitoring copper poisoning recovery after treatment (Hidiroglou et al., 1984). In order to determine if serum levels of AST and GGT could be used as predictors of copper-induced liver damage during oral molybdenum/sulfate treatment, the two enzymes were measured in the serum of all experimental animals before the beginning of the experiment and at wk 1, 2 and 3 of treatment. All the experimental animals presented GGT levels above normal values before treatment started. Twenty-six of the rams also had elevated AST levels at this time, thus indicating that all animals had some degree of liver damage. Significant decreases in the levels of GGT and AST were not observed in either of the experimental groups by the end of the experiment, suggesting that either molybdenum/sulfate treatment had no beneficial effect on liver function or that measurement of liver enzymes is not sensitive enough to detect moderate improvement of liver function. The levels of both enzymes were significantly higher in the control group before molybdenum/sulfate treatment and remained higher in this group throughout the experiment. Because the animals in the two experimental groups were allocated randomly , most likely the difference in values resulted as a random event.

Serum copper levels were higher in the control group than in the molybdenum/sulfate group at the beginning of the experiment. After treatment started, serum copper increased in the molybdenum/sulfate-treated group and remained above normal levels for the rest of the experiment. On the other hand, serum copper levels in the control group started above normal ranges and decreased to normal values by the end of the experiment. The precise mechanism by which molybdenum reduces liver copper is not known. However, it has been reported that intravenous injection of ammonium tetrathiomolybdate causes the release of liver copper into the plasma (Ledoux et al. 1996). In this experiment, most of the serum copper was found to be insoluble, and therefore, unavailable for tissue uptake representing a loss of copper from liver. Furthermore, molybdenum increases copper excretion in bile with only a slight increase in urinary copper (Gooneratne and Christensen, 1997).

Average copper levels in the liver of the four animals killed at the beginning of the experiment were above normal levels. Although not significant, a decrease in copper levels in liver was observed in the molybdenum/sulfate-treated but not in the control group. Lack of significance may have been due to the small number of animals in each group. However, average copper levels in the livers of the two experimental groups were still above the normal range at the end of the treatment. Further studies are necessary to determine the long term effects of molybdenum/sulfate treatment.

Average copper levels in the kidney of the pre-treatment killed, the molybdenum/sulfate-treated and the control animals were above the normal level; however, differences among the three groups were not significant. Individually, there was a wide variation in kidney copper levels. It is thought that copper accumulation in the kidney is related to the number and severity of hemolytic crises (Ledoux et al., 1996).

In order to better understand the effects of sodium molybdate and sulfate supplementation on the diet of sheep chronically intoxicated with copper, additional analyses are being conducted, and the final results of this experiment will be published in the future.

Implications

Results of these experiments suggest that the addition of sodium molybdate and sulfate in the diet for 3 wk, significantly decreased mortality among sheep intoxicated with copper and promoted weight gain. Because the evaluation of liver and kidney functions and of serum and tissue copper concentrations did not reveal a significant improvement after treatment, further experiments are necessary to better understand the mechanisms by which molybdenum improves the survival rate during copper toxicosis. All other animals that participated in the RPT and survived the initial bout

of copper-associated mortality were fed the same molybdenum/sulfate diet as used in this experiment before being returned to their places of origin. It is possible that if these sheep had not been fed the molybdenum/sulfate diet, mortality among them would have been much higher, thus resulting in a calamity of greater proportions.

Acknowledgments

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Pretreatment with Dietary Ethoxyquin for Control of Bitterweed Poisoning in Sheep

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ABSTRACT

Twenty Rambouillet lambs (86.0 ± 2.2 lb LW) were fed a diet with .5% ethoxyquin at the rate of 2.2 lb/lamb/day for intervals of 0, 4, 8 or 16 d prior to exposure to bitterweed. Upon completion of the designated pretreatment time, dried, ground bitterweed containing 1.72% hymenoxon was suspended in water and given via rumen tube at a level to provide each lamb 22.7 mg hymenoxon/lb LW/d, for four consecutive days. Serum urea nitrogen, creatinine, total bilirubin, lactic dehydrogenase, aspartate aminotransferase, γ-glutamyltransferase and hematocrit were increased by bitterweed in lambs not receiving ethoxyquin. There were linear decreases in urea nitrogen and creatinine with increasing number of days on ethoxyquin pretreatment. Lactic dehydrogenase and aspartate aminotransferase levels were less in lambs receiving ethoxyquin for 8 and 16 d than for lambs not receiving ethoxyquin. Total bilirubin and hematocrit were less in lambs given the diet with .5% ethoxyquin for 16 d compared with untreated lambs. Based on the results of this study, ethoxyquin (.5% in the diet) should be included in the diet at least 16 d prior to exposure to bitterweed to provide protection against poisoning.

Introduction

Bitterweed (*Hymenoxys odorata*) was first recognized as being toxic to sheep over seventy years ago (Hardy et al., 1931). Since then, bitterweed poisoning has been a consistent problem to sheep producers. The problem is most severe on limestone-derived soils in western Texas and has been a significant factor in the decline in sheep numbers in that region (Ueckert and Calhoun,1988).

The toxic constituent of bitterweed is hymenoxon, a sesquiterpene lactone with an exocylic α-methylene group (Kim et al., 1975). The intraperitoneal LD_{50} of hymenoxon in sheep is 3.2 mg/lb LW (Kim et al.,1975) and the acute oral LD_{50} is 34 mg/lb LW (Terry et al., 1981). Hymenoxon content of bitterweed is highly variable depending on the location where it is growing, stage of growth and environment (Pfeiffer and Calhoun, 1987). Highest concentrations of hymenoxon are found in seedlings and levels decrease as the plant matures. In mature plants, the leaves and flowerheads contain the highest concentrations.

Signs of bitterweed poisoning are inappetence, weight loss, depression or listlessness in subacute cases, and occasional green nasal discharge and vomition in acute poisoning (Witzel et al., 1974; Witzel et al., 1977; Calhoun et al., 1981). Physiopathologic changes include gaseous fluid distention in the rumen, reticulum, lower ilium and cecum, ascitic and pericardial edema, increase in liver size and weight, cholestasis, distention of the gall bladder and nephrosis and congestion of the kidneys (especially along the cortico-medullary junction) (Witzel et al., 1974; Ivie et al., 1975; Kim et al., 1975; Calhoun et al., 1981; Calhoun et al., 1988).

Bitterweed causes elevations in serum concentrations of urea nitrogen, creatinine, creatine kinase, aspartate aminotransferase, total bilirubin, inorganic phosphorus (Calhoun et al., 1981; Terry et al., 1981; Kim et al., 1982),γ-glutamyl transferase (Calhoun et al., 1986, Calhoun et al., 1988), alkaline phosphatase, lactic dehydrogenase and alanine aminotransferase (Terry et al., 1981). Calhoun et al. (1981) also reported a bitterweed dose related decrease in serum protein and albumin.

Toxicity of sesquiterpene lactones depends on the number of alkylating centers present, and hymenoxon has an α-methylene-γ-lactone and a bishemiacetal center (Kim, 1980). Bridges et al. (1980) reported hymenoxon reacts readily with sulfhydryl groups, and its cytotoxic effects may be due to inactivation of key enzymes in this manner.

Cysteine was one of the early antidotes tested and was very effective; however, cysteine must be infused into the bloodstream, or abomasum and it is expensive and can be toxic (Bridges et al., 1980). Increasing sulfhydryl groups in the feed and adding antioxidants in the feed have been the major efforts for decreasing hymenoxon poisoning (Bridges et al., 1980; Kim et al.,1982; Kim et al., 1983; Calhoun et al., 1986). Feeding a protein supplement with increased sulfur provided some protection against bitterweed poisoning (Bridges et al., 1980; Calhoun et al., 1986). Addition of ethoxyquin (EQ; an antioxidant) to the diet of sheep at .5% provided good protection against the toxic effects of bitterweed (Kim et al., 1982; Kim et al., 1983; Calhoun et al., 1986). The major draw back to EQ is that it is unpalatable. The purpose of this study was to determine the pretreatment time prior to bitterweed

ingestion necessary for EQ to provide protection against bitterweed poisoning.

Materials and Methods

Twenty Rambouillet lambs (86.0 ± 2.2 lb; approx. 8 mo old) were assigned at random to four treatments (five lambs/treatment). Treatments consisted of feeding a diet containing .5% EQ for 0, 4, 8 and 16 d prior to dosing with BTW. During the study, lambs were maintained in individual pens and fed 2.2 lb/day of a diet that either contained .5% EQ or no added EQ (Table 1) as follows: 1) the 0-d pretreatment group (controls) was fed the diet without EQ for 16 d prior to BTW dosing, 2) the 4-d pretreatment group was fed the diet without EQ for 12 d and then the diet with .5% EQ for 4 d prior to BTW dosing, 3) the 8-d pretreatment group was fed the diet without EQ for 8 d and then the diet with .5% EQ for 8 d prior to BTW dosing and 4) the16-d pretreatment group was fed the diet with .5% EQ for 16 d prior to BTW dosing. By following this procedure, it was possible to start dosing all lambs with BTW on the same day. All lambs were continued on their respective diets for a 4-d BTW dosing period and an 11-d recovery period.

Table 1. Percentage ingredient composition of experimental diets

	Ethoxyquin level, %	
Ingredient	0	.5
Sorghum grain,milo	43.40	42.80
Alfalfa meal, dehydrated	15.00	15.00
Cottonseed meal	32.00	32.00
Molasses,cane	8.00	8.00
Calcium carbonate	.60	.60
Premix	1.00	1.00
Santoquin[a]	-.-	.56

[a] Monsanto Chemical Co., 90% Ethoxyquin (6-ethoxy- 1,2-dihydro-2,2,4-trimethylquinoline).

The BTW used in this study was air-dried, ground through a 2 mm screen, and contained 1.72% hymenoxon, as determined by gas-liquid chromatography using the procedure of Hill et al. (1979). The daily dose (calculated to provide a hymenoxon intake of 22.7 mg/lb LW/d) was suspended in 1 quart of warm water and administered via a rumen tube at 0800 for four consecutive days. Lambs were weighed initially. Feed was fed daily, and feed refusals were weighed back the following morning.

Blood samples were collected from the external jugular vein into two 10 mL vacuum tubes at 0, 2 and 4 d of the BTW dosing period and 3, 7 and 11 d of the recovery period. One vacuum tube contained sodium heparin as an anticoagulant. This blood sample was used for the determination of hematocrit. The other tube contained no additives and was centrifuged to obtain serum. Serum was stored frozen (-20°C) and subsequently used for analysis of serum constituents at the Texas Veterinary Medical Diagnostic Laboratory in College Station.

The General Linear Models Procedure of the Statistical Analysis System (SAS, 1985) was used in the statistical treatment of the data. Duncan's Multiple Range Test was used to test for differences between treatments means. Differences were considered significant when $P < .05$.

Results

Initial live weights and feed intakes are presented in Table 2. Adding .5% EQ to the diet resulted in a slight and transitory decrease in feed intake. However, feed intakes for the lambs given the diet with added EQ for 8 and 16 d were approaching 2.2 lb/d prior to the time BTW dosing started. Dosing with bitterweed caused the lambs to go off feed. Although there was not a significant treatment effect for feed intakes during the 4-d BTW dosing period, lambs pretreated for 16 d with EQ had slightly higher feed intake than the control, 4- and 8-d pretreatment groups. Lambs receiving EQ for only 4 d prior to BTW dosing were slower to resume eating. During the first three d after BTW dosing ceased, feed intake for the lambs given EQ for 16 d was significantly higher ($P < .05$) than for the group receiving EQ for 4 d. From 4 to 7 d after BTW dosing ceased, feed intakes for the control lambs and those receiving EQ for 8 and 16 d were near the pre- BTW dosing levels, while intake for the group receiving EQ for 4 d was only 58% of the pre-dosing level ($P < .05$). Feed intake for the lambs that received EQ for only 4 d remained depressed throughout the 11-d recovery period.

Initial hematocrit values for all treatment groups were higher than normal for sheep (Table 3). Feeding a diet with .5% EQ did not affect the initial hematocrit values. Lambs receiving the control diet and the EQ diet for 4 d prior to BTW dosing had higher ($P < .05$) hematocrit values after 2 and 4 d of BTW dosing than lambs receiving the diet with EQ for 16 d prior to BTW dosing. Hematocrit levels for all treatments were less than their initial values by the 3rd day of the recovery period (Table 3).

Table 2. Initial live weights (LW) and feed intakes of lambs fed a diet with .5% ethoxyquin (EQ) for 0, 4, 8 and 16 days prior to dosing with bitterweed (BTW) for four consecutive days at a level to provide 22.7 mg hymenoxon/lb LW per day

	EQ Pretreatment period, days				
Criterion	0	4	8	16	SEM
Initial LW, lb	83.8	87.1	85.5	87.3	2.3
Feed intakes, lb/d					
Pre-EQ[a]	2.07	2.20	2.20	2.20	.059
Pre BTW dosing[b]	2.07	1.92	2.07	2.14	.130
4-d BTW dosing[c]	26	26	.22	42	.071
3-d recovery[d]	75[gh]	35[h]	.88[gh]	1.41[g]	.227
7-d recovery[e]	2.05[g]	1.10[h]	1.83[gh]	1.98[g]	.277
11-d recovery[f]	2.20	1.43	1.92	1.94	.278

[a] Average daily feed intakes for the four-day period prior to feeding the EQ diet.
[b] Average daily feed intakes for the four-day period just prior to dosing with BTW.
[c] Average daily feed intakes for the four d BTW was administered.
[d] Average daily feed intakes for the first three d of the recovery period.
[e] Average daily feed intakes for d four thru seven of the recovery period.
[f] Average daily feed intakes for days seven thru eleven of the recovery period.
[g,h] Means on the same row without a common superscript are significantly different ($P < .05$).

Table 3. Effects of adding .5% ethoxyquin (EQ) to the diet of lambs for 0, 4, 8 and 16 days prior to dosing with bitterweed (BTW) on hematocrit (%)[a]

	EQ Pretreatment period, days				
Criterion	0	4	8	16	SEM
Initial	48.9	48.5	46.1	46.0	1.62
2-d BTW dosing	54.4[b]	54.3[b]	50.2[bc]	48.3[c]	1.69
4-d BTW dosing	58.6[bc]	60.9[c]	54.6[cd]	49.4[d]	2.64
3-d recovery	46.3[b]	46.4[b]	43.2[bc]	40.6[c]	1.77
7-d recovery	43.3	45.3	41.3	40.9	1.91
11-d recovery	45.3	44.0	40.5	39.9	2.52

[a] Lambs were dosed with BTW for four consecutive days at a level to provide 22.7 mg hymenoxon/lb LW per day.
[b,c,d] Means on the same row without a common superscript are significantly different ($P < .05$).

Serum urea nitrogen values are presented in Table 4. Lambs fed the diet with EQ for 4 d had lower ($P < .05$) initial serum urea nitrogen values than those not receiving EQ. After 2 d of BTW dosing, urea nitrogen levels were elevated for all treatment groups, but after 4 d of BTW dosing, lambs on the control diet had significantly higher urea nitrogen values compared to those fed the EQ diet for 8 and 16 d prior to BTW dosing. Urea nitrogen levels were still elevated at 3 d of the recovery period for lambs not fed the EQ diet and those fed the EQ diet for only 4 d, but treatment differences were not significant because of the large variation among lambs within treatments. Levels of urea nitrogen had returned to near normal levels by the seventh day of the recovery period.

Table 4. Effects of adding .5% ethoxyquin (EQ) to the diet of lambs for 0, 4, 8 and 16 days prior to dosing with bitterweed (BTW) on serum urea nitrogen (mg/dl)[a]

	EQ Pretreatment period, days				
Criterion	0	4	8	16	SEM
Initial	26.6[b]	20.4[c]	23.4[bc]	26.2[bc]	1.88
2-d BTW dosing	38.4	41.6	34.6	40.4	4.58
4-d BTW dosing	44.0[b]	41.6[bc]	29.4[c]	31.0[c]	4.06
3-d recovery	40.8	41.8	21.0	30.6	9.98
7-d recovery	26.8	28.4	21.8	29.0	5.19
11-d recovery	28.6	23.8	22.4	21.8	4.15

[a] Lambs were dosed with BTW for four consecutive days at a level to provide 22.7 mg hymenoxon/lb LW per day.
[b,c] Means on the same row without a common superscript are significantly different ($P < .05$).

Values for serum creatinine are presented in Table 5. Initial serum creatinine levels for the 4-, 8- and 16-d EQ pretreatment groups were depressed ($P < .05$) as compared to the control animals. Bitterweed dosing for 2 d increased serum creatinine levels across all treatments with no significant differences between treatments. After 4 d of BTW dosing, control lambs had higher ($P < .05$) creatinine values than the 8- and 16-d EQ pretreatment groups. Although not significant, creatinine values for the control, 4- and 8-d EQ pretreatment groups remained elevated at 3 d into the recovery period. Serum creatinine values returned to near normal levels by the end of the recovery period.

Table 5. Effects of adding .5% ethoxyquin (EQ) to the diet of lambs for 0, 4, 8 and 16 days prior to dosing with bitterweed (BTW) on serum creatinine (mg/dl)[a]

	EQ Pretreatment period, days				
Criterion	0	4	8	16	SEM
Initial	1.22[b]	.98[c]	1.02[c]	1.00[c]	.048
2-d BTW dosing	1.62	1.52	1.40	1.32	.101
4-d BTW dosing	2.50[b]	2.18[bc]	1.72[cd]	1.48[d]	.184
3-d recovery	2.44	2.84	1.40	1.12	.723
7-d recovery	1.18	1.58	1.08	1.04	.288
11-d recovery	1.00	.88	.98	.90	.177

[a] Lambs were dosed with BTW for four consecutive days at a level to provide 22.7 mg hymenoxon/lb LW per day.
[b,c,d] Means on the same row without a common superscript are significantly different ($P < .05$).

Serum total bilirubin values are presented in Table 6. Although initial values for total bilirubin are within the normal range, consumption of EQ appeared to elevate bilirubin for all three pretreatment groups as compared to the control group. Bilirubin levels for the 0 and 4 d EQ pretreatment groups were elevated above the normal range after 4 d of BTW dosing; however, the only significant differences in bilirubin were increases ($P < .05$) in the control group vs the 16-d EQ pretreatment group. With the exception of the lambs fed EQ for only 4 d prior to BTW dosing, total bilirubin levels for all treatments were similar to their initial values by d 3 of the recovery period. By the eleventh day of the recovery period there were no significant differences between treatments.

Table 6. Effects of adding .5% ethoxyquin (EQ) to the diet of lambs for 0, 4, 8 and 16 days prior to dosing with bitterweed (BTW) on serum total bilirubin (mg/dl)[a]

	EQ Pretreatment period, days				
Criterion	0	4	8	16	SEM
Initial	.28[c]	.34[bc]	.32[bc]	.36[b]	.022
2-d BTW dosing	.34	.42	.40	.38	.029
4-d BTW dosing	.74[b]	.66[bc]	.42[bc]	.36[c]	.114
3-d recovery	.32[c]	.48[b]	.36[c]	.30[c]	.037
7-d recovery	.22[c]	.36[b]	.30[bc]	.30[bc]	.027
11-d recovery	.18	.26	.26	.24	.028

[a] Lambs were dosed with BTW for four consecutive days at a level to provide 22.7 mg hymenoxon/lb LW per day.

[b,c] Means on the same row without a common superscript are significantly different ($P < .05$).

A summary of serum lactic dehydrogenase values is presented in Table 7. Serum lactic dehydrogenase values were within the normal range for all treatment groups initially and after 2 d of BTW dosing. Pretreatment with EQ for 8 or 16 d prevented the extreme increases in lactic dehydrogenase observed for the 0-and 4-d EQ pretreatment groups after 4 d of BTW dosing. After 3 d of recovery, lactic dehydrogenase levels remained elevated for the 0-, 4- and 8-d EQ groups, but the only significant difference was between the 4- and 16-d EQ pretreatment groups. With the exception of lambs pretreated with EQ for 4 d, by the end of the 11-d recovery period lactic dehydrogenase values were near the initial levels for all treatment groups.

Table 7. Effects of adding .5% ethoxyquin (EQ) to the diet of lambs for 0, 4, 8 and 16 days prior to dosing with bitterweed (BTW) on serum lactate dehydrogenase (U/l)[a]

	EQ Pretreatment period, days				
Criterion	0	4	8	16	SEM
Initial	320	271	311	296	51.3
2-d BTW dosing	390	347	352	348	19.9
4-d BTW dosing	923[b]	1014[b]	545[c]	373[c]	98.0
3-d recovery	626[bc]	752[b]	475[c]	427	87.9
7-d recovery	484[bc]	534[b]	372[c]	457[bc]	46.2
11-d recovery	292	463	332	325	56.9

[a] Lambs were dosed with BTW for four consecutive days at a level to provide 22.7 mg hymenoxon/lb LW per day.

[b,c] Means on the same row without a common superscript are significantly different ($P < .05$).

Values for serum aspartate aminotransferase are summarized in Table 8. Initial aspartate aminotransferase values were within the normal range for all lambs, but those fed the EQ treatments had lower aspartate aminotransferase values than the control lambs. After 4 d of BTW dosing, aspartate aminotransferase values were elevated compared with initial values for all treatment groups; however, values were higher ($P < .05$) for the 0- and 4-d EQ pretreatment groups compared with the 8- and 16-d EQ pretreatment groups. Average aspartate aminotransferase values for all treatment groups remained elevated thru the 3rd day of the recovery period, but only the 4-d EQ group was higher ($P < .05$) than the 8- and 16-d EQ groups. On the seventh day of the recovery period, aspartate aminotransferase values for the control and 4-d EQ treatments were significantly higher ($P < .05$) than the 16-d EQ group, and by recovery d 11 there were no significant differences between treatments.

Table 8. Effects of adding .5% ethoxyquin (EQ) to the diet of lambs for 0, 4, 8 and 16 days prior to dosing with bitterweed (BTW) on serum aspartate aminotransferase (U/l)[a]

	EQ Pretreatment period, days				
Criterion	0	4	8	16	SEM
Initial	101	75	73	75	9.3
2-d BTW dosing	114[b]	73[bc]	73[bc]	69[c]	13.9
4-d BTW dosing	1318[b]	1691[b]	555[c]	158[c]	206.5
3-d recovery	464[b]	709[b]	329[c]	157[c]	105.5
7-d recovery	174[b]	177[b]	130[bc]	106[c]	21.3
11-d recovery	79	103	141	81	32.5

[a] Lambs were dosed with BTW for four consecutive days at a level to provide 22.7 mg hymenoxon/lb LW per day.

[b,c] Means on the same row without a common superscript are significantly different ($P < .05$).

A summary of serum γ-glutamyltransferase values is presented in Table 9. Pretreatment with EQ for 4, 8 and 16 d increased ($P < .05$) γ-glutamyltransferase levels compared to the group not fed EQ. Bitterweed dosing for 4 d increased ($P < .05$) serum γ-glutamyltransferase levels for the 0- and 4-d EQ pretreatment groups, but not the 8- and 16-d EQ pretreatment groups, and these effects persisted through the first 3 d of the recovery period. Serum levels remained higher for the 0- and 4-d EQ group throughout the 11-d recovery period; however, treatment differences were not significant.

Table 9. Effects of adding .5% ethoxyquin (EQ) to the diet of lambs for 0, 4, 8 and 16 days prior to dosing with bitterweed (BTW) on serum γ-glutamyltransferase (U/l)[a]

	EQ Pretreatment period, days				
Criterion	0	4	8	16	SEM
Initial	78[c]	96[b]	98[b]	108[b]	5.8
2-d BTW dosing	85	88	94	99	7.2
4-d BTW dosing	393[b]	299[b]	101[c]	114[c]	34.1
3-d recovery	262[b]	252[b]	140[c]	133[c]	30.3
7-d recovery	186	185	135	121	22.6
11-d recovery	162	169	126	118	18.1

[a] Lambs were dosed with BTW for four consecutive days at a level to provide 22.7 mg hymenoxon/lb LW per day.

[b,c] Means on the same row without a common superscript are significantly different ($P < .05$).

Discussion

Hymenoxon, the principal toxin in BTW, is a cumulative toxin. The occurrence of BTW poisoning in animals is a function of the amount of hymenoxon consumed and the number of consecutive days it is consumed (Dollahite et al., 1973) As long as sheep are not severely poisoned, removal from BTW results in fairly rapid recovery. Sheep producers have taken advantage of this to manage sheep on bitterweed-infested pastures by removing them at the first signs of bitterweed poisoning (Ueckert and Calhoun, 1988).

The level of hymenoxon used in this study and the number of days it was administered (22.7) mg/lb LW per day for four consecutive days) produced a marked decrease in voluntary feed intake accompanied by elevations in a number of serum constituents, which was followed by fairly rapid recovery after the last BTW dose. This provided a sensitive procedure for assessing the minimum number of days sheep must consume EQ to provide protection against BTW poisoning. The results varied depending on the measurement examined. Some protection was apparent for most criteria by the time lambs were fed the diet with EQ for 8 d, but almost complete protection was apparent for all the criteria examined when lambs were pretreated with EQ for 16 d prior to BTW dosing. The practical implications of this research are that sheep must be fed a supplement containing EQ for about 2 wk or longer before they start eating bitterweed to be protected against BTW poisoning.

Acknowledgements

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Serologic, Virologic, and Pathologic Responses to Experimental Ovine Lentivirus Infection Among Different Breeds of Sheep

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ABSTRACT

Ovine lentivirus (OvLV) infection is a chronic, multi-systemic disease of sheep that results in chronic wasting and chronic respiratory failure as a result of lymphoid interstitial pneumonia (LIP). Previous studies suggest that genetic factors in the host may determine susceptibility to OvLV-induced disease and that some breeds of sheep may be more susceptible. To determine differences in individual and breed susceptibility to OvLV infection, a group of 32 lambs from four different breeds (Barbado, Florida Native, Rambouillet and Suffolk) were inoculated with OvLV. The antibody response to OvLV, the virus load and the degree of OvLV-induced LIP were evaluated after inoculation. This study demonstrated a large degree of variation among individuals from all breeds in immune responses to OvLV-infection, in virus load, and in the degree of susceptibility to developing LIP. However as group, Barbados were more susceptible and Suffolks were more resistant. A strong correlation was found between the degree of OvLV-induced LIP and virus titers in both blood mononuclear cells (BMNC) ($r = .478$; $P = .008$) and bronchoalveolar lavage (BAL) cells ($r = .491$; $P = .005$). Further studies are necessary to identify genetic markers that correlate with susceptibility or resistance to OvLV infection and disease.

Introduction

Lentiviruses comprise a group of viruses that cause chronic, multi-systemic disease in domestic animals and humans (Narayan et al., 1988; Clements and Zink, 1996; Brahic and Haase, 1981; Clements et al., 1994). Ovine lentivirus (OvLV), is genetically and structurally very similar to caprine arthritis encephalitis virus (CAEV) and to the human immunodeficiency virus (HIV) (Narayan et al., 1988; Narayan and Clements, 1989; de la Concha-Bermejillo et al., 1995b; Sonigo et al., 1985; de la Concha-Bermejillo et al., 1995a; Petursson et al., 1992). Most frequently, OvLV infection results in chronic wasting and chronic respiratory failure as a result of lymphoid interstitial pneumonia (LIP); however, chronic mastitis with reduced milk production, and arthritis that leads to lameness can also be manifestations of the disease (Cadore et al., 1996; de la Concha-Bermejillo, 1997). Ovine lentivirus infection occasionally results in inflammation of the brain and spinal cord that may result in progressive paralysis.

In the US, 26% of all sheep are persistently infected with OvLV, thus making this viral infection one of the major concerns for American sheep producers. Our previous studies have shown that the prevalence of OvLV in Texas sheep is only 0.5%. Although the reasons for the difference in OvLV prevalence between Texas and other sheep-producing states is not clear, differences in climate, management practices and breed susceptibility may play an important role. However, because of changing demographics, production objectives and management practices in the sheep industry, Texas producers need to be aware of the potential risk of OvLV infection.

Only between 20 to 50% of OvLV-infected sheep eventually develop LIP (de la Concha-Bermejillo, 1997). Differences in virus strain pathogenicity, environmental factors and host genetics are among the reasons given to explain this difference in susceptibility among individuals (de la Concha-Bermejillo, 1997). In a recent study, sets of genetically identical twin lambs were cloned by embryo split. When the twin lambs were born, one member of each set was infected with a pathogenic strain of OvLV, whereas the co-twin was infected with a non-pathogenic strain. Regardless of the virus strain used for inoculation, sets of twins developed the same degree of LIP indicating that host genetic factors may play an important role in determining disease susceptibility (de la Concha-Bermejillo et al., 1995a). Furthermore, studies conducted in different breeds of sheep suggest that susceptibility and resistance to OvLV-induced disease may vary among breeds (Perk et al., 1996; Cutlip et al., 1986; de la Concha-Bermejillo, 1997; Petursson et al., 1989; Narayan and Clements, 1989; Brahic and Haase, 1981; Carey and Dalziel, 1993; Narayan, 1990). For example, Texel sheep appear to be particularly susceptible to OvLV-induced disease while the pure Awassi breed, which is susceptible to infection, does not develop disease.

Currently, no effective vaccines or treatments exist for OvLV infection. Therefore, alternative methods for controlling OvLV-induced disease, such as selection for disease resistance or the introduction of genes

responsible for resistance to disease, should be explored. The identification of susceptible/resistant breeds and the subsequent characterization of the genes conferring susceptibility/resistance will facilitate the selection of genetically OvLV resistant sheep. The purpose of this research was to identify individual sheep and(or) breeds of sheep that are resistant or susceptible to OvLV-induced LIP.

Materials and Methods

Experimental Animals and Virus Inoculum

Thirty-two OvLV seronegative, age-matched lambs comprising four breeds and born to OvLV seronegative ewes were used in this experiment. The breeds included Rambouillet, Suffolk, Florida Native, and Barbado and were chosen based on importance to the Texas sheep industry and diversity. Experimental lambs were inoculated intratracheally with 10^6 $TCID_{50}$ of OvLV strain 85/34, a purified biological clone classified as lytic (rapid/high). An additional eight OvLV-negative, age-matched Rambouillet lambs were used as contact negative controls.

Antibody Determination

Serum was collected biweekly from all forty sheep from wk 0 to 6, weekly from wk 7 to 11, and at wk 14 and 18. Serum was tested for antibodies to OvLV by the agar gel immunodiffusion (AGID) test to monitor seroconversion rates. To determine specific antibody responses to OvLV transmembrane (TM) and p25 structural proteins, recombinant enzyme-linked immunosorbent assays (rELISA) were performed as previously described (Kwang et al., 1993; Kwang and Cutlip, 1992).

Virus Titration

Blood was collected from experimental lambs at wk 6, 8, and 10 post-inoculation, and blood mononuclear cells (BMNC) were separated by Ficoll-Hypaque gradient centrifugation. At necropsy, bronchoalveolar (BAL) cells were collected by lung lavage and purified in the same way as BMNC. Infectious OvLV in BMNC and BAL cells was titrated by an end point dilution method into 96-well plates containing confluent goat synovial membrane (GSM) cell monolayers. After 3 wk of incubation, wells were stained with Giemsa and scored as negative or positive for syncytia. The minimum number of infected BMNC/BAL cells per million (cell-associated viremia) was determined by dividing the percentage of positive wells for each dilution by the number of BMNC/BAL cells in that dilution (Juste et al., 1998).

Polymerase Chain Reaction

The polymerase chain reaction (PCR) was performed to provide a semiquantitative estimate of OvLV DNA load (de la Concha-Bermejillo et al., 1995a). For this purpose, DNA was extracted from Ficoll-Hypaque separated BMNC and BAL cells in a buffer containing non-ionic detergents and proteinase K. DNA was amplified through two sets of thirty cycles of PCR using primers specific for the long terminal repeat (LTR) of the OvLV genome. Amplification resulted in a 280 bp DNA product. One tenth volume of amplified proviral DNA was resolved by agarose gel electrophoresis and visualized by staining with ethidium bromide. The gel image was photographed, and band densities were analyzed by a Scimetrics IS1000 image analyzer system (Alpha Innotech Corporation, San Leandro, CA).

Gross and Histologic Assessment of Lesions

Thirty experimental animals and all control sheep were killed by barbiturate overdose approximately 9 mo post-inoculation. Complete necropsies were performed, and macroscopic changes were recorded. The left lung was excised and insufflated with 10% buffered formalin solution for 48 h prior to sectioning for histologic examination. Sections were scored for lung lesions according to four criteria in a logarithmic scale (Singh and de la Concha-Bermejillo, 1998). Presence of areas of interstitial pneumonia, lymphoid perivascular infiltration, and lymphoid peribronchial infiltration were assigned a score ranging from 0 to 32 in twofold steps (0, 2, 4, 8, 16, 32) whereas the presence of lymphoid follicles not associated with blood vessels or airways was given the highest score (0, no lymphoid follicles; 24, 1 to 9 follicles/section; and 48, 10 or more follicles/section) because it is considered the most specific OvLV lesion. The final score for each section was determined by calculating the geometric mean of the four criteria scored from each section, and then the means were added to obtain a single histopathology (HP) score for each animal.

Determination of resistance and susceptibility

Breeds were classified as susceptible, resistant, or intermediate. For this purpose each breed was ranked from first to fourth place for each of the means for anti-TM titers, anti-p25 titers, OvLV titers in BMNC, OvLV titers in BAL cells, proviral DNA load in BMNC, proviral DNA load in BMNC at wk 2, proviral DNA load during early viremia, proviral DNA load in BAL, and HP scores. The breed that scored first more frequently in these categories was considered highly susceptible, while the breed that scored fourth more frequently was considered highly resistant.

Analysis of Results

Individual and breed differences were analyzed using an analysis of variance (ANOVA) and a student's t test using the Statmost software package for Windows.

Independence of antibody titers, virus loads, and HP scores were tested using Pearson correlations.

Results

Antibody Determination

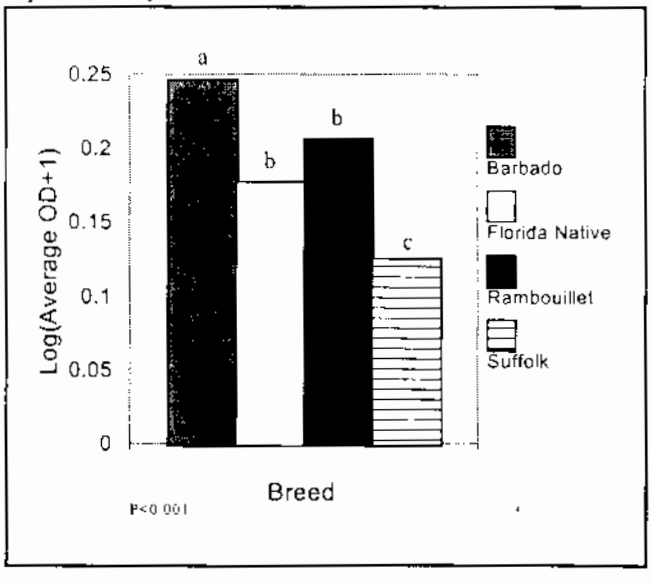
Results of the AGID test show that all experimental lambs seroconverted by wk 8 (Table 1). However, none of the contact control lambs became positive. By employing a Chi-square test, rate of seroconversion as detected by the AGID test was found to be dependent on breed. As a group, Barbado and Florida Native lambs seroconverted faster ($P < .05$) than Rambouillet and Suffolk lambs.

Table 1. Rate of seroconversion determined by the agar gel immunodiffusion (AGID) test in four breeds of sheep experimentally infected with ovine lentivirus

	Wk				
Breed (n = 8/each)	0	2	4	6	8
Barbado	0	4	4	0	0
Florida Native	0	6	2	0	0
Rambouillet	0	1	5	2	0
Suffolk	0	2	2	3	1

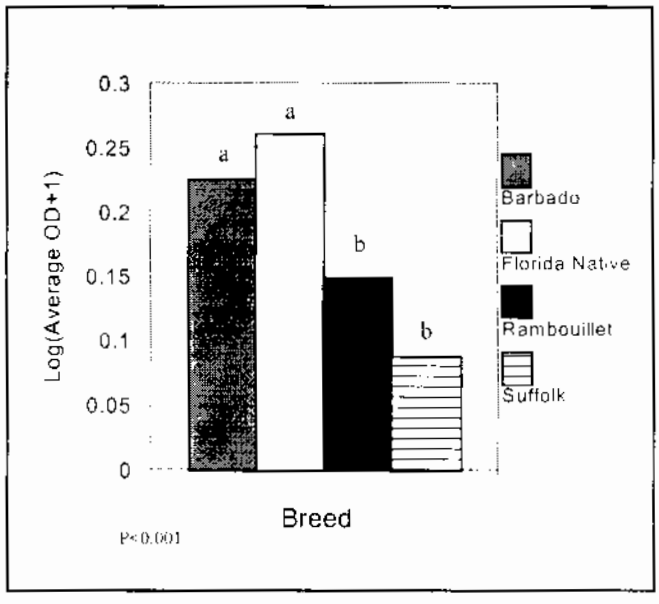
Mean antibody responses to the OvLV-TM and -p25 proteins determined by ELISA varied greatly among individual animals. However as a group, Barbados had the highest mean anti-TM titer while Suffolks had the lowest (Fig 1). For anti-p25 antibody titers, Barbados and Florida Natives were the highest, and Suffolks and Rambouillets were the lowest (Fig 2).

Figure 1. Mean antibody titers against ovine lentivirus transmembrane (OvLV-TM) protein in four breeds of sheep experimentally infected with OvLV.



Mean anti-TM titers were positively correlated ($r = .518$, $P = .003$) with virus titers in BAL cells. On the other hand, mean anti-p25 titers were negatively correlated ($r = -.57$, $P = .001$) with mean proviral DNA load. Both antibody responses (anti-TM and anti-p25) correlated ($r = .48$, $P = .007$) positively with each other but did not correlate significantly with HP scores.

Figure 2. Mean antibody titers against ovine lentivirus p25 (OvLV-p25) protein in four breeds of sheep experimentally infected with OvLV.



Virus Titration

OvLV was isolated at least in one occasion from all experimental lambs except two (Rambouillet #54 and Suffolk #52). Extensive individual variation in virus titers was observed among animals. Although as a group, Barbados had the highest mean OvLV titer in BMNC and Suffolks had the lowest, mean virus titers were not significantly different among breeds. OvLV was never isolated from BMNC of the non-inoculated contact controls.

OvLV was isolated from BAL cells from all experimental lambs except four (Rambouillet #56, Suffolk #51, Suffolk #70, and Florida Native #67) and was not isolated from any of the negative control lambs. Barbados had a higher ($P = .001$) virus load in BAL cells than any of the other three breeds (Fig 3).

Both mean OvLV titers in BMNC and OvLV titers in BAL cells were positively correlated with HP scores ($r = .478$, $P = .008$ and $r = .491$, $P = .005$, respectively) (Fig 4 and 5) and with the amount of proviral DNA amplified by PCR from BAL cells ($r = .377$, $P = .04$ and $r = .464$, $P = .009$, respectively).

Figure 3. Mean OvLV titers in brochoalveolar lavage (BAL) cells in four breeds of sheep experimentally infected with OvLV.

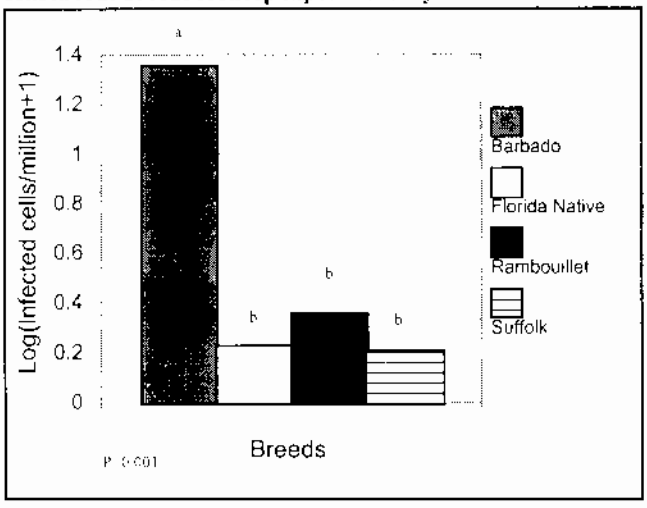


Figure 4. Correlation between mean OvLV titers in BMNC and mean histopathology (HP) scores in sheep experimentally infected with OvLV.

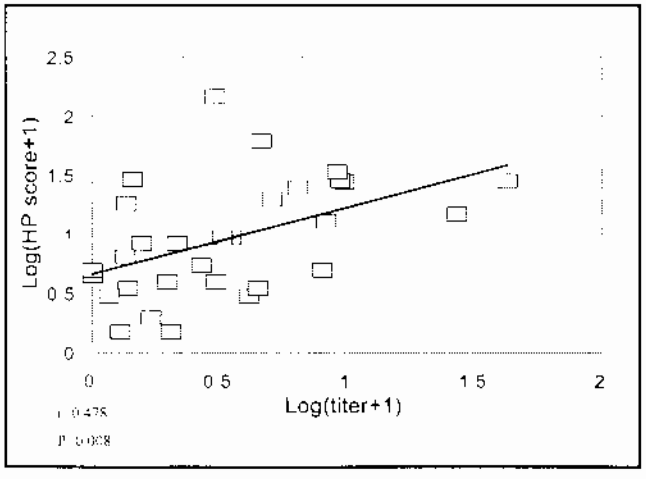
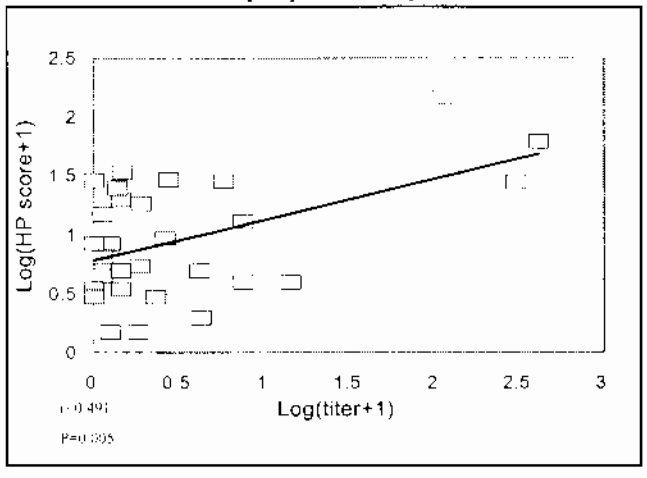


Figure 5. Correlation between OvLV titers in BAL cells and mean HP scores in sheep experimentally infected with OvLV.

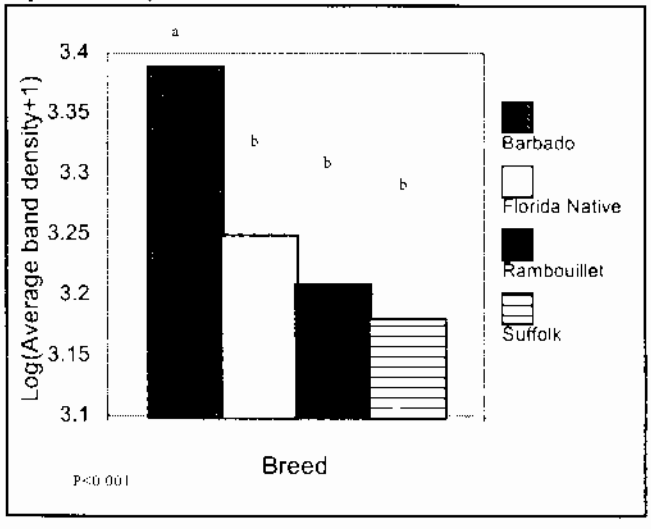


Polymerase Chain Reaction

OvLV DNA was amplified by PCR at least in one occasion from BMNC of all OvLV inoculated lambs. Barbados, Florida Natives, and Suffolks mean proviral DNA load peaked at wk 2 post-inoculation and at wk 4 in Rambouillets. Barbados had the highest peak ($P < .001$) proviral DNA load in BMNC (mean band density 3.389) (Fig 6). Mean proviral DNA in BMNC varied greatly among individual animals. However, Suffolks had the highest amount of proviral DNA in BMNC. Breed weekly mean proviral DNA load varied greatly among breeds.

Proviral DNA was amplified from BAL cells of all virus inoculated animals. Differences in the proviral DNA load in BAL cells were not significant among breeds. DNA mean band densities from BMNC and from BAL cells were not correlated with HP scores. DNA band densities from BAL cells correlated positively with both mean OvLV titer in BMNC ($r = .377$, $P = .04$) and with OvLV titers in BAL cells ($r = .464$, $P = .01$).

Figure 6. Peak OvLV proviral DNA load (band density) on blood mononuclear cells (BMNC) of four breeds of sheep experimentally infected with OvLV.



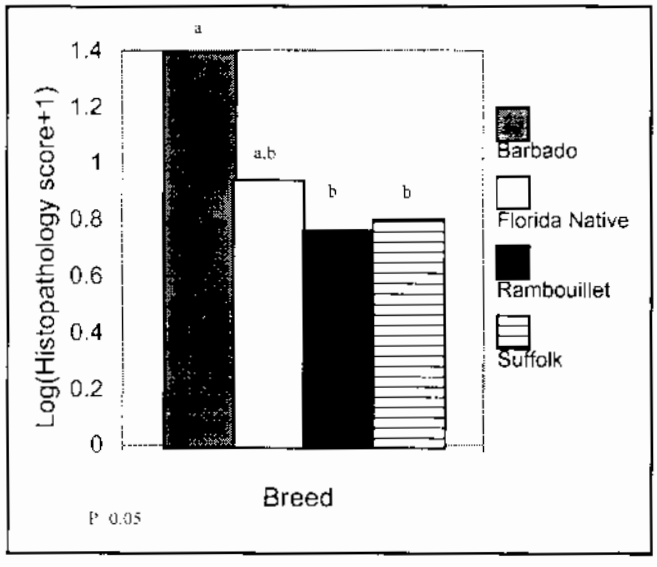
Gross and Histologic Assessment of Lesions

Clinical signs of progressive respiratory failure were observed in only one OvLV-inoculated lamb (Barbado #39). Macroscopic lesions compatible with LIP were observed in six experimental lambs, five Barbados and one Florida Native. Barbado #39 had the highest degree of LIP.

The most common microscopic lesion found in lung sections of lambs inoculated with OvLV was hyperplasia of lymphoid follicles associated with blood

vessels or airways, followed by thickening of the alveolar walls by mononuclear cell infiltrates. Hyperplasia of lymphoid follicles not associated with blood vessels or airways was the least frequently observed lesion. Individual HP scores varied greatly. Barbados had the highest (P = .05 vs Rambouillets and Suffolks) mean HP score while the Rambouillets had the lowest mean HP score (Fig 7). HP scores had a significant positive correlation with mean OvLV titers in BMNC (r = .478; P = .008) and with OvLV titers in BAL cells (r = .491; P = .005).

Figure 7. Mean histopathology score of OvLV-induced lung lesions in four breeds of sheep experimentally infected with OvLV.



Resistance and Susceptibility

Barbados scored the highest (first place) in 6 of the 9 criteria for resistance susceptibility (66.6%) and therefore, were classified as the most susceptible breed to OvLV infection. By contrast, Suffolks scored the lowest in 6 of the 9 criteria (66.6%) and were classified as the most resistant. The Florida Natives and Rambouillets were intermediate for most of the criteria; thus, they were considered to have intermediate susceptibility.

Discussion

Several studies of OvLV seroprevalence in mixed-breed flocks suggest that some breeds may be more susceptible to OvLV infection than others. Reports from studies on different continents suggest that Finnish breeds have a greater tendency to become infected by OvLV than the Ile de France breed (Houwers et al., 1989), Rambouillet or Columbia breeds (Gates et al., 1978). However, interpretation of such retrospective studies is plagued by uncertainty or inconsistent exposure histories. In addition, breed-related resistance to OvLV-induced disease has been suggested by epidemiological studies in Iceland, which indicated that crosses between Icelandic and Border Leicester sheep were particularly resistant and that in these crosses the progression of pulmonary lesions was delayed (Nathanson et al., 1976; Palsson, 1976). Interpretation of these results is complicated by variances in viral strains. In the present study, groups of sheep of four different breeds were experimentally infected with an OvLV biological clone and susceptibility to virus infection was characterized by nine criteria. A large degree of variation among individuals from all breeds was observed in immune responses to OvLV-infection, in virus load, and in the degree of susceptibility to developing LIP. However, Barbados were more susceptible and Suffolks were more resistant.

Studies have demonstrated that while TM and p25 directed antibodies are produced in response to OvLV infection, they do not play a significant role in controlling viral replication. In fact, antibodies may enhance infection, so those animals with the greatest humoral response may also have the most severe OvLV lesions (Petursson et al., 1992; de la Concha-Bermejillo, 1997). In this study, even though the positive correlation between antibody titers and HP scores was not significant, the most susceptible breed (Barbados) had the highest average anti-TM titer and the resistant breed, the Suffolks, had both the lowest anti-TM and anti-p25 titers.

A significant, positive correlation was found between degree of LIP and both BMNC titers and BAL cell titers. Previous studies have also shown a direct correlation between the severity of lentivirus-induced disease and degree of viremia (de la Concha-Bermejillo et al., 1995a; Juste et al., 1996; DeMartini et al., 1993; Brodie et al., 1992; Woodall et al., 1997; Ho, 1996; Mellors et al., 1996; Schechter et al., 1991). For example, Juste et al. (1996) demonstrated a clear positive correlation between virus load in OvLV-infected sheep and degree of LIP, and Brodie et al., (1992) found that the inability to detect OvLV proviral DNA in MNCs from seropositive sheep correlated with a lack of significant lesions, possibly indicating a slower progression of disease in those individual animals. Likewise, studies have demonstrated that low viremia levels in HIV seropositive individuals correlates with a slower progression to AIDS; consequently, viremia levels have been used as markers to predict disease progression in HIV+ individuals (Ho,

1996; Mellors et al., 1996; Schechter et al., 1991). Levels of cell-associated viremia serve as useful markers in determining disease progression in OvLV-infected animals as well.

Previous studies have demonstrated a positive correlation between levels of PCR amplified proviral DNA and disease severity (Brodie et al., 1992; de la Concha-Bermejillo et al., 1995a; Woodall et al., 1997; DeMartini et al., 1993), but in the present study, levels of OvLV proviral DNA in BMNC did not correlate with degree of LIP. Most likely, this lack of correlation was due to the great fluctuations in viremia over the weeks. For example, while most of the Barbados belonged in the susceptible category for amplified proviral DNA at post-inoculation wk 8 and 10, at wk 6 all Barbados except one (#40) did not have detectable levels of proviral DNA in BMNC. This probably reflected an attempt by the immune systems of the Barbados to control viral replication. The Suffolks, on the other hand, had only two cases in which proviral DNA was not detected, thus resulting in the Suffolks having the highest mean proviral DNA.

In the current study, although all experimental sheep were inoculated with rapid/high OvLV strain 85/34, the degree of lesions induced by infection varied markedly among both individuals and breeds. These results support previous research in suggesting that genetic factors of the host play a critical role in determining the degree of OvLV-induced disease (de la Concha-Bermejillo et al., 1995a; Cutlip et al., 1986; Petursson et al., 1989; Narayan and Clements, 1989; Perk et al., 1996; de la Concha-Bermejillo, 1997).

Implications

This study demonstrated a large degree of individual variation in immune responses to OvLV-infection, in viral load, and in the degree of susceptibility and resistance to developing LIP. Despite this, breed differences were apparent, and these differences facilitated their classification as susceptible, intermediate, or resistant to developing LIP. Barbados appeared to be the most susceptible breed while Suffolks appeared the most resistant.

Vaccines and treatments have been ineffective in controlling OvLV infection and disease; therefore, alternative methods should be explored. This includes the selection and expansion of resistant breeds and(or) the development of genetically engineered resistant sheep (Perk et al., 1996). Because limited data are available on differences in breed resistance and susceptibility to OvLV-induced disease (Perk, 1995), the results of this study provide valuable information about a possible breed to target for selective breeding. Further research is necessary to identify genetic markers for susceptibility and resistance, which will expedite the selection of genetically OvLV resistant sheep.

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RESEARCH BRIEF

Mohair Production and Properties of South African, South African x Texan, and Texan Angora Goats in a Western Texas Environment

C.J. Lupton and F.A. Pfeiffer

Highly selected South African (SA) Angora goats were imported into the United States to determine performance of their offspring under Texas (TX) conditions. Selection emphasis for the SA animals had been placed on mohair production, medullated fiber content, and staple length. Three SA bucks were bred to highly selected does of SA and TX origins to produce SA (28) and SA x TX (18) male and female kids. The kids were raised as a group with six highly selected contemporary TX male kids on a quarantine ranch facility at Kerrville, Texas. Kids were shorn at 6-mo intervals and the mohair fleeces were weighed and evaluated for grease fleece production, percentage yield, average fiber diameter, staple growth rate, and medullated fiber content. For the third set of fleeces shorn (from 18-mo-old animals), mohair production by SA and TX males was not different (26.5 and 26.2 g/d, respectively, $P > .05$. Table 1). However, for males, SA mohair was higher yielding (80.4 vs 73.2%), coarser (41.5 vs 31.1 μm), faster growing (.88 vs .82 mm/d), and less medullated (.18 vs .96%) than TX mohair ($P < .05$ for all reported differences). Clean mohair production of SA x TX males was higher than for TX males (23.4 vs 19.2 g/d, respectively). All other properties were intermediate between SA and TX males. Mohair production by SA and SA x TX females was not different (23.2 and 24.4 g/d, respectively, $P > .05$). However, for females, SA mohair was higher yielding (81.8 vs 78.9%), coarser (39.6 vs 36.4 μm), less medullated (.49 vs .99%), and of similar staple length (16.4 and 15.9 cm/6 mo) compared to that of SA x TX mohair.

Results of this preliminary evaluation on a very small number of highly selected goats indicated that these SA genetics might be useful for improving the following traits in TX Angora goats: percentage yield, staple length, and medullation. However, these improvements would probably be accompanied by an undesirable increase in average fiber diameter and little or no overall increase in mohair production.

Our research with South African Angora goats will continue following the donation of 81 Angoras from other South African herds to the Texas Agricultural Experiment Station. In particular, selected animals from this flock will be used to not only improve the characteristics listed above but also to assist in the development of a true, dual-purpose (fiber, meat) Angora goat by crossing with selected Texan stock.

Acknowledgement

The authors are indebted to the owners of the Angora goats for permitting access to these precious animals and for giving permission to publish this report. Mr. H. Haby, Mr. J. Lockhart, Dr. J.D. Ross, and Dr. F. Speck are to be highly commended for their continuing efforts to improve Angora goats and mohair production in Texas. The authors would also like to acknowledge the generosity of Mr. A.P. Leonards who donated 81 South African Angora goats to the Texas Agricultural Experiment Station in October, 1997.

Table 1. Third fleece mohair production and properties of South African (SA), South African x Texan (SA x TX), and Texan female (F) and male (M) Angora goats.

	SA		SA x TX		TX
Item	F	M	F	M	M
Number of goats	17	11	11	7	6
Grease fleece production, g/d	23.2[d]	26.5[a,b,c]	24.4[c,d]	29.8[a]	26.2[a,b,c,d]
Lab scoured yield, %	81.8[a]	80.4[a,b]	78.9[b]	78.5[b]	73.2[c]
Clean fleece production, g/d	19.0[d]	21.3[a,b,c]	19.2[b,c,d]	23.4[a]	19.2[b,c,d]
Average fiber diameter, µm	39.6[a]	41.5[a]	36.4[b]	36.8[b]	31.1[c]
Staple growth rate, mm/d	.90[a]	.88[a]	.87[a,b]	.86[a,b]	.82[b]
Med content, %	.36[b,c]	.14[c]	.64[a]	.34[a,b,c]	.63[a,b]
Kemp content, %	.13[b]	.04[b]	.35[a]	.20[a,b]	.33[a]

[a,b,c,d] Row means lacking a common superscript are different ($P < .05$).

Prediction of Cashmere Style Using Objective Fiber Measurements

C.J. Lupton, F.A. Pfeiffer, and A.R. Dooling

ABSTRACT

Multiple objective fleece and fiber measurements were made on 25 raw cashmere samples (5 of each style score [1-5] from Cashmere goats) to establish mathematical relationships between the objectively determined characteristics and cashmere style score (CSS) subjectively assessed by an expert cashmere classer. Measurements included cashmere down yield (DY), average fiber diameter (AFD), guard hair and down staple lengths (GHSL and DSL), and average fiber (2 mm in length) curvature (AFC). The AFD and AFC were measured concurrently using an Optical Fibre Diameter Analyser. Cashmere style score was significantly correlated (in increasing order) with DSL, GHSL, AFD, and AFC. A second set of 25 raw cashmere samples was measured in the same manner and AFC was used to predict CSS. For actual vs predicted CSS, r^2 = .63 with a standard error of prediction (SEP) = 1 (cashmere style score units). Discriminant analysis confirmed that predicted CSS would invariably be within ± 1 unit of actual CSS.

Fiber curvature was shown to be the best single objectively measured trait for predicting cashmere style score. It should provide a useful, inexpensive, and potentially more accurate and consistent alternative for assessing this important trait.

Introduction

Cashmere style is an ill-defined but important characteristic of raw cashmere. Early attempts to define style invariably resulted in some objections from one segment of the industry or another. A definition of "good style" that has received some degree of acceptance is as follows: cashmere of good style has irregular crimp of relatively small magnitude and high frequency that does not lie in two dimensions but rather changes directions at irregular intervals along the length of individual fibers (Lupton, 1991). Straight fibers or those containing bold (mohair-like) or two-dimensional (like some fine wools) crimp are considered to have poor style. In an attempt to better describe the spectrum of cashmere styles currently being produced by goats in the U.S., a numerical scoring system was devised (by A. R. Dooling) that is being used in conjunction with subjective assessment.

Cashmere style is considered to be important by processors for several reasons. First, it distinguishes cashmere from other fine fibers; secondly, it affects the efficiency of the dehairing process and other mechanical processes up to spinning; and thirdly, it affects the hand (feel) of the finished fabric. Since cashmere goats were introduced into the United States of America in 1989, assessment of cashmere style has also been influenced (to varying degrees) by amount of luster in the down fibers, fleece color, down yield, average fiber diameter, and length of guard hair and down fibers. Intensive training is required for developing the ability to consistently and accurately assess style. Regular practice using fleeces of established style scores is necessary for the classer to retain the acquired skill. There has been a need to develop a method for objectively measuring cashmere style.

Recently, the manufacturer of the Optical Fibre Diameter Analyser (OFDA; Baxter et al., 1992) introduced a program for measuring snippet (a short fiber ~ 2 mm in length) curvature (degrees/mm). This program has been used to measure curvature of wool snippets, a characteristic that has been shown to be highly correlated with fiber crimp and bulk (Edmunds and Sumner, 1996). The objective of this study was to compare objectively measured fiber curvature and other fiber and fleece characteristics to subjectively assessed cashmere style.

Materials and Methods

A set of cashmere fleece samples (25) representing the broad spectrum of cashmere style scores (CSS; 1-5) was obtained from a U.S. cashmere buyer/manufacturer (Montana Knits, Inc., Dillon, MT). Cashmere style score was assessed for each sample by an expert cashmere classer. A score of 1 signified excellent style whereas a score of 5 meant poor style. Subsamples were removed from each raw cashmere sample and used to determine straightened down and guard hair staple lengths (DSL and GHSL, respectively) using a standard method of the American Society for Testing and Materials (ASTM, 1997). Subsequently, the remainder of each sample was dehaired using a Shirley Analyzer (International Wool Textile Organisation [IWTO], 1992) and the resulting separated down was quantified in terms of average fiber diameter (AFD; IWTO, 1995) and average fiber curvature (AFC; IWTO, 1997) using

an OFDA. After separation, the guard hair and down portions from the Shirley Analyzer were individually weighed, thus permitting calculation of cashmere down yield (DY) for each sample. Stepwise multiple linear regression analysis was used to establish a linear relationship between dependant variable CSS and the objectively measured characteristics. In addition, correlation analysis was used to establish the linear relationships among all characteristics assessed, measured, and derived. A second set of 25 raw cashmere samples was then measured in the same manner as the first, and AFC was used to predict CSS using the previously established regression equation. Next, simple linear regression analysis was used to examine the relationship between predicted and actual CSS. Finally, discriminant analysis was used to classify each sample of the second set in terms of CSS. All statistical analyses were conducted using the CORR, DISCRIM, MEANS, and REG procedures of SAS (SAS, 1996).

Results and Discussion

The simple statistics for variables estimated, measured, and derived from the two sets of raw cashmere samples are summarized in Tables 1 and 2. Mean values of each variable in the two sets were not different ($P > .05$) even though the first set of samples was slightly coarser (down AFD) and higher yielding than the second set. Stepwise multiple linear regression analysis of the first data set for dependant variable CSS resulted in only AFC and SD of AFC entering the model at the .1 significance level (producing an $r^2 = .64$). This occurred despite the significant correlations shown in Table 3 between CSS and down staple length, guard hair staple length, and down average fiber diameter. For this set of samples, CSS is obviously related to several other variables but most highly and significantly to average fiber curvature. The equation relating CSS, AFC, and SD of FC is as follows:

$$CSS = 6.33 - .15 \times AFC + .10 \times SD \text{ of } AFC$$

After the second set of raw cashmere samples was objectively measured, the above equation was used to predict CSS. When predicted CSS were regressed against actual CSS values, an r^2 value = .63 was obtained with a SEP = 1 (CSS).

Next, data generated using all 50 raw cashmere samples were analyzed by the stepwise multiple regression procedure for dependant variable CSS. This time GHSL entered the equation in step 2, in addition to AFC (step 1) and SD of AFC (step 3), to produce the following equation:

$$CSS = 6.90 - .26 \times GHSL - .12 \times AFC + .08 \times SD \text{ of } AFC, \text{ having an } r^2 = .70$$

No other variables entered the equation below the $P < .3$ level. To further evaluate the accuracy of predicting classification variable CSS using objectively measured data, the DISCRIM procedure of SAS was used to derive a linear discriminant function for CSS using the qualitative variables AFC, GHSL, and SDAFC of the first data set (the calibration data set). Subsequently, this discriminant function was used to classify each sample of the second set in terms of CSS. The results of this analysis are summarized in Tables 4 and 5. For the test data, only one predicted CSS value was more than one CSS unit greater than the actual value (a sample scored as a 5 was predicted to be at 3). All other predictions were within ± 1 CSS unit (as expected from the SEP calculated from the earlier regression analysis). The error rates (probabilities of misclassification) in the classification of future observations were .40 and .36 for the calibration and test data, respectively.

Subsequently, correlation analyses for CSS versus all the other variables were conducted on the combined sets of 50 samples, and showed that CSS is significantly correlated with GHSL ($r = -.48$, $P = .0004$), AFD ($r = .37$, $P = .008$), SD of AFD ($r = .48$, $P = .0004$), AFC ($r = -.77$, $P = .0001$) and SD of AFC ($r = -.51$, $P = .0002$). In other words, better cashmere style scores (i.e., lower numbers) are associated with longer guard hair and finer, more uniform (in terms of AFD) down having higher fiber curvature values (i.e., more crimp). This conclusion would tend to confirm the "conventional wisdom" of most cashmere breeders. These data indicate that cashmere style is not associated with yield ($P = .11$).

Conclusions

This preliminary study indicates that average fiber curvature as measured by the Optical Fibre Diameter Analyser is significantly correlated with subjectively assessed cashmere style score. Further work is required to validate this conclusion for other cashmere classers and for a greater distribution of cashmere samples.

Implications

If the significant relationship between cashmere style score and fiber curvature holds true for other cashmere classers, we will have discovered a simple, objective,

potentially inexpensive, and likely a more consistent way to estimate cashmere style score. The AFC measurement should be inexpensive because it can be obtained concurrently with the down AFD measurement using the OFDA while incurring no extra cost. Such a measurement would be very useful to the many cashmere breeders who have not undergone the intensive training required to become a cashmere classer or who have undergone the training but failed to develop or maintain the necessary skill.

Table 1. Simple statistics for variables estimated, measured, and derived on the first set of raw cashmere sample

Variable	Mean	SD[b]	Minimum	Maximum
Cashmere style score, 1-5[a]	3.0	1.4	1.0	5.0
Down staple length, in	2.9	.8	1.6	4.8
SD of down staple length, in	.4	.2	.1	.8
Guard hair staple length, in	3.1	1.3	1.7	5.9
SD of guard hair staple length, in	.6	.4	.2	1.8
Down average fiber diameter, µm	18.2	2.5	14.7	24.5
SD of down fiber diameter, µm	4.1	.8	2.9	6.5
Average fiber curvature, degrees/mm	59.4	11.3	35.6	80.2
SD of fiber curvature, degrees/mm	51.7	6.9	35.0	67.0
Down yield, %	54.5	18.5	18.8	91.5

[a] 1 = Excellent, 5 = Poor
[b] Standard deviation

Table 2. Simple statistics for variables estimated, measured, and derived on the second set of raw cashmere sample

Variable	Mean	SD[b]	Minimum	Maximum
Cashmere style score, 1-5[a]	3.1	1.4	1.0	5.0
Down staple length, in	3.1	.8	1.8	4.9
SD of down staple length, in	.3	.2	.1	1.2
Guard hair staple length, in	3.1	1.2	1.4	5.7
SD of guard hair staple length, in	.7	.5	.1	1.8
Down average fiber diameter, µm	17.0	1.7	14.7	20.6
SD of down fiber diameter, µm	3.7	.6	2.9	5.1
Average fiber curvature, degrees/mm	57.9	11.7	34.5	78.4
SD of fiber curvature, degrees/mm	52.6	6.7	39.0	68.0
Down yield, %	52.6	13.8	36.3	90.9

[a] 1 = Excellent, 5 = Poor
[b] Standard deviation

Table 3. Correlation coefficients and probability values for the linear relationships between cashmere style score (CSS) and the listed variable

Variable	Correlation coefficient, r	Probability
Down staple length	.42	.04
SD of down staple length	-.04	.85
Guard hair staple length	-.42	.04
SD of guard hair staple length	-.03	.87
Down average fiber diameter	.53	.006
SD of down fiber diameter	.60	.002
Average fiber curvature	-.74	.0001
SD of fiber curvature	-.42	.04
Down yield	.23	.27

Table 4. Classification summary for cashmere style score using the calibration data

Actual	Total	Number of derived cashmere style scores				
classification	observations	1	2	3	4	5
1	5	4	0	1	0	0
2	5	1	3	0	1	0
3	5	0	1	1	3	0
4	5	0	1	2	2	0
5	5	0	0	0	0	5

Table 5. Classification summary for cashmere style score using the test data

Actual	Total	Number of derived cashmere style scores				
classification	observations	1	2	3	4	5
1	4	4	0	0	0	0
2	5	3	2	0	0	0
3	5	0	0	3	2	0
4	7	0	0	1	3	3
5	4	0	0	1	0	3

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RESEARCH BRIEF

Reduction of Vegetable Matter in Wool and Mohair Using Enzymes and Microorganisms

C.J. Lupton and R.B. Gobert

Contamination of raw wool and mohair by vegetable matter (plant material) results in tens of thousands of dollars being lost annually in producers' income. Although the contaminants can be removed in a textile process known as carbonization (treatment with sulfuric acid), the results are not entirely satisfactory because the fibers can be weakened, discolored, and delustered to varying degrees by the process. The cost of the process and loss in value of the products are used to justify discounts for the "defective" raw materials. Producers have attempted to decrease the amount of vegetable material in fleeces by spraying animals prior to shearing with oily compounds such as Red Oil (oleic acid) and Corvus Oil (mineral oil). Although benefits have been reported by numerous practitioners, reductions in vegetable content of fleeces treated in this way have never been substantiated in controlled experiments. Some years ago, scientists with the Texas Agricultural Experiment Station investigated the enzyme cellulase for its ability to remove plant material from raw wool and mohair. Though their experiment was not successful, the logic for conducting it remained sound and persuaded us to further investigate this approach.

A series of experiments was designed to investigate the effects of cellulase, pectinase, and two mixtures containing enzyme-producing microorganisms on four types of plant seeds known to contaminate wool and mohair with the ultimate objective of developing an enzymatic system for removing plant material from the fleeces of sheep and goats. Seed collections were made for horehound *(Marrubium vulgare)*, bur-clover *(Medicago minima)*, purple threeawn and Wright's threeawn *(Aristida purpurea* and *A. wrightii)*, and Texas wintergrass *(Stipa leucotricha)*. Three sources of cellulase enzymes (Cellulase 4000, Multifect GC, and Multifect CL from Genencor International, Rochester, NY) were tested as well as pectinase (Clarex L also from Genencor) and two mixtures of enzyme-producing microorganisms (Septic Helper and Septic Helper 2000 from Miller-Plante, Inc., Maitland, FL).

The potential of each enzyme and microorganism mixture to solubilize each seed type was investigated using various concentrations, pH's, temperatures, times, and buffer concentrations. Seed destruction was evaluated gravimetrically and by microscopic observation. Maximum enzymatic activity was observed for the Multifect cellulases on the horehound seeds. Subsequently, the enzymes were evaluated for their ability to remove vegetable matter from wool contaminated with this type of seed. Enzymatic solubilization of horehound seeds contained in a wool substrate produced 2 to 5% overall decrease in weight. Wool itself may be serving as an inhibitor of the cellulase activity. More likely, other materials in the seed structure (e.g., lignin) may be obstructing accessibility of the enzyme to cellulose. Because cellulase solutions alone are unable to effectively destroy vegetable material in wool, even under the optimized conditions of our experiments, future work will focus on identifying an economical source of ligninase (fungal or microbial, for example) that could be used in conjunction with cellulase to more effectively remove seed material.

Fatty Acid Composition of Goat Meat Patties as Affected by Breed Type and Feeding Regimen

Y.A. Ziprin, K.S. Rhee, C.E. Bishop, and D.F. Waldron

ABSTRACT

Ground meat patties were made with lean composites of meat-type (Spanish, Spanish x Boer) goats from two feeding regimens (feedlot, range) and fiber-type (Angora, Spanish x Angora) goats from the feedlot regimen. For both Spanish and Spanish x Boer goats, the percentage of total unsaturated fatty acids was higher in feedlot goat samples than in range goat samples. Extracted fat from feedlot Spanish goats was more unsaturated than the fat from feedlot Angora or Spanish x Angora goats. Overall, fatty acid composition was affected more by feeding regimen than breed type.

Introduction

Goats are a major meat source in many parts of the world. The majority of meat-type goats in the U.S. are Spanish goats, while the Angora is a fiber-type breed. The Boer breed, developed in South Africa for meat production, could potentially produce more usable meat per animal (Blackburn, 1995).

Consumers are increasingly aware of diet-health relationships. The major diet/health concerns with regard to meat consumption are high fat contents of some meat products and relatively high proportions of saturated fatty acids in meats. Among the dietary factors that may increase plasma cholesterol levels in humans, extra saturated fat intake seems to make the greatest contribution.

It is well known that goat meat is low in total fat content. There also is a general belief that the fat in goat meat may be more unsaturated when compared to other red meats. However, research on factors influencing the fatty acid composition in goat meat has been limited. Fatty acid profiles have been reported for some organ meats and muscles of Alpine and Nubian goats (Park and Washington, 1993) and for ground meat patties from Florida native, Florida native x Nubian, and Spanish goats (Johnson et al., 1995). Feeding regimen effects on fatty acid composition have been well documented for meats like beef and lamb. However, such information is lacking for goat meat. The objective of this study was to determine the effects of breed type (Spanish, Angora, Spanish x Angora, Spanish x Boer) and feeding regimen (feedlot, range) on fatty acid profiles of raw and cooked meat.

Materials and Methods

Following weaning at about 5 mo of age, meat-type (Spanish, Spanish x Boer) goats were assigned to two feeding regimens (feedlot, range) and fiber-type (Angora, Spanish x Angora) goats were assigned only to the feedlot regimen. For the feedlot regimen, a high-energy diet was given *ad libitum* for 4 mo prior to slaughter; the diet contained 50.4% milo, 20.0% cottonseed hulls, 15.0% dehydrated alfalfa, 4.0% cottonseed meal, 4.0% soybean meal, 4.0% molasses, 0.5% ammonium chloride, 0.6% mono- and dicalcium phosphate, 1.0% calcium carbonate, and 0.5% vitamin premix. The range kids were given access to rangeland populated with multiple species of native grasses and forbs without supplemental feed. The dominant grass species were curlymesquite, silver bluestem, Texas wintergrass, and purple threeawn. All animals were about 9 mo old at time of slaughter. There was a total of six breed/feeding treatments: Spanish/feedlot (S/F); Angora/feedlot (A/F); Spanish x Angora/feedlot (SA/F); Spanish x Boer/feedlot (SB/F); Spanish/range (S/R), and Spanish x Boer/range (SB/R). Each treatment included four animals. A lean composite was obtained from each animal using muscles from leg (34.4% of final composite weight), shoulder (33.6%), shank (9.8%), rack (8.2%), breast (6.5%), plate (5.1%), and shortloin (2.3%). The combined meat from two animals was used for each of the two replications made for a given treatment. Samples were ground through 1.27 cm plate, reground through a 0.32 cm plate, and formed into 115 g patties. Patties were pan-fried at 165°C to an internal temperature of 74°C.

Total fat was extracted using the procedure of Folch et al. (1957) and transmethylated (Metcalfe and Wang, 1981). Fatty acid methyl esters (FAMEs) were analyzed using a gas chromatograph fitted with a fused silica capillary column. Data for individual fatty acids were expressed as percentages of all fatty acids with unidentified/unknown fatty acids included.

Data were analyzed by the General Linear Models (GLM) Procedure using the SAS program (SAS, 1990). The model included treatment (breed/feeding), replication, and treatment-by-replication interaction.

Contrast comparisons were made to assess differences between treatments. The comparisons included S/F vs A/F, SA/F vs S/F, SA/F vs A/F, SB/F vs S/F, S/F vs S/R, SB/F vs SB/R, and SB/R vs S/R for each of the individual fatty acids and fatty acid groups. Results of contrast comparisons are not presented in a tubular form, but noted in the text.

Results and Discussion

Fatty acid percentage data are shown in Table 1. For breed effect on raw samples, Spanish/feedlot (S/F) treatment was higher ($P < 0.05$) in linoleic acid (18:2) and total polyunsaturated fatty acids (PUFA) and the ratio of PUFA to saturated fatty acids (SFA) when compared to Angora/feedlot (A/F) or Spanish x Angora/feedlot (SA/F). This indicates that meat from the Spanish goat may have less oxidative storage stability than meat from the other two breed types, because linoleic acid is the major PUFA and PUFAs are most susceptible to oxidation. Likewise, total unsaturated fatty acids were higher ($P < 0.05$) for S/F and SA/F than for A/F, confirming a greater lipid oxidation potential of Spanish goat meat.

Fatty acid profiles were similar ($P > .05$) between Spanish x Boer (SB) and Spanish (S) goats whether on feedlot or range regimen. This means that cross-breeding Spanish goats with Boer goats may not result in a more healthful fatty acid profile.

Within a breed type, raw sample fatty acid profiles were markedly different ($P < .05$) between feedlot and range goats (S/F vs S/R and SB/F vs SB/R). The range goat samples were higher ($P < .05$) in stearic acid (18:0) percentage and lower in oleic acid (18:1), the major monounsaturated fatty acids, and total unsaturated fatty acid percentages than feedlot goat samples. Linoleic acid (18:2), the primary polyunsaturated fatty acid, and total PUFA percentages were not different ($P > 0.05$) among samples from the two feeding regimens. However, the unsaturated to saturated fatty acid ratio (U/S) as well as the monounsaturated to saturated fatty acid ratio (M/S) were higher ($P < .05$) for feedlot goats than for range goats (Table 2).

Our feeding regimen results (S/F vs S/R and SB/F vs SB/R) were similar to results reported for beef (Melton, 1983) with regard to 18:0 and 18:1 percentages. However, whereas ground beef samples from grass-fed beef cattle were higher in linolenic acid (18:3) and lower in linoleic acid (18:2) percentages when compared to grain-fed cattle, these fatty acids were not significantly different ($P > 0.05$) between range and feedlot goat meat samples. It is not known whether there were substantial differences in PUFA content between the plants on the range where the goats grazed and the pasture plants in the beef studies.

In cooked patties, no notable fatty acid differences between breed types were found among feedlot goats, except for the proportion of total unsaturated fatty acids, which was greater ($P < .05$) in Spanish than Angora goats, as with raw samples (Table 1). The feeding regimen effects on fatty acid composition of cooked patties were generally similar to its effects on raw patties.

No report has been published on conjugated linoleic acid (CLA) levels in goat meat. CLAs reportedly have anticarcinogenic effects in animal models (Ha et al., 1990; Ip et al., 1991). The raw and cooked samples of S/R contained 3.14 mg CLA/g raw fat (or 0.086 mg/g raw sample) and 3.25 mg/g cooked fat (or 0.144 mg/g cooked sample). The value of CLA for the raw goat meat sample (3.14 mg/g fat) was higher than amounts reported for raw samples of veal (2.7 mg/g fat), fresh ground turkey (2.5), chicken (0.9), or pork (0.6), but lower than those for raw samples of fresh ground beef (4.3) or lamb (5.6) (Chin et al., 1992).

We compared fatty acid profiles (specifically, percentages of total unsaturated, monounsaturated and polyunsaturated fatty acids) of our feedlot and range goat samples to data on goat meat and other meats which were compiled from USDA Agriculture Handbook 8 series (Table 2). All USDA data were assumed to be for meats from grain-finished animals. For this comparison, the Table 1 data (percentages computed with all fatty acids including unknown/unidentified acids) were recalculated excluding those unknown fatty acids. Also, our data were averaged by feeding regimen, i.e., averaged over breed types, because feeding regimens had a much greater effect on fatty acid composition than breed types, as discussed. Our values for feedlot goats were similar to the USDA values for "raw goat meat." Thus, our range goat samples, when compared to USDA samples or our feedlot goat samples, were lower in % unsaturated fatty acids and higher in saturated fatty acids. Accordingly, range goats had the lowest ratio of unsaturated to saturated fatty acids. As for differences between goat meat and other meats, meat from grain-fed goats was lower in % saturated fatty acids and higher in % unsaturated fatty acids when compared to beef and lamb, but similar to pork and chicken breast. Meat from range goats was similar to beef with regard to total saturated and unsaturated fatty acid percentages.

Implications

Results with the feedlot regimen indicate that the cross-breeding of Spanish goat with Boer goats may not result in a more healthful fatty acid profile. However,

such cross-breeding would yield meat with enhanced oxidative storage stability. Meat (separable lean) from feedlot goats has more healthful fatty acid profiles than corresponding beef and lamb samples; it is similar to pork and chicken breast in % total saturated or unsaturated fatty acids. However, meat from range goats is similar to beef in fatty acid saturation.

Table 1. Fatty acid composition for goat meat patties as related to breed type and feeding regimen

	% (based on total fatty acids including unidentified acids)[a]						
	Feedlot				Range		
	Spanish (S/F)	Angora (A/F)	Spa. x Ang. (SA/F)	Spa. x Boer (SB/F)	Spanish (S/R)	Spa. x Boer (SB/R)	SEM[b]
Raw							
14:0	2.08	2.92	1.39	2.28	3.16	4.28	0.49
14:1	0.26	0.38	0.31	0.55	0.51	0.50	0.09
16:0	21.15	22.71	22.80	21.45	22.27	23.97	0.65
16:1	3.12	3.44	3.58	3.73	2.43	2.93	0.18
18:0	12.77	11.69	11.82	10.83	18.85	16.98	0.62
18:1	43.86	42.66	45.67	41.84	36.74	34.90	1.10
18:2, linoleic	7.04	4.22	4.52	6.04	6.05	6.30	0.53
18:2, CLA[c]	0.60	0.44	0.58	0.56	0.56	0.63	0.07
18:3	0.39	0.21	0.20	0.30	0.60	0.64	0.19
20:4	1.95	1.01	1.25	1.98	2.59	2.61	0.31
Saturated	35.99	37.32	36.01	34.55	44.27	45.22	0.83
Unsaturated	57.20	52.35	56.10	54.99	49.47	48.50	0.92
Monounsaturated	47.23	46.48	49.55	46.12	39.68	38.33	1.25
Polyunsaturated	9.97	5.87	6.55	8.88	9.79	10.17	0.83
Cooked							
14:0	2.15	2.88	2.50	2.28	2.90	4.38	.14
14:1	.30	.38	.50	.59	.38	.50	.06
16:0	21.31	22.47	21.98	21.54	21.42	23.83	.68
16:1	3.14	3.44	3.58	3.77	2.38	2.98	.18
18:0	12.92	11.54	11.19	10.98	18.92	16.77	.66
18:1	44.23	42.82	44.94	42.92	36.58	34.58	.94
18:2, linoleic	6.58	4.38	4.65	6.19	6.62	6.12	.65
18:2, CLA[c]	.58	.42	.49	.49	.62	.68	.07
18:3	.33	.23	.18	.29	.71	.65	.14
20:4	1.70	1.04	1.30	2.14	2.75	2.70	.32
Saturated	36.38	36.88	35.67	34.79	43.23	44.98	.87
Unsaturated	56.85	52.70	55.63	56.38	50.02	48.19	1.04
Monounsaturated	47.67	46.63	49.02	47.27	39.34	38.05	1.05
Polyunsaturated	9.18	6.07	6.61	9.11	10.68	10.14	1.06

[a]Percentages are not shown for unidentified fatty acids.
[b]Standard error of the mean.
[c]Conjugated linoleic acid (*c9,t11*-isomer).

Table 2. Fatty acid profile (%) comparison of knife-separable lean samples from goat meat and other meats

	Goat Meat			Other meats				
	Our data (Based on identified fatty acids)		USDA[a]	(Compiled from USDA Agriculture Handbook 8 series)[b]				
							Chicken	
Fatty acid group or ratio	Feedlot goats	Range goat		Beef	Lamb	Pork	Breast	Leg
Saturated (S)	39.47	47.74	37.17	44.79	41.96	38.30	36.26	31.51
Unsaturated (U)	60.53	52.26	62.83	55.21	58.04	61.70	63.74	68.49
Monounsaturated (M)	51.96	41.62	53.93	50.45	47.20	50.08	32.97	37.94
Polyunsaturated (P)	8.58	10.65	8.90	4.75	10.74	11.62	30.77	30.55
U/S ratio	1.53	1.09	1.69	1.23	1.38	1.61	1.76	2.17
M/S ratio	1.32	.87	1.45	1.13	1.12	1.31	.91	1.20
P/S ratio	.22	.22	.24	.11	.26	.30	.85	.97

[a] Based on Agriculture Handbook No. 8-17 (USDA, 1989).
[b] NLSMB, 1988; Rhee, 1992.

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Feeding Regimen Effects on Oxidative Storage Stability and Cooking Properties of Meat Patties from Meat-Type Goats

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ABSTRACT

Ground meat patties were made with lean composites of meat-type (Spanish, Spanish x Boer) goats assigned to two feeding regimens (feedlot, range). Both raw patties and those cooked at 164°C to an internal temperature of about 74°C were aerobically packaged and stored at 4°C for 3 or 6 d or at -20°C for up to 120 d. Cooking losses (mainly moisture loss) ranged from 17.7 to 21.6%. Refrigerated patties (raw or cooked) from the range goats had less potential for development of thiobarbituric acid-reactive substances (TBARS), indicating less lipid oxidation and oxidative flavor deterioration than the corresponding samples from the feedlot goats. For the breed-type effect with the range regimen, less oxidation occurred in samples (raw or cooked) from Spanish x Boer goats when compared to those from Spanish goats. When frozen, all samples exhibited low TBARS values throughout 120 d of storage.

Introduction

To promote the consumption of goat meat in the U.S., it is important to characterize the meat from the most popular or promising meat-type goats raised in this country, such as Spanish and Spanish x Boer goats. Published goat meat characterization/composition studies have dealt with proximate composition of *semimembranosus* muscle from desert goats (Babiker et al., 1990) and moisture, total fat, or minerals in tissues from Alpine and Nubian goats (Park, 1988, 1990; Park et al., 1991). Also, meat patties from Florida native, Florida native x Nubian, or Spanish goats have been evaluated for proximate composition, cholesterol, minerals, and fatty acids (Johnson et al., 1995).

Little published information exists on other quality determinants of goat meat, such as cooking/processing properties and storage stability of raw and cooked meat, or effects of breed type or feeding regimen. Our objective was to evaluate such attributes and parameters.

Materials and Methods

All the lean meat samples used in this study were from meat-type goats (about 9 mo old, intact males), Spanish and Spanish x Boer, on two feeding regimens (feedlot, range). Thus, breed/feeding treatments were: Spanish/feedlot (S/F), Spanish x Boer/feedlot (SB/F), Spanish/range (S/R), and Spanish x Boer/range (SB/R). For the feedlot regimen, a high-energy diet was given *ad libitum* for 4 mo prior to slaughter. The ration contained 50.4% milo, 20.0% cottonseed hulls, 15.0% dehydrated alfalfa, 4.0% each of cottonseed meal, soybean meal and molasses, and 2.6% of various diet supplements including ammonium chloride, mono- and dicalcium phosphate, calcium carbonate, and vitamin premix. The kids assigned to the range regimen grazed on multiple species of native grasses and forbs without supplemental feed. The dominant plants on the rangeland included curly-mesquite, silver bluestem, Texas wintergrass, and purple threeawn.

The meat for this study was taken from one side of each of 16 carcasses (four animals/treatment) and meat from two carcasses was used for each of the two replications made for a given treatment. The meat was vacuum packaged and stored at -20°C (about 6 mo) until processing. Prior to processing, the meat samples were thawed overnight at 4°C. A lean composite of leg and shoulder meat (68% together) and 32% from the shank, rack, breast, plate, and shortloin was ground twice, once through 1.27 cm plate and a second time using the 0.32 cm plate. Patties (115 g each) were formed using a hand mold. Some patties within each treatment replication were pan-fried, four patties at a time (5 min on one side and 9 min on the other), in a preheated, Teflon-coated electric skillet at 164°C to about 74°C internal temperature. Cooked patties were drained and cooled about 15 min at room temperature before weighing or packaging for storage. Raw or cooked patties were placed on lined polyfoam trays in single layers and over-wrapped with oxygen-permeable polyvinyl chloride (PVC) film. Samples were stored either at 4°C for 3 or 6 d, or at -20°C for 30, 60, or 120 d.

Moisture was determined by the AOAC (1990) oven-drying procedure. Total fat was extracted by the procedure of Folch et al. (1957) and gravimetrically determined on aliquots of each sample extract after solvent removal.

Lipid oxidation was determined by measuring 2-thiobarbituric acid reactive substances (TBARS) using a modified distillation procedure (Rhee, 1978).

Cooking loss was determined by weighing 16 patties/treatment replication before and after cooking.

Data were analyzed by the General Linear Models (GLM) Procedure using the SAS program (SAS Institute, Inc., 1990). Treatment (breed/feeding), replication, and treatment-by-replication interaction were included in the model for data on samples that had not undergone storage at 4° or -20°C or data involving a given storage time. For analysis of lipid oxidation (TBARS) data on samples stored at 4° or -20°C, the model included treatment, replication, storage time, and treatment-by-replication, treatment-by-storage time, and treatment-by-replication-by-storage time. The following contrast comparisons were made to assess differences between treatments: SB/F vs S/F, S/F vs S/R, SB/F vs SB/R, and SB/R vs S/R. Results of these statistical analyses are not presented in a tabular form, but noted in the text.

Results and Discussion

The fat content in raw patties ranged from 3.05 to 3.45% and 4.14 to 4.82% in cooked patties (Table 1). These percentages were higher than those reported on muscles samples from various breeds of goat, mostly < 3% for raw samples (Babiker et al., 1990; Park and Washington, 1993; Oman, 1995). The meat used to make the patties in this study was not comprised of only muscles, but a composite of lean portions separated with a knife. Thus, it had some visible fat, although minimal, on the surface of separated lean pieces. Fat content of raw or cooked patties was similar ($P > .05$) between Spanish and Spanish x Boer goats within each feeding regimen and between feedlot and range goats within each breed-type. Likewise, moisture of raw or cooked patties (Table 1) was not significantly different in any comparisons.

Moisture and fat retentions after cooking were not affected by feeding regimen or breed type. Fat was completely retained during cooking, whereas moisture retention ranged from 70.5 to 74.5%.

Cooking loss also was similar ($P > .05$) for the feedlot goats, whether Spanish or Spanish x Boer cross. With range regimen, however, Spanish x Boer patties lost more ($P < .05$) weight during cooking than patties from Spanish goats. Cooking loss percentages correlated positively with raw moisture and negatively with moisture retention. This, along with the complete fat retention, indicated that cooking loss in lean goat meat patties occurred through moisture loss.

Oxidative storage stability was measured by TBARS values due to high correlations documented between TBARS values and sensory scores for oxidized off-flavors. A low TBARS content indicates a low potential for oxidative flavor deterioration. When refrigerated for 3 or 6 d, patties (raw or cooked) from range goats had lower ($P < .05$) TBARS values than feedlot goats (S/F vs S/R and SB/F vs SB/R) (Table 2). This was not related to fat content; total fat content (Table 1) was similar between the treatment groups.

Similar feeding regimen effects also have been reported for TBARS values of raw ground beef (> 18% fat) stored frozen for 30 or 60 d (Brown et al., 1979). TBARS values were lower for ground beef from steers finished on grass (orchardgrass, fescue and clover pasture) or a limited-grain ration than for ground beef from steers finished on a grain ration (fed *ad libitum*). The major cause of TBARS differences between meat from grass-fed and grain-finished steers may be tissue tocopherol (natural antioxidant) differences. When steers were removed from pasture and fed a corn-based diet, the α-tocopherol content in *longissimus* muscle decreased (Mann, 1983). The level of α-tocopherol in meat of grass-fed animals may be related to the type of pasture. Beef (*longissimus*) from animals raised on a temporary pasture of rye, ryegrass and clover had only 3.0 mg α-tocopherol/g compared to 6.9 mg/g for meat from animals grazed on fescue, orchardgrass and clover (Holden, 1985). Carotenoid (natural antioxidant) content was 453 mg (β-carotene/g fat) in the former group of steers and 711 mg in the latter group. When cattle grazed on fescue, orchardgrass and clover were placed on a corn-based diet, the total carotenoid level decreased with increasing time on feed. It is not known whether levels of antioxidants, such as α-tocopherol and carotenoids, might have been higher in the meat from range goats than in the meat from feedlot goats in our study.

Another trend for refrigerated raw patties was that, in the range regimen, TBARS were higher ($P < .05$) for samples from Spanish x Boer goats than for Spanish goats. However, no such consistent differences were found with the feedlot regimen. Thus, results indicate that, when animals are grazed on rangeland, meat from Spanish goats will be less susceptible to oxidative quality deterioration than meat from Spanish x Boer goats.

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When patties were frozen, all patties (raw or cooked), whether from Spanish or Spanish x Boer goats,

had low TBARS throughout 120-d storage. This was not expected of aerobically-packaged cooked meat that had undergone prolonged frozen storage. When cooked samples remaining after TBARS assays at d 120 were stored frozen aerobically for about 5 additional months, TBARS values underwent minimal change. When differences were found between treatments, trends were generally similar to those found when samples were refrigerated.

The storage time effect on TBARS values was evaluated for refrigerated and frozen patties. Raw patties were not stored at 4°C beyond 3 d due to the potential effect on TBARS of substantial microbial growth (Rhee et al., 1997). TBARS increased ($P < .05$) with storage days for both raw and cooked patties. TBARS increase during refrigeration was much faster for cooked than raw patties, as with other species (Rhee et al., 1996).

Conclusions

Feeding regimen had greater effects on oxidative storage stability than breed type. Meat from feedlot goats was more susceptible to lipid oxidation than meat from range goats. This was true whether patties were stored raw or after cooking. With the range regimen, meat from Spanish x Boer goats oxidized more than did meat from Spanish goats when refrigerated. Further studies are needed to determine why meat from range goats is more resistant to oxidative changes.

Table 1. Cooking loss and fat content and moisture of goat patties of meat-type goat breeds from two feeding regimens

		Treatment (breed type/feeding/regimen)				
		Feedlot		Range		
		Spanish (S/F)	Spanish x Boer (SB/F)	Spanish (S/R)	Spanish x Boer (SB/R)	SEM[c]
Cooking loss (%)[a]		20.28	20.71	19.94	21.56	1.10
Fat content (%)[b]						
	Raw	3.38	3.45	3.05	3.16	0.47
	Cooked	4.82	4.67	4.14	4.23	0.56
Moisture (%)[b]						
	Raw	74.10	74.21	75.34	75.39	0.37
	Cooked	65.72	65.93	67.63	68.66	0.81

[a] Means represent data from 4 cooking batches/treatment replication, with 4 patties/batch and a total of 2 treatment replications. Each
[b] treatment replication consisted of ground muscle composite of 2 animals.
[c] Composite of 4 patties/treatment replication.
Standard error of the mean.

Table 2. Effects of storage time on TBARS values of raw and cooked samples stored at 4°C or -20°C

			TBARS (mg malonaldehyde/kg sample)				
			Feedlot		Range		
		Storage time (days)	Spanish (S/F)	Spanish x Boer (SB/F)	Spanish (S/R)	Spaish x Boer (SB/R)	SEM[d]
4°C Storage							
	Raw	0	0.40[b]	0.28[b]	0.14[b]	0.27[b]	0.02
		3	0.63[a]	0.64[a]	0.21[a]	0.41[a]	0.02
	Cooked	0	0.50[c]	0.42[c]	0.31[c]	0.29[c]	0.03
		3	4.21[b]	4.93[b]	1.55[b]	3.52[a]	0.06
		6	8.15[a]	8.25[a]	3.59[a]	6.65[a]	0.16
-20°C Storage							
	Raw	0	0.40[b]	0.28[b]	0.14[a]	0.27[a]	0.02
		60	0.37[b]	0.30[ab]	0.16[a]	0.27[a]	0.03
		120	0.50[a]	0.35[a]	0.18[a]	0.32[a]	0.03
	Cooked	0	0.50[a]	0.42[a]	0.31[a]	0.29[a]	0.03
		60	0.51[a]	0.37[a]	0.49[a]	0.34[a]	0.04
		120	0.57[a]	0.42[a]	0.39[a]	0.37[a]	0.06

[a,b,c] Means within the same column within each storage temperature/product state (raw or cooked) category followed by common superscripts are not different ($P > .05$).
[d] Standard error of the mean.

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