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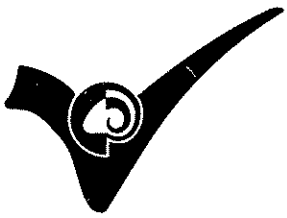

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Fiber Diameter Measurements of Angora Goats on Performance Test[1,2]

C.J. Lupton[3,4] D.F. Waldron[3] and F.A. Pfeiffer[3]

Summary

Average fiber diameter (AFD) and variability of fiber diameter (standard deviation, SD; coefficient of variation, CV) were measured on the fleeces of 301 male Angora goats participating in the 1994 and 1995 Angora Goat Performance Tests conducted by the Texas Agricultural Experiment Station. This was achieved by core-sampling each fleece and measuring a representative sub-sample using an Optical Fibre Diameter Analyser (OFDA; BSC Electronics Pty. Ltd., Attadale, Western Australia). These values were then compared to similar measurements from neck, side and britch samples that were taken halfway through the test. AFD measured on core samples were highly correlated ($r^2 > 0.65$; $P < 0.01$) with each individual and the average of the three measurements made on neck, side and britch samples. The same was true for measures of variability of fiber diameter (SD, CV). However, the variability among neck, side and britch average fiber diameter (traditionally used as an indicator of fleece uniformity) was poorly correlated ($r^2 < 0.01$) with variability of fiber diameter in the fleece core sample (CSD). It was concluded that the most accurate way to estimate the average fiber diameter and variability of a mohair fleece is to measure a representative core sample.

Key words: Angora goat, average fiber diameter (AFD), performance test, fleece sampling.

Introduction

Performance testing using objective measurements of economically important traits provides useful information for making selection decisions. The Angora Goat Performance Test was begun by the Texas Agricultural Experiment Station (TAES) in 1967, discontinued in the early 1970s and restarted in 1980. The program emphasizes the value of selecting males on their overall merit rather than focusing on a single trait (Lewis and Shelton, 1985). Since its inception, fiber diameter measurements were made on samples removed from the neck, side and britch regions about halfway through the test. This practice is rationalized as follows. Taking the samples eight weeks before the end of the test provided the lab adequate time to make all the fiber diameter measurements. This much time was necessary when a projection microscope technique was being used. Even so, a sufficient number of fibers could not be measured using a microscope to provide very accurate estimates of average fiber diameter of variability. Measuring samples taken at three distinct locations was thought to provide a good indicator of fleece uniformity. Averaging the three measurements was considered to provide a number that would be close to the true AFD of the whole fleece grown during the test period. This value was then used in the index equation for ranking animals on overall merit. In recent years, whenever one or more of the three AFD measurements exceeded 50 µm, the goat became ineligible for certification (Waldron and Lupton, 1995).

For several years, the TAES Wool and Mohair Research Lab has been equipped with instrumentation that can measure mohair AFD and distribution much more rapidly and accurately than the projection microscope (when relatively few fibers were measured). Thus, the requirement of sampling at the midpoint of the test is no longer necessary. Fleeces grown

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during the test period can now be fully quantified in terms of yield, AFD and medullated fibers in less than three weeks.

In both years of the experiment, animals were managed and fed in an identical manner. It was of interest to determine if and to what extent other environmental factors might affect the various measures of AFD. However, the experiment was designed primarily to establish the relationships among AFD measured on the neck, side, britch and whole fleeces, as well as to compare variability of fiber diameter in the whole fleece to those measures of variability determined for the neck, side and britch samples and the traditional indicator of variability (i.e., variation among neck, side and britch AFD).

Materials and Methods

Mohair patch samples (approximately 3 in × 3 in) were removed from the neck, side and britch regions of each yearling goat participating in the 1994 and 1995 Angora Goat Performance Tests conducted at the TAES Sonora facility. Each sample (representing eight weeks of mohair growth) was subsampled close to the base of the staple, cleaned, conditioned and measured for AFD, and SD and CV of fiber diameter. Subsequently, 112-day fleeces were shorn from the animals and cored (with 32.5-in coring tubes) to obtain a sample representative of the whole fleece (Johnson and Larsen, 1978). This sample was cleaned in a standard manner (ASTM, 1995), conditioned and measured for AFD, SD and CV. The Optical Fibre Diameter Analyser was used to make all the measurements in both years of the experiment (IWTO, 1995).

For the analysis, it was assumed that all goats were genetically independent of each other. In fact, this was not the case. Although several goats had common sires, we considered that these few relationships would not significantly affect the results of our analyses. Data were analyzed to provide simple statistics (mean, SD and CV) for each variable measured. In addition, paired T tests, simple linear regression analyses and analyses of variance were performed on the data using the MEANS, REG and GLM procedures of SAS (SAS, 1992).

Results and Discussion

Data from the 301 animals completing the 1994 and 1995 performance tests were analyzed. A summary of the simple statistics is given in Table 1. Overall, the AFD of the fleece core samples (CAFD) was not different ($P = 0.13$) than that of the side samples (SAFD). However, CAFD was 1.5 µm smaller ($P < 0.0001$) than AFD of the neck samples (NAFD), 4.6 µm smaller ($P < 0.0001$) than AFD of the britch samples (BAFB) and 2.0 µm smaller ($P < 0.0001$) than the mean AFD of the neck, side and britch samples (AAFD). The last value (AAFD) is that used in the index equation to rank animals. As expected, the variability of fiber diameter in the core sample (CV) was greater ($P < 0.0001$) than in either the neck or side samples. However, it was comparable in magnitude (27.6 vs. 28.0%, $P = 0.16$) to that measured for mohair growing in the britch region. This study confirms that mohair fibers from the britch of Angora goats are the coarsest and most variable tested.

In terms of year differences, all 1994 AFD and SD of fiber diameter were greater than comparable measurements made in 1995 ($P < 0.002$; Table 2). CV of fiber diameter were unaffected by year ($P > 0.26$).

Table 3 and Figure 1 show that CAFD and AAFD are highly corre-

Table 1. Minimum and maximum values, means and standard deviations for core, neck, side and britch average fiber diameters (AFD), standard deviations (SD) and coefficients of variation (CV) of fiber diameter.

Items	Min.	Max.	Mean	SD
Core:				
AFD, µm	29.5	57.0	39.9	3.9
SD, µm	7.8	17.2	11.0	1.6
CV, %	20.7	37.5	27.6	2.9
Neck:				
AFD, µm	28.1	59.4	41.4	5.3
SD, µm	6.1	17.4	10.2	2.0
CV, %	16.5	39.3	24.7	4.0
Side:				
AFD, µm	27.0	56.3	39.7	4.9
SD, µm	6.1	17.3	9.5	1.7
CV, %	15.9	36.7	24.1	3.8
Britch:				
AFD, µm	28.9	64.0	44.5	5.9
SD, µm	6.9	22.7	12.3	2.4
CV, %	17.0	51.6	28.0	5.6
Average of neck, side and britch:				
AFD, µm	28.0	59.0	41.9	5.1
SD, µm	6.5	18.7	10.7	1.8
CV, %	17.9	38.0	25.6	3.9

lated. More than 84% of the variation in CAFD can be accounted for by the variation in AAFD. The CAFD is also significantly correlated with SAFD, NAFD and BAFD (r^2 = 0.8190, 0.7785 and 0.6673, respectively). Any one of these measures of AFD could be used to give a fair estimate of CAFD, but AAFD would give a better estimate than any of the three individual measures. Nevertheless, such an estimate would not be perfect (because $r^2 \neq 1$) and CAFD is best determined by direct measurement.

Variability of fiber diameter in the core samples is quantified by CSD and CCV. The CSD values are significantly correlated with average standard deviation of diameter values measured on neck, side and britch samples (ASD; r^2 = 0.6679, Figure 2). The correlation between CCV and ACV is also quite high (r^2 = 0.6040). However, because the correlations are not perfect, the best estimate of variability of fiber diameter in the whole fleece is also that determined by direct measurement.

In the past, neither ASD nor ACV values have been available in the performance test report. A more tradi-

Table 2. Differences in average fiber diameter and distributions between years, and its statistical significance (P).

Items	1994	1995	P
Core:			
AFD, µm	40.7	39.3	0.0016
SD, µm	11.3	10.8	0.0015
CV, %	27.8	27.4	0.2597
Neck:			
AFD, µm	42.9	40.2	0.0001
SD, µm	10.7	9.8	0.0001
CV, %	25.0	24.5	0.2711
Side:			
AFD, µm	40.8	38.9	0.0004
SD, µm	9.9	9.2	0.0008
CV, %	24.3	23.9	0.3952
Britch:			
AFD, µm	46.1	43.2	0.0001
SD, µm	12.8	11.9	0.0005
CV, %	28.1	27.9	0.7322
Average of neck, side and britch:			
AFD, µm	43.3	40.7	0.0001
SD, µm	11.1	10.3	0.0001
CV, %	25.8	25.4	0.4222

Table 3. Linear relationships between various measures of average fiber diameter (AFD) and variability of fiber diameter.

Dependent variable		Intercept		Slope		Independent variable	r^2
CAFD[b]	=	10.03	+	0.71	×	AAFD[c]	0.8461
CAFD[b]	=	13.05	+	0.65	×	NAFD[d]	0.7785
CAFD[b]	=	10.89	+	0.73	×	SAFD[e]	0.8190
CAFD[b]	=	15.89	+	0.54	×	BAFD[f]	0.6673
CSD[g]	=	3.41	+	0.71	×	ASD[h]	0.6679
CSD[g]	=	10.82	+	0.08	×	STD[i]	0.0049
CCV[j]	=	13.15	+	0.56	×	ACV[k]	0.6040

r^2 = coefficient of determination.
CAFD = average fiber diameter of the fleece core sample.
AAFD = average of the neck, side and britch average fiber diameters.
NAFD = average fiber diameter of the neck sample.
SAFD = average fiber diameter of the side sample.
BAFD = average fiber diameter of the britch sample.
CSD = standard deviation of fiber diameter of the fleece core sample.
ASD = average of the neck, side and britch standard deviations of fiber diameter.
STD = standard deviation of the neck, side and britch average fiber diameters.
CCV = coefficient of variation of fiber diameter of the fleece core sample.
ACV = average of the neck, side and britch coefficients of variation of fiber diameter.

tional method of gauging variability (or uniformity) of mohair fiber diameter in these test animals has been to mentally compare the neck, side and britch AFD. Table 2 and Figure 3 show that the correlation between actual variability of fiber diameter in the fleece (CSD) and the variability among neck, side and britch average fiber diameters (STD) is very low. In other words, comparing the AFD of the neck, side and britch sample is a very poor method of estimating fiber diameter variability in the fleece as a whole. The CSD is calculated from measurements on fibers obtained in a manner so as to be representative of the entire fleece. The STD cannot separate bucks that have a small area of coarse fiber from those that have a large area of coarse fiber because data used to calculate STD were generated from measurements made on three small patches.

Conclusions

The overall AFD of the fleece core samples and side samples were not different. However, neck, britch and the average of neck, side and britch AFD were all greater than the core sample AFD.

AFD measured on core samples were highly and significantly correlated with each individual and the average of the three measurements made on neck, side and britch samples. The same was true for measures of fiber diameter variability.

The variability among neck, side, and britch AFD was poorly correlated with variability of fiber diameter in the fleece core sample.

The most accurate way to estimate the AFD and variability of a mohair fleece is to measure a representative core sample.

Implications

Procedures of several Angora goat performance tests in this country (Oklahoma) and abroad (Canada, New Zealand, Australia) have been based on those developed and used by the Texas Agricultural Experiment Station. Assuming that high-speed measurement of fiber diameter is available, sampling mohair at three

Figure 1. Average of fiber diameter at three locations (AAFD) versus core sample average fiber diameter (CAFD).

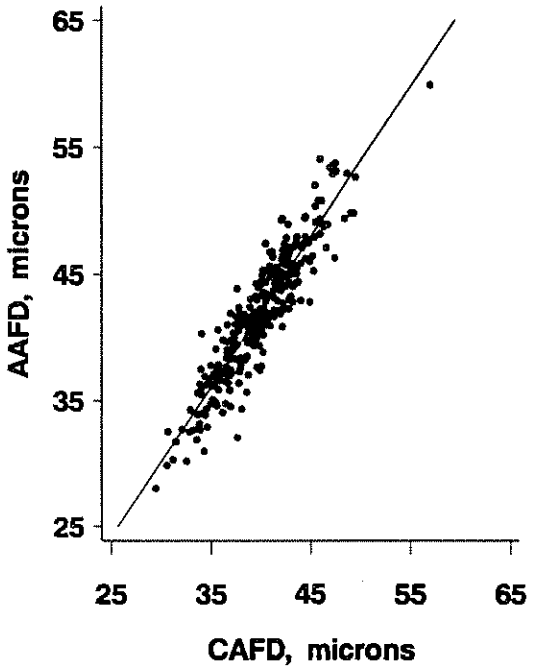
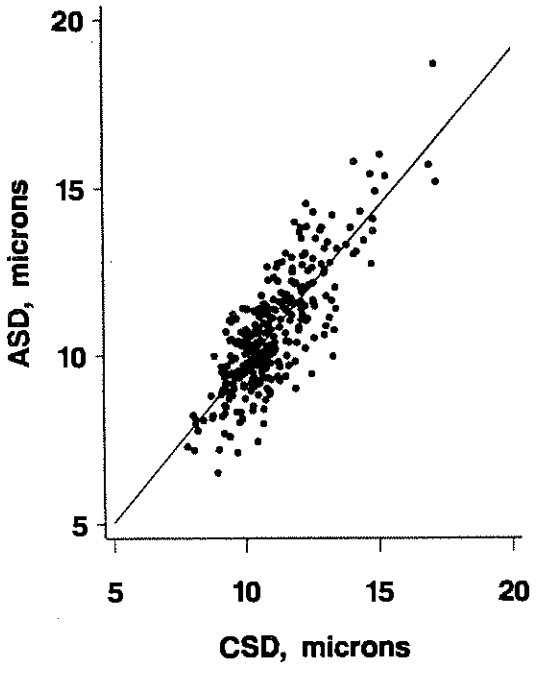


Figure 2. Average of standard deviation of fiber diameter at three locations (ASD) versus core sample standard deviation (CSD).



body locations part-way through the performance test can no longer be justified. Measuring a core sample of the fleece shorn at the end of the test period provides the most accurate estimates of AFD and variability of fiber diameter within the fleece.

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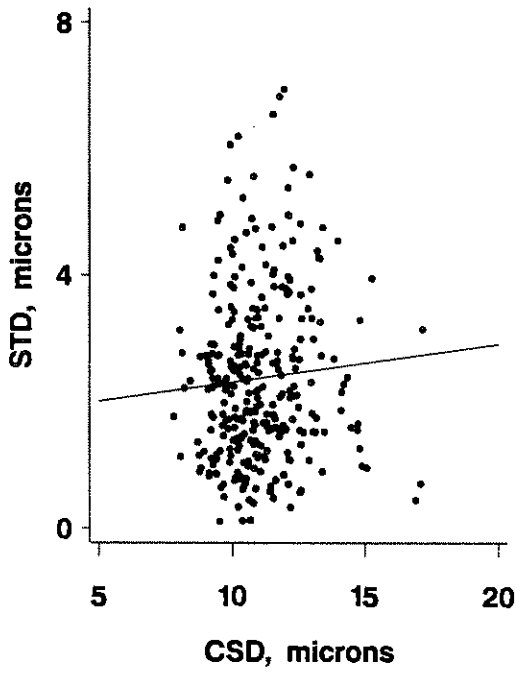
Figure 3. Standard deviation of average fiber diameter (AFD) for three locations (STD) versus core sample standard deviation of fiber diameter (CSD).



A Comparison of Sheep- and Wildlife-Grazed Willow Communities in the Greater Yellowstone Ecosystem

Charles E. Kay[1] and John W. Walker[2]

Summary

The effects of grazing by sheep and wildlife on willow communities in the Greater Yellowstone Ecosystem (GYE) were compared in this study. Willow communities grazed by wildlife (elk and bison) were on the northern range of Yellowstone National Park (YNP). Sheep-grazed areas were in the Centennial Mountains on the U.S. Sheep Experiment Station (USSES) summer range about 100 km west of the YNP. Both locations are in the GYE, an area surrounding YNP that encompasses over six million hectares. Willow height and canopy cover were measured inside and outside four exclosures (established 26 to 31 years prior to sampling) on the northern range of YNP and compared to ten grazed willow communities on the USSES summer range. Repeat photographs were taken at both locations to estimate long-term changes in extent of willow communities. Willow canopy cover at the USSES summer range (93%) was similar ($P > 0.05$) to cover inside exclosures at YNP (95%), but both were greater ($P < 0.05$) than willow canopy cover outside exclosures at YNP (14%). Willow heights averaged 189, 285 and 36 cm at the USSES summer range, inside the exclosures at YNP and outside the exclosures at YNP, respectively, and all means differed ($P < 0.05$). Willows have disappeared in 95% of the repeat photographs from the northern range of YNP but are still present in all repeat photographs of the USSES. Beaver are also ecologically extinct on the northern range of YNP but are present in all drainages with an appropriate habitat on the USSES summer range. The loss or near loss of two major biotic components (beaver and tall willows) indicates that the northern range of YNP is not in healthy ecological condition.

Key words: elk, repeat photography, rangeland health.

Introduction

Western range sheep operations typically depend upon public lands for over 40% of their forage needs (Taylor et al., 1982). Furthermore, there are essentially no alternatives to public land forage. Dependence on public land grazing by the western sheep industry is demonstrated by the willingness of producers to pay an average of over $5 per AUM more for federal forage than comparable private land forage as determined by a total cost approach to forage valuation (Torell et al., 1993). Access to forage on public lands is becoming increasingly tenuous because of public concern over the effect of livestock grazing on the health of rangelands. However, concern for the health of rangelands often appears to be more a function of values and philosophies than concern for rangelands. In an article highly critical of livestock grazing on western rangelands, Fleischner (1994) pointed out the importance of values when he wrote: "Is there an ecologically sustainable future for livestock grazing in western North America? This ultimately is a question of human values, not of science."

This study compared indicators of ecosystem health in wildlife- and sheep-grazed willow communities of the Greater Yellowstone Ecosystem. The GYE is an area extending approximately 100 to 200 km beyond the borders of YNP and encompassing six to eight million hectares. Much of the land in the GYC is public land and it is considered by many to be critical for insuring a properly functioning ecosystem in this area (Noss and Copperrider, 1994). The GYE is considered a bellwether for policy on public land and wilderness ecosystem management and as such provides a useful case study for demonstrating

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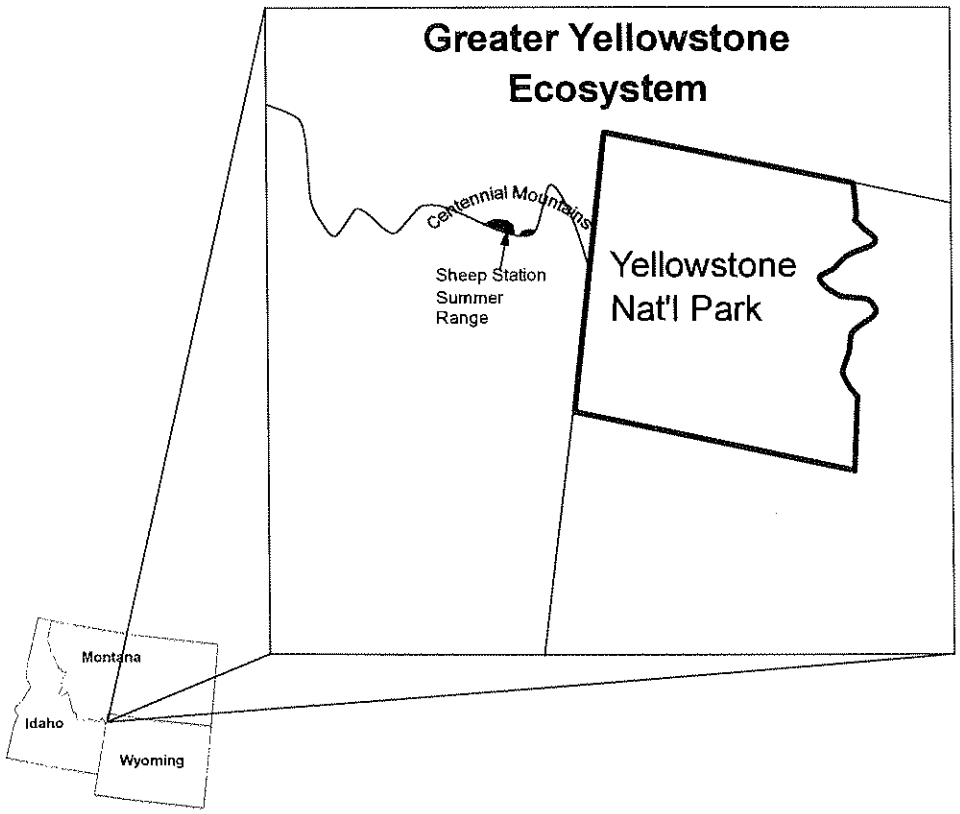
how standards for ecosystem health differ depending upon whether defoliation is by wildlife or domestic livestock. Keiter and Boyce (1991) described many problems that must be dealt with in the GYE. "In significant respects, fire, elk and wolves epitomize the transition to ecosystem management that is now occurring in Greater Yellowstone; how they are handled on the public domain will set the stage for how other human-nature conflicts are addressed. Transcending the bureaucratic domain of any single agency, these resources can be managed effectively only on an ecosystem scale. And ecosystem management policies can be devised only by reaching consensus on how to integrate humans and nature on America's remaining wildlands ... . What we are witnessing in greater Yellowstone is the emergence of a new era in public land management. Predicated on a fundamental realignment of the human relationship with nature." The fundamental realignment discussed by Keiter and Boyce (1991) is that man should no longer try to manage nature, but at least in the GYE, he should minimize the impact of his presence.

While philosophies and values may ultimately decide how ecosystems are managed, one of the purposes of science is to provide empirical evidence about the effect of different management options. The objective of this study was to compare managed sheep grazing to "naturally regulated" wildlife grazing on flora and fauna of willow communities in the GYE.

Materials and Methods

We studied willow (*Salix* spp.) communities on the northern range of YNP and on the USSES summer range located in the Centennial Mountains about 100 km west of the park (Figure 1). The USSES summer range lies between 2,100 and 2,900 meters elevation and the northern range of YNP lies between 1,500 and 2,400 meters elevation. The USSES summer range consists of 6,700 hectares in the Centennial Mountains that were withdrawn from the public domain in 1922 for sheep breeding and grazing research. The USSES summer range is divided into three allotments and these seasonal ranges are grazed during July and August. Prior to 1988, each allotment was grazed annually by a band of sheep at a moderate stocking rate (equal to or less than Natural Resources Conservation Service recommended rate). Rest-rotation grazing has been used since 1988 with each allotment rested every third year. Sheep bands consist of about 1,000 ewes and 1,400 lambs under the care of a herder.

Figure 1. Map showing the location of the U.S. Sheep Experiment Station and Centennial Mountains in relation to Yellowstone National Park.



Yellowstone National Park (890,000 hectares) was set aside in 1872 as our nation's and the world's first national park. Park administrators originally thought there were not enough game animals so they controlled predators and fed wintering elk (*Cervus elaphus*), bison (*Bison bison*) and other wild ungulates. By the late 1920s, concerns grew that the unnaturally large elk population was severely overgrazing the park, and in particular YNP's northern winter range. From 1949 to 1968, rangers shot more than 13,500 elk to reduce the northern herd. Under mounting political opposition, the National Park Service abandoned its elk-reduction program in 1969 and by the early 1970s had switched to "natural regulation" management (Kay, 1990; Boyce, 1991). Under natural regulation, predation is an assisting but non-essential adjunct to the regulation of ungulates through density-dependent homeostatic mechanisms. Elk and other wild ungulates are limited by food; death from starvation is considered a natural phenomenon.

Ten willow communities at the USSES were sampled during the summer of 1993 and compared with measurements of four willow communities on the northern range of YNP taken in 1988. Communities sampled at YNP were located inside and outside of elk-proof exclosures located at Mammoth (established in 1957), Lamar-East (established in 1957), Lamar-West and Junction Butte (established in 1962). Houston (1982) and Barmore (1981) provide background information on these exclosures. At all locations, line-intercept transects were used to determine willow canopy cover by species and height was measured at regularly spaced points on each transect. For complete information on the YNP data, see Chadde and Kay (1988; 1991), Kay (1990; 1994b) and Kay and Chadde (1992). The effect of the three treatments (YNP inside, YNP outside, USSES) on total willow cover and height of Geyer willow (*Salix geyeriana*) were compared using a one-way analysis of variance with each exclosure or community as an experimental unit.

Beaver (*Castor canadensis*) is a keystone species in the GYE and beaver activity was recorded at both locations as an indicator of ecosystem health (Kay, 1994b). Repeat photographs were also used to determine long-term changes at both locations. Forty-four historical photographs that contained scenes of willow communities in YNP were relocated and photographed from 1986 to 1989. Because few pictures of willow communities on the USSES's summer range could be located, the study area was expanded to include the entire Centennial Mountains. While exact management for the entire range is not known, all large ungulates are managed to some degree either through grazing systems or hunting regulations. In the Centennial Mountains study area, 28 historical photographs originally taken between 1871 and 1939 that contained scenes with willows were relocated in the field and photographed during 1994 and 1995.

Results and Discussion

Willow Communities

The willow canopy cover on the USSES summer range was similar ($P > 0.05$) to willow canopy cover inside exclosures in YNP. Furthermore, willow canopy cover at the USSES and inside the YNP exclosures was greater ($P < 0.001$) than the cover outside exclosures in YNP. The height of Geyer willow differed ($P < 0.001$) among all three locations. Willows were tallest inside and shortest outside the exclosures in YNP; whereas on the USSES summer range, willow height was intermediate to the two locations in YNP, but more similar to willows inside exclosures than outside (Figure 2). The shorter height of willows on the USSES summer range compared with willows inside exclosures in YNP may be the result of repeated browsing by wild ungulates, primarily wintering moose (*Alces americana*). We attribute the browsing to moose rather than domestic sheep because the plants were browsed well above what domestic sheep can normally reach.

Of the 44 repeat sets of photographs of willow communities on YNP's northern range, dating to the 1870's, tall willows have totally disappeared in 41 sets of photographs (Figure 3), while in the other three, only 5 to 10% of the original tall willows remain. When discussing repeat photographs, tall willows are differentiated from shorter, browsed willows because only the former can be seen in the photographs. In 1871, Captains Barlow and Heap (1872) toured YNP and on the northern range they reported "thickets of willows along the river bank." P.W. Norris (1880), YNP's second superintendent, noted that the Park was "well supplied with rivulets invariably bordered with willows." Since that time, though, the area occupied by tall willow communities on the northern range has declined by 95% or more (Kay, 1990). In contrast to the repeat sets of photographs in YNP, tall willows are still present in all of the sets of photographs from the Centennial Mountains and may have increased in stature at some locations (Figure 4). A recent study reported 100 times more bank erosion on streams in YNP compared with higher reaches of the same streams outside the park where willows are still abundant (Rosgen, 1993).

Beaver

Beaver were common on YNP's northern range during the 1800s, but are now ecologically extinct (although occasional beaver may be found they no longer affect ecosystem function) due to repeated ungulate browsing of the willows and aspen (*Populus tremuloides*) beaver need for food and dam-building materials. In the 1920s, a detailed survey of one small portion of the YNP's northern range reported extensive active dams and 232 beaver. During the 1950s and again in 1986 to 1988, no beaver or any recent activity were recorded (Kay, 1990; Chadde and Kay, 1991). In contrast, on the USSES summer range beaver are present in all drainages that have appropriate habitat. Without tall willows and beaver in YNP, biodiversity is greatly reduced, many streams are downcut and the water tables are lowered (Kay, 1994b). Since beaver is a keystone species, its loss has ramifications far beyond the demise of a single species (Kay, 1994b). Keystone

species play pivotal roles in their ecosystems and a large part of the community is dependent upon them. Beaver create habitats used by many species and also regulate hydrology and other ecosystem functions (Naiman et al., 1988).

Conclusion

The loss or near loss of two major biotic components (beaver and tall willows) indicates the northern range of YNP is not in healthy ecological condition. We believe the differences between YNP's northern range and the USSES summer range are caused primarily by differences in levels of defoliation of willows by large ungulates. This conclusion is based on the dramatic fenceline contrast seen at elk-proof exclosures in YNP (Figure 5) and the decline in willow communities since the turn of the century demonstrated in the repeat sets of photographs (Kay, 1990). Patten (1993) and Wagner et al. (1995) also concluded that elk grazing was the major reason willow communities have deteriorated on the northern range of YNP. We believe the major difference between the effect of grazing at these two locations is not the difference in species of herbivores but differences in level of management and the resultant differences in levels of defoliation. Similar conclusions were drawn in Australia where it was shown that over-stocking by either sheep or kangaroos (*Macropus giganteus*) had a similar effect on vegetation structure (Freudenberger and Palmer, 1996).

Environmental organizations and some government agencies appear to have different standards for ecosystem health depending upon whether the herbivore is native wildlife or domestic livestock. These differences have important implications concerning the development of standards for rangeland health. Many environmentalists think of nature in its healthy condition as characterized by its independence (i.e., unaffected by human interference; Borgman, 1995). Furthermore, the impact of "natural" populations of wildlife on resources is apparently not a concern to some. Thus, regarding potential resource damage due to high elk numbers, Boyce (1991) asks the rhetorical question: "Is there anything necessarily unnatural or undesirable about soil erosion?" To which he answers: "Anthropogenic, excessive soil erosion maybe." In a similar line of thought Coughenour and Singer (1991) state: "The concept of overgrazing has no meaning in ecosystems where there are no humans to alter or evaluate natural processes." We disagree with the idea that the impact of herbivores on the vegetation and soil of an

Figure 2. Willow canopy cover and height inside and outside elk-proof exclosures in Yellowstone National Park (YNP) and on the USSES summer range. Bars within a group with different letters are significantly different ($P < 0.05$).

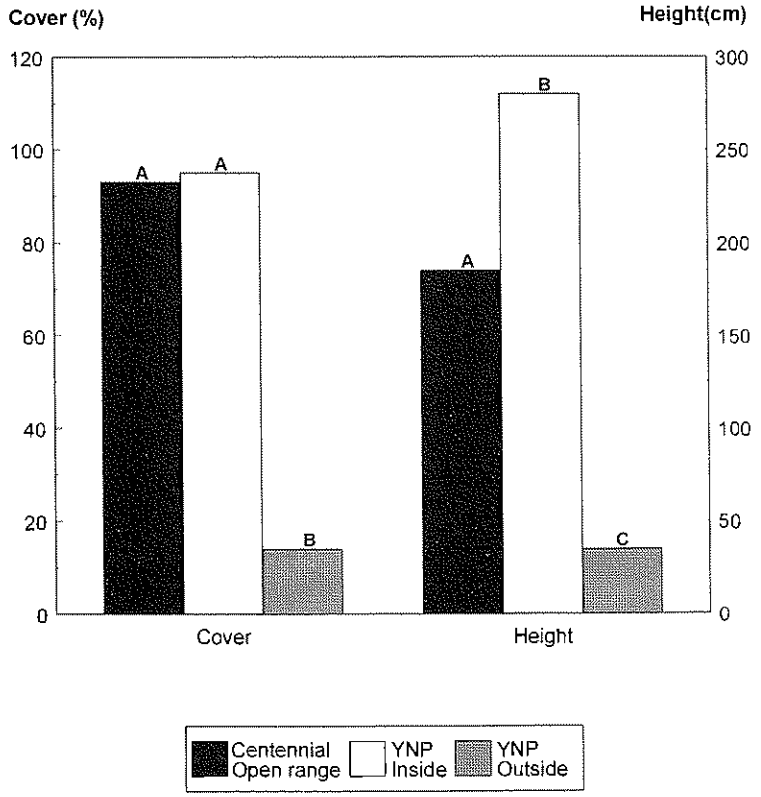


Figure 3. Tall-willow communities in Yancy's Hole on Yellowstone's northern range.

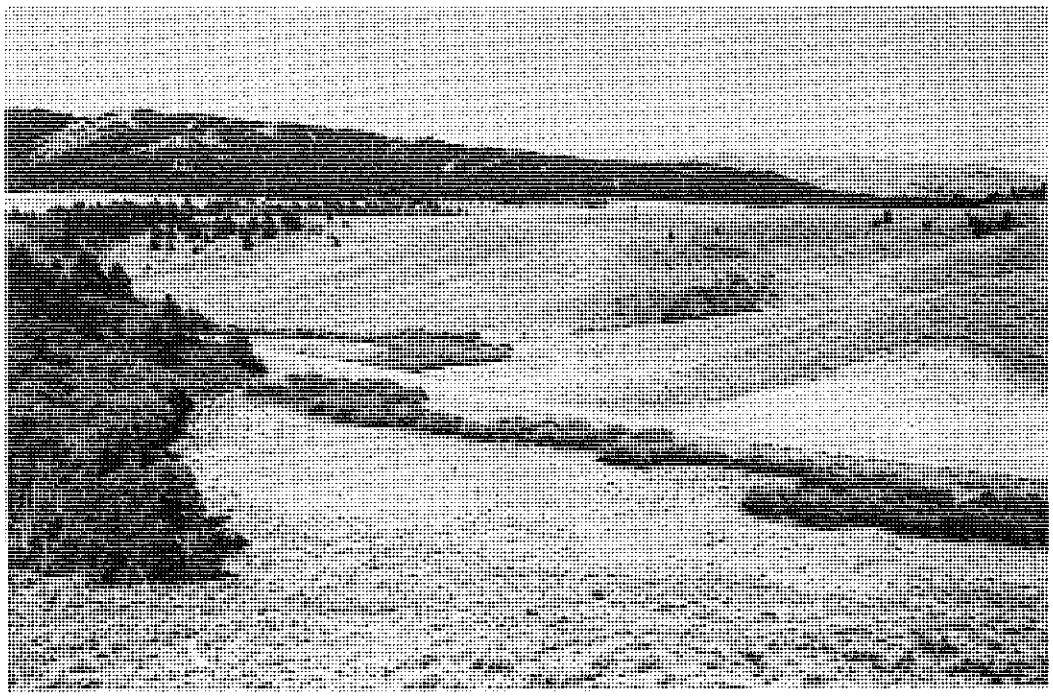
(a) 1893 photo by F. Jay Haynes (H-3080) viewed east. Photo courtesy Haynes Foundation Collection, Montana Historical Society, Helena.

(b) That same area in 1988. Note the loss of tall willow communities, less than 100 years later. Other photos of this area show that the tall willows had been heavily browsed and were declining by 1921. Tall willows were absent in 1954 photos. Photo by Charles E. Kay (no.3051-12) August 20.

Figure 4. A tall-willow community along Miners Creek in the west end of the Centennial Mountains, Idaho.

(a) 1910 photo courtesy of Jim Hagenbarth.

(b) That same area in 1994. Except for the new road constructed up Miners Creek, willows appear unchanged despite yearly grazing by cattle and sheep. Photo by Charles Kay (No. 3833-4).



ecosystem should be evaluated based on the species of animal causing the impact.

The same standards should be applied whether the herbivore is wild or domestic. Concerning livestock grazing, the Greater Yellowstone Coalition (GYC) state that sloughing of streambanks is of greater consequence to riparian ecosystem functioning than are utilization rates (Harting and Glick, 1994). Yet streambanks are sloughing throughout the northern range of Yellowstone National Park (Figure 6; Budiansky, 1996). The GYC also recommend, again concerning livestock grazing, exclosures to distinguish environmental and/or random variation from that attributable to land-uses or management (Harting and Glick, 1994). Yet at exclosures in the YNP, fenceline contrasts exist that are far greater than differences normally seen at livestock exclosures (Figure 5).

Rangeland health is defined as an indication of proper or normal functioning of ecological processes resulting in the production of commodities or values (Committee on Rangeland Classification, 1994). Riparian ecosystems must have an appropriate composition of woody and herbaceous species to maintain their integrity and stability (Elmore and Beschta, 1987). These data show that the characteristics of willow communities on the northern range in YNP are not consistent with properly functioning riparian systems. The effect of overgrazing should be of equal importance to a conservationist whether the impacts are caused by livestock or wildlife. Current values and philosophies concerning the relationship of humankind to the environment are derived from the concept that the moral community should be expanded to include "nature" (Leopold, 1970; Nash, 1988). The law requires that all persons be treated equally. If the moral community is expanded to include nature, as suggested by many environmentalists, it would be inappropriate to have double standards (i.e., one set of standards for wildlife and another set for livestock) for the relationships between society and nature. Livestock producers and other environmentalist should demand the same set of standards applied for wildlife be applied for livestock or vice versa.

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Figure 5. Fenceline contrast along a willow exclosure in Yellowstone National Park. The Lamar-West exclosure shown here was constructed in 1962 and this photograph was taken 25 years later in 1987. Photo by Charles Kay (print from color slide).

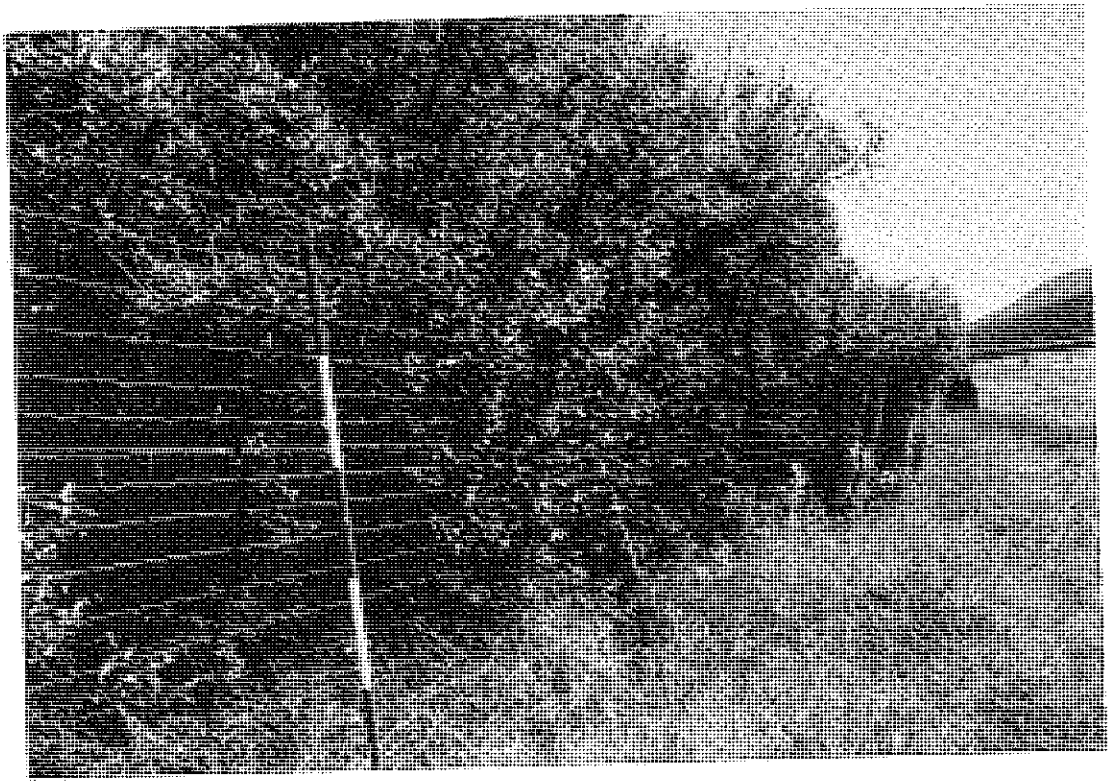

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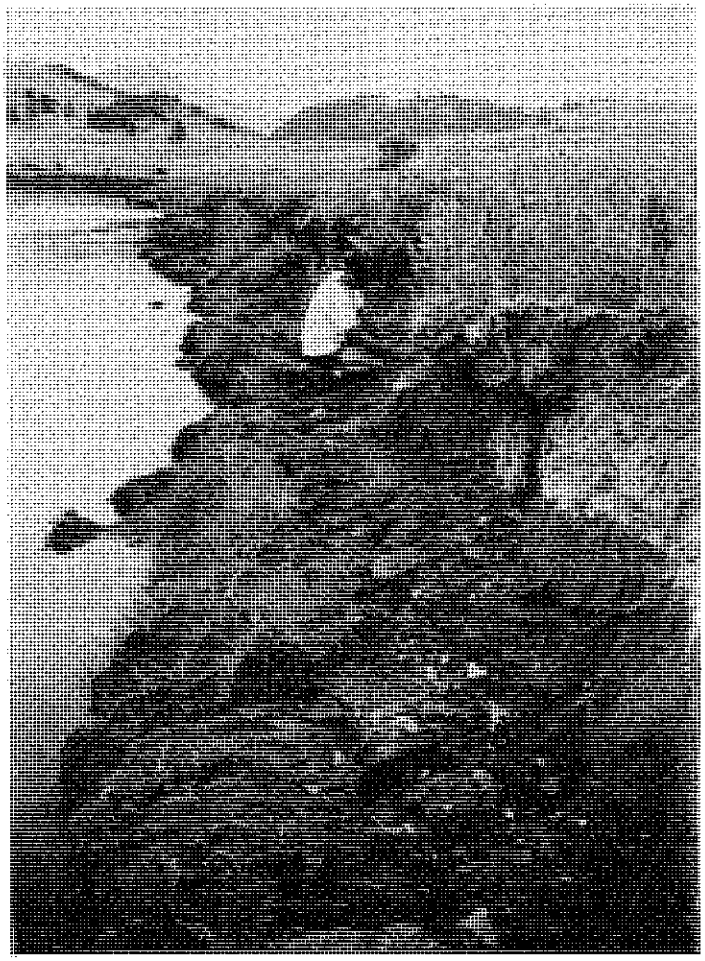
Figure 6. Stream bank Sloughing on Slough Creek on the northern range Yellowstone National Park. Photo by Charles Kay, August 1996.



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Effect of Zeranol Implantation and Yeast Supplementation on Performance and Carcass Traits of Finishing Wether Lambs[1,2,3]

B.A. Jones, M.K. Neary, D.L. Hancock, E.P. Berg, J. Huffman and J.R. Flanders

Summary

This study was conducted to determine the effect of Zeranol and the yeast culture *Saccharomyces cerevisiae* (SC) on performance and carcass traits of finishing lambs. Sixty-four wether lambs (average initial weight of 39.1 kg) were selected and pair-fed diets (12% crude protein; CP) based on 85% high-moisture corn and 10% corn silage. Treatments were arranged as a 2-by-4 factorial with lambs either implanted (IM) or non-implanted (NI) and supplemented with SC at 0, 0.5, 1.0 or 1.5 g/head/day. Lamb average daily gain (ADG), feed efficiency and feed intake (FI) were not affected ($P > 0.05$) by dietary level of SC. Implanted lambs had a higher ($P < 0.05$) ADG and a more efficient ($P < 0.05$) feed conversion than NI lambs. There were no differences ($P > 0.05$) in FI regardless of lamb implant status. Total carcass lean deposition and hot carcass weight were greater ($P < 0.05$) in IM lambs compared to NI lambs. The level of SC fed had no ($P > 0.05$) significant effect on lamb carcass composition. These results indicate that lambs implanted with Zeranol grew faster, were more efficient in feed utilization and had heavier carcasses with increased carcass lean and fat deposition.

Key words: Zeranol, yeast, lambs, growth, carcass.

Introduction

Generally, it has been shown that utilization of anabolic implants, such as Ralgro (Pittman-Moore, Terre Haute, IN), increase growth performance in lambs. The use of anabolic implants in beef cattle is an accepted industry practice, yet only 1.7% of sheep operations utilize growth promoting implants (USDA, 1996). Wiggins et al. (1976), Sharp and Dryer (1971) and Nold et al. (1992) all reported increases in ADG, although the results were non-significant. Lane and Kemp (1990) reported increased ADG in lambs, but not until 20 days after Zeranol implantation. While Wilson et al., (1972a,b) reported a significant increase in ADG over an entire study. Feed conversion tends to improve (Nold et al., 1992) by implanting Zeranol, but not always at a statistically significant level (Wiggins, 1976; Sharp and Dryer, 1971; Wilson 1972a). Most authors report that carcass characteristics do not differ between implanted and non-implanted lambs (Wilson et al., 1972b; Wiggins et al., 1976; and Nold et al., 1992).

Direct-fed microbes (DFM) are naturally occurring bacteria in the gut of animals which are not genetically engineered (Harris, 1994). The use of microorganisms as a feed additive has regained interest over the past few years as a means of increasing feed efficiency and as a natural alternative to chemical feed additives (Kilmer, 1993).

Studies conducted with dairy cattle, found feeding DFM can increase dry matter intake, milk yield and the fat and protein content of milk (Hancock, 1994; Harris, 1994; Kilmer, 1993; Williams and Newbold, 1990) while other studies have shown non-significant increases or no response to DFM additives to lactating dairy cows (Hancock, 1994; Harris, 1994; Kilmer, 1993; Williams and Newbold, 1990). Williams (1988) reported improvements in feed conversion and liveweight gain of finishing bulls when yeast culture was added to the diet. Previous studies by Hancock (unpublished) showed increased ADG and feed intake when growing and finishing steer diets were topdressed with a DFM. However, these results were only seen in steers not implanted with Zeranol.

The objective of this study was to determine if Zeranol implantation, in

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[2] Journal paper No. 15287, Purdue University Agriculture Research Programs.

[3] Purdue University, W. Lafayette, IN 47907.

combination with supplementation of SC, had a positive interactive affect on growth performance and carcass characteristics of finishing lambs.

Materials and Methods

Sixty-four crossbred wether lambs were procured from a private sheep producer and were selected from a larger group of lambs numbering approximately 350 head. Breed makeup of the lambs included Rambouillet, Suffolk, Dorset and a small percentage of Finnish Landrace. They were predominately whiteface with some dark speckles. At the time of procurement, lambs were five to six months of age and had been grazing improved cool-season grass and legume pasture. Selected lambs were transported to the Purdue University Animal Sciences Research Center, where they were shorn, treated for internal parasites and vaccinated against clostridial diseases.

Lambs were pair-fed in pens with an expanded metal flooring and the pens contained a nipple watering system. Experimental treatments were arranged in a 2-by-4 factorial to evaluate the influence of Zeranol implantation, the feeding of yeast culture and any interactive affects between the two treatments. Lambs were either implanted with 12 mg of Zeranol (IM) at the initiation of the study or not implanted (NI). Lambs were also fed 0, 0.5, 1.0 or 1.5 grams per lamb per day of the yeast culture *Saccharomyces cerevisiae* (SC). Activity of SC was 20 billion live yeast cells per gram.

Response variables to determine the affect of implant status and yeast supplementation on lambs were ADG, daily FI and kilograms of feed required per kilograms of gain (F:G). Lamb carcass response variables were hot carcass weight (HCWT), dressing percent (DP), USDA quality grade, kilograms of boneless, closely trimmed primal cuts (BCTPC) and percent BCTPC (%BCTPC), percent carcass lean (%LEAN), kilograms of total carcass lean (TOTLN) and kilograms of leg lean (LEGL).

Ingredient composition of the diets are contained in Table 1. Lambs were adapted to the finishing diet over a 21-day period. Diets were calculated to be 12% CP and were fed daily at approximately 0800 hours. Feed refusal was recorded twice weekly to determine lamb FI.

Lambs were weighed twice, once each on consecutive days, at the initiation and conclusion of the trial. The consecutive weights were averaged to determine a start and end weight, respectively. They were also weighed once at 14-day intervals throughout the length of the study.

Upon conclusion of the study, all lambs were transported to Wolverine Pack, Inc. (Detroit, MI) for slaughter. Hot carcass weights were recorded and after a 24-hour chill, the remaining carcass measurements were recorded. The response variables of BCTPC, %BCTPC, PLEAN, TOTLN and LEGL were determined using equations developed by Berg et al. (1995) and Berg (1996). The equations for each individual variable were:

$$\text{BCTPC} = -0.7709 + (0.4348 \times \text{HCWT}) + (-0.1291 \times \text{FD}) + (0.2032 \times \text{REA})$$

$$\%\text{BCTPC} = 45.73 + (-0.1853 \times \text{HCWT}) + (-0.4025 \times \text{FD}) + (0.7218 \times \text{REA})$$

$$\text{TOTLN} = 0.6365 + (0.4139 \times \text{HCWT}) + (-0.329 \times \text{FD}) + (0.2319 \times \text{REA})$$

$$\%\text{LEAN} = 51.50 + (-0.2804 \times \text{HCWT}) + (-1.098 \times \text{FD}) + (0.8198 \times \text{REA})$$

$$\text{LEGL} = 0.1153 + (0.1566 \times \text{HCWT}) + (-0.1334 \times \text{FD}) + (0.1093 \times \text{REA})$$

Where:

HCWT = hot carcass weight;

FD = fat depth over the ribeye between the 12th and 13th rib; and

REA = ribeye area between the 12th and 13th rib.

Performance and carcass data were analyzed by analysis of variance using the general linear models procedure of SAS (1988) for a completely randomized design with a 2-by-4 factorial arrangement of treatments. Model sums of squares were separated into effects of level of yeast fed, implant status, interaction of yeast and implant, and the effect of yeast-by-implant within pen. Pen was considered the experimental unit for analysis of performance data while individual lamb was considered the experimental unit for analysis of carcass data. Least significant difference (LSD) were used to separate treatment means (SAS, 1988).

Results and Discussion

Performance Characteristics

One concern with implanting lambs with zeranol is potential for an increase in rectal prolapses. We did not have any lambs prolapse on this study, regardless of implant status.

There were no significant interactions between SC and implant status ($P > 0.05$). Lamb ADG, F:G and FI were not influenced ($P > 0.05$) by level of dietary SC (Table 2). Birch et al. (1994) also reported no difference in lamb growth regardless of dietary DFM status; however, they did find a 5.5% improvement in feed conversion. Lambs in our study were fed a diet of 85% concentrate, while the Birch et al. (1994) lambs were fed a diet containing a 60:40 concentrate-to-forage ratio. Williams (1989) reported that diet composition may influence animal response to yeast culture. Williams et al. (1991) reported increased milk yield when dairy cows were fed SC in a 3:2 concentrate-to-forage ratio, but no differences were detected in milk yield when the diet was a 1:1 concentrate-to-forage ratio.

Although the lambs were allowed a 21-day adaptation period to diets and environmental conditions, apparently this was not a long enough adaptation period, as they lost weight for the first 14 days of the study. Harris (1994) suggested that DFM may be used during times of stress to enhance rumen function by minimizing growth of pathogenic bacteria,

increase desirable gut microbial populations, increase ruminal fermentation and enhance fiber digestion. Obviously the lambs in our study were stressed, as evidenced by the weight loss exhibited in the first 14 days. The lambs consuming the control diet had a weight loss of 0.03 kg per day, those consuming 0.5 g of SC lost 0.08 kg per day, those fed 1.0 g of SC lost 0.06 kg per day and those consuming 1.5 g of SC lost 0.05 kg per day. These values were not ($P > 0.05$) significantly different. Thus the inclusion of a DFM in our diets did not lessen the impact of a dietary or environmental stress to the lambs in this specific situation as measured by ADG, FI or F:G.

Over the course of the study, implanted lambs had higher ($P < 0.05$) ADG and a more desirable ($P < 0.05$) F:G than NI lambs (Table 3). During the first 42 days of the study, there were no significant differences in ADG due to implant status of the lambs (Table 4); however, IM lambs gained 21% faster and 32% faster from 42 days to 56 days and 56 days to 69 days, respectively, than NI lambs. Lane and Kemp (1990) reported a lag period after implanting lambs with Zeranol and hypothesized that implant-stimulated growth may require an initial period after implant deposition for synthesis of the necessary additional enzymes and substrates to support tissue accretion. Increases of 14.2% in ADG by Zeranol-implanted lambs were reported by Lane and Kemp (1990) from day 21 through day 40 of their study. Numerical improvements in ADG were reported by Sharp and Dryer (1971; 14.98%), Wiggins et al. (1976; 11.1%), and Nold et al. (1992; 6.9%), due to implanting with Zeranol. Nold et al. (1992) found increased feed conversion in implanted lambs. Sharp and Dryer (1971) and Wiggins et al. (1976) also reported 16.6% and 10.41% increased feed utilization, respectively, although the results were not statistically significant. Wilson et al. (1972b) found a 10.6% improvement in ADG across all sex-types, with wethers exhibiting the greatest enhancement at 12.5%.

Carcass Characteristics

There was no significant ($P > 0.05$) interaction between probiotic and implant status on lamb carcass variables. No significant ($P > 0.05$) difference was seen in carcass characteristics across any of the four levels of probiotic fed (Table 5). Birch et al. (1994) reported no significant difference for carcass traits (with the exception of a tendency for smaller loin eye area) in *Lactobacillus acidophilus*-supplemented wethers.

Our study indicates a significant ($P < 0.05$) increase (Table 6) in HCWT of lambs due to implanting. Wilson et al. (1972a) also found higher HCWT in Zeranol-implanted lambs across sex. In contrast, Nold et al. (1992) reported no differences in carcass weight due to implant status. In our study, IM lambs had increased ($P < 0.05$) BCTPC and deposited more ($P < 0.05$) lean tissue as evidenced by more TOTLN (6.8%) and LEGL (6.82%) than NI lambs. However, IM lambs also had a lower ($P < 0.05$) %TOTLN and %BCTPC than NI lambs. Thus it appears that IM lambs had a higher absolute amount of carcass lean and fat deposition than NI lambs and this could be due to differences in growth rate between IM and NI lambs. The IM lambs grew faster, were heavier at slaughter, had a higher HCWT and deposited more carcass lean as well as carcass fat. Implanted lambs also had a significant ($P < 0.05$) increase in quality grade. Our results are in contrast with other studies that showed no differences in carcass primal cut weights due to implanting lambs (Nold et al., 1992; Wiggins et al., 1976; Wilson 1972a,b). Nold et al. (1992) did report a significant increase in leg score due to implanting. Our study found no significant differences ($P < 0.05$) in dressing percentage, ribeye area and fat depth, which is consistent with other studies (Nold et al., 1992; Sharp and Dryer, 1971; Wiggins et al., 1976; Wilson et al., 1972a,b)

Table 1. Composition of diet.

Ingredient	% of diet dry matter
Corn silage	10.45
High-moisture corn	84.59
Soybean meal	1.21
Urea	0.23
Calcium carbonate	1.57
Dicalcium phosphate	0.26
Potassium chloride	0.77
Calcium sulfate	0.26
Trace mineral salt	0.66

Table 2. Effect of dietary yeast addition on performance of finishing lambs.

	Yeast supplement (g/day)[a]				
Item	0	0.5	1.0	1.5	SEM
ADG, kg	0.24	0.24	0.22	0.23	0.01
FI, kg/d	1.95	2.09	1.89	1.96	0.07
F:G, kg	8.16	8.71	8.58	8.52	0.36

[a] Means within rows did not differ ($P > 0.05$).

Conclusion

Feeding this specific strain of the probiotic *Saccharomyces cerevisiae* to finishing lambs with a diet based on high-moisture corn did not have a significant ($P > 0.05$) effect in performance traits and carcass characteristics in feeder lambs. However, lambs that were implanted with Zeranol had an increased ADG of 19% and a 14.4% superior F:G and had heavier carcasses with increased lean and fat deposition. Based on these results, more sheep producers should consider Zeranol implants to improve ADG and F:G of finishing lambs.

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Table 3. Effect of lamb implant status on performance of finishing lambs.

Item	Non-implanted	Implanted	SEM
ADG, kg	0.21[a]	0.25[b]	0.008
FI, kg/day	1.92	1.96	0.05
F:G, kg	9.15[a]	7.83[b]	0.25

[a,b] Means within rows not followed by common superscript differ ($P < 0.01$).

Table 4. Effect of implant over time on lamb average daily gain (ADG).

Days	Non-implanted (kg of ADG)	Implanted (kg of ADG)	SEM
0 - 14	-0.078	-0.035	0.024
14 - 28	0.249	0.238	0.020
28 - 42	0.359	0.394	0.026
42 - 56	0.263[a]	0.319[b]	0.022
56 - 69	0.271[a]	0.360[b]	0.026
0 - 69	0.211[a]	0.252[b]	0.007

[a,b] Means within rows not followed by common superscript differ ($P < 0.05$).

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Table 5. Effect of dietary yeast level on carcass traits of lambs.

	Yeast level (g/day)[a]				
Item	0	0.5	1.0	1.5	SEM
HCWT[b], kg	27.9	28.1	28.1	28.1	0.72
DP[c], %	49.2	49.4	49.9	49.2	0.37
Quality grade[d]	11.5	11.3	11.4	11.6	0.18
BCTPC[e], kg	11.8	11.9	11.9	11.9	0.32
BCTPC[e], %	42.3	42.4	42.3	42.3	0.13
PLEAN[f], %	45.5	45.5	45.4	45.5	0.20
TOTLN[g], kg	12.7	12.8	12.8	12.8	0.31
LEGL[h], kg	4.5	4.5	4.5	4.5	0.11

[a] Means within rows do not differ (P > 0.05).
[b] HCWT = hot carcass weight.
[c] DP = dressing percentage.
[d] Quality grade: 15 = Prime+, 14 = Prime°, 13 = Prime−, 12 = Choice+, 11 = Choice°, 10 = Choice−.
[e] BCTPC = boneless, closely trimmed primal cuts.
[f] PLEAN = percent carcass lean.
[g] TOTLN = kg of carcass lean.
[h] LEGL = kg of leg lean.

Table 6. Effect of implant status on carcass traits of lambs.

Item	Non-implant	Implant	SEM
HCWT[c], kg	27.07[a]	29.93[b]	0.89
DP[d], %	49.36	49.44	0 .51
Quality grade[e]	11.25[a]	11.63[b]	0.13
BCTPC[f], kg	11.49[a]	12.36[b]	0.23
BCTPC[f], %	42.46[a]	42.20[b]	0.09
PLEAN[g], kg	12.35[a]	13.19[b]	0.22
TOTLN[h], %	45.71[a]	45.27[b]	0.14
LEGL[i], kg	4.37[a]	4.69[b]	0.08

[a,b] Means within rows not followed by common superscript differ (P < 0.05).
[c] HCWT = hot carcass weight.
[d] DP = dressing percentage.
[e] Quality grade: 15 = Prime+, 14 = Prime°, 13 = Prime−, 12 = Choice+, 11 = Choice°, 10 = Choice−.
[f] BCTPC = boneless, closely trimmed primal cuts.
[g] PLEAN = percent carcass lean.
[h] TOTLN = kg of carcass lean.
[i] LEGL = kg of leg lean.

Evidence of Breed Susceptibility to Experimentally Produced Ovine Subclinical Mastitis

Angeliki R. Burriel[1,2]

Summary

The intramammary infection values and the intensity of intramammary inflammation caused by coagulase-negative staphylococci experimentally introduced into lactating mammary glands of Mule and Welsh Mountain ewes indicated the existence of breed susceptibility to subclinical mastitis. The virulence of different strains of coagulase-negative staphylococci differed between strains and breeds. The Welsh Mountain ewes resisted infection more effectively than the Mule ewes. The calculated difference in resistance supports a conclusion that there are breed differences in ability of ewes to avert subclinical mastitis.

Key words: subclinical, mastitis, resistance, coagulase-negative, staphylococci.

Introduction

The incidence of subclinical mastitis (SCM) varies from one study to another and from breed to breed (McCarthy et al., 1988; Watson et al., 1990; Watkins et al., 1991). Some workers (McCarthy et al., 1988; Watson et al., 1990) suggest that the variation among breeds is the result of differences in sheep breed susceptibility to mammary infection, but in contrast to bovine mastitis (Emanuelson, 1980), very little is known about the role of genetics in ovine mastitis.

One of the main causes of ovine SCM is coagulase-negative staphylococci (C-NS; Watkins et al., 1991; Ahmed et al., 1992). C-NS are considered to increase the milk somatic cell count (SCC) to similar values as coagulase-positive strains (Maisi et al., 1987), but are not reported from clinical cases of ovine mastitis.

Non-involvement of C-NS in clinical mastitis and their reported prevalence in SCM indicate that these organisms may be good markers for the study of breed differences associated to mastitis susceptibility. The mammary glands of ewes from two meat breeds, Mule and Welsh Mountain (WM)–each breed selected from ewes from the same farm–were inoculated with C-NS and their infection levels and intensity of intramammary inflammation were measured to identify breed differences.

Materials and Methods

Ewes and Inoculum

The udders of ten Mule and ten WM ewes were experimentally infected 12 to 14 days after lambing. The ewes and their lambs (one per ewe) were penned in groups of four (two Mule and two WM) and fed hay and concentrates ad libitum. Each group of ewes was inoculated with one of five strains of C-NS. The species of C-NS were *Staphylococcus epidermidis* (N28), *Staph. simulans* (N56) and *Staph. warneri* (N50, N145 and NH45), identified by the commercial method Staph-Zym (Rosco Laboratories, Denmark). All except strain NH45 had been isolated from milk with SCC above 10^6 per ml of milk and long duration intramammary infection (IMI). Strain NH45 had been isolated from the milking machine teat cup of the same dairy flock as strain N145.

The infective inocula were kept at –70 °C in glycerol blood broth and cultured in 110 staphylococcus selective medium (Difco, USA) for six hours at 37 °C before their use. After centrifugation, they were suspended in sterile phosphate buffer saline (PBS) at approximately 10^7 bacteria per ml. One ml of this suspension was inoculated in the right mammary of each ewe while the left mammary received 1 ml of sterile PBS.

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Milk Samples

Milk samples were collected 24 hours before and after inoculation, at three and seven days post-inoculation and once every week to the end of the experiment (49 days). In each sampling day, one milk sample was collected aseptically for the determination of bacteria counts by the method of Miles et al. (1938) and a second for determination of SCC by the Fossomatic Counter (Milk Marketing Board, Tunbridge Wells, U.K.).

Virulence of C-NS

Assuming that a virulent C-NS would cause the strongest cellular response and would remain in the udder in large numbers for a long time, a formula was devised to determine the virulence (V) of each C-NS strain infecting each ewe separately:

$$V = B + C$$

The formula takes into account the bacteria counts (B) and SCC (C) of bacteria-positive milk samples. B is the sum of each sampling day's bacteria value strength of a ewe infected with the particular C-NS and C is the sum of each sampling day's SCC value strength of the same ewe. The value of V depends on the number of sampling days that bacteria were isolated from the milk.

The bacteria value strength is 0 if no bacteria were isolated, 1 if less than 500 colony-forming units (cfu) per ml milk were counted, 2 if less than 10^3, 3 if less than 5×10^3, 4 if less than 10^4, and 5 if the cfu per ml of milk is above 10^4.

The SCC value strength is 0 for milk samples not infected, 1 if the SCC of an infected milk sample is less than 6×10^5 per ml milk, 2 if less than 2×10^6, 3 if less than 3×10^6, 4 if less than 4×10^6 and 5 if the SCC is above 4×10^6 per ml milk.

The mean V factor (MV) of each strain of C-NS infecting each breed is determined by the formula:

$$MV = V_1 + ..V_n/n$$

which is the sum of each ewe's V over the number of ewes infected with the same strain of C-NS. MV was between 0 and 90 for the present experiment. The MV is zero if C-NS were not isolated from milk after inoculation and 90 if they were present in the milk of all inoculated ewes and sampling days in numbers above 10^4 per ml of milk and contributed to SCC above 4×10^6 per ml of milk.

Statistical Method

The statistical program Instat version 1.15 (Lotus, USA) was used for the required statistical comparison. ANOVAR was used to determine the P-values.

Results and Discussion

C-NS, unlike *Staph. aureus*, are not involved in clinical mastitis. They are also weak producers of toxins (Burriel, 1994) thought to be important virulence determinants (Bramley et al., 1989). C-NS seem unable to overcome the defenses of the udder and cause severe clinical mastitis, thus they allow the study of each animal's ability to eliminate their pathogenic effects. Genetics have been found to influence the susceptibility of cows to mastitis (Emanuelson, 1988), but information about sheep is lacking.

Breed differences in IMI have been observed in epidemiological field investigations (McCarthy et al., 1988; Watson et al., 1990) and similar evidence was produced in the present experimental investigation. All WM ewes were able to eliminate IMI faster than Mule ewes and this ability affected the incidence of IMI (25.8% vs. 64.4%). C-NS were not isolated from six (60%) of the inoculated WM and three (30%) of the Mule ewes within three days from inoculation. Strain NH45 was not isolated from the milk of any of the infected ewes and strain N50 caused mild clinical mastitis with light redness of the udder and discolored "thick" milk. This strain was isolated from the milk of both breeds in large numbers (greater than 10^6 per ml) and caused a significant reduction of milk production within 14 days post-inoculation. Bacteria of the same species and morphology of strain N50 were isolated from mammary secretion of Mule ewes to the end of the experiment, but for only 28 days after inoculation from the milk of WM ewes. The remaining strains of C-NS caused various degrees of inflammation of which two (N28 and N145) were not isolated from the milk of WM ewes within a week from inoculation.

The MV of the evaluated C-NS varied between the strains and the breeds suggesting breed differences in susceptibility. Increases in the MV of a C-NS resulted in analogous statistically significant increases in breed susceptibility (Table 1). The formula adopted gives an accumulative indication of the duration and intensity of inflammation among the two breeds. The SCC threshold of milk from control and infected mammary glands and the number of infected milk samples with SCC above recommended normal thresholds (Fthenakis et al., 1991; Burriel, 1997) further supports the existence of breed differences (Table 2). The SCC of normal milk was similar for both breeds and both breeds responded to the invasion of bacteria with a raise in SCC. However, proportionally more milk samples from WM ewes infected with C-NS were above both the recommended thresholds. A stronger cellular response could have been

Table 1. Mean virulence (MV) of each C-NS strain affecting each breed of ewes and its statistical significance (P)

Breed	NH45	N28 P = 0.1	N145 P = 0.02	N56 P = 0.04	N50 P = 0.009
MV of Mule	0	13.5	35.0	39.5	86.0
MV of WM	0	3.5	3.5	21.5	39.5

contributing to the faster elimination of C-NS from the mammary glands of WM ewes.

A normal SCC threshold of 10^6 per ml milk as determined with the Coulter Counter (Lower Wick, Worcester, U.K.) has been recommended for meat breed ewes (Fthenakis et al., 1991). At this threshold, fewer control milk samples will be detected as false-positives, but also fewer bacteria-positive milk samples will be detected as cases. The SCC determined by the Coulter Counter is influenced by the presence of cytoplasmic bodies as compared to the Fossomatic Counter (Burriel, 1994), thus a lower normal SCC threshold has been adopted (Burriel, 1997). The present findings indicated that the threshold of 6×10^5 per ml milk increases the sensitivity, based on Fossomatic Counter-derived data, with only a 4.2% increase in the number of false-positive samples.

The SCC of control milk from each breed indicate that normal thresholds of SCC from milk samples of meat breed ewes is not significantly influenced by the breed ($P = 0.2$) and is similar to that of dairy breeds (Heredia and Inurritza, 1988; Burriel, 1997) or goats (Kalogridou-Vassiliadou et al., 1991). A universally-applicable normal SCC threshold could be adopted for all small ruminants when the SCC is determined by the Fossomatic Counter.

Conclusions

Breed differences in the incidence of experimentally-produced SCM were observed between Mule and Welsh Mountain ewes. The two breeds significantly differed in their susceptibility to virulent C-NS and the proportion of milk samples with SCC above the recommended thresholds, but they did not differ in their normal SCC.

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Table 2. Number of milk samples above recommended normal SCC thresholds with number of milk samples above the mean in parenthesis.

Milk status	NS	MSCC[a] $\times 10^5$	NS[b] $> 6 \times 10^5$	NS[b] $> 10^6$
Mule breed:				
Control	74	2.4 (16)	7	3
Infected	38	44.5 (31)	28	26
B(-)[c]	21	21.6 (8)	8	8
WM breed:				
Control	75	2.0 (1)	6	2
Infected	16	47.3 (12)	15	14
B(-)[c]	46	13.0 (5)	16	12

[a] MSCC = mean somatic cell count.
[b] NS = number of milk samples.
[c] B(-) = milk samples from experimentally infected mammary halves that were bacteria-free at collection.

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The Impact of Foot Rot on Pre-weaned Lambs and Efficacy of a Fusobacterium Vaccine[1]

R.D. McCoy[2], D.E. Hansen[3] and J.M. Thompson[4]

Summary

This is a summary of two separate trials conducted in 1994 and 1995. The flock selected was closed and had a history of severe foot rot. The trials were initiated to evaluate the impact of foot rot in lambs and to determine the efficacy of a commercial vaccine against foot rot disease in nursing lambs on pasture.

In trial one, lambs were vaccinated between 65 and 80 days of age. Lambs that developed foot rot averaged 7.1 pounds less than their infection-free counterparts ($P < 0.05$). At the end of that trial, no significant differences were detected between or within treatment groups of singles and twins or of vaccinates and non-vaccinates in mean foot scores, new-disease rates or cure rates.

In trial two, twin lambs of infected mothers were three times more likely to develop foot rot than twin lambs nursing non-infected dams ($P < 0.01$). Single lambs were 1.8 times at increased risk of foot rot from their infected dams ($P < 0.10$). Non-vaccinated lambs had a 20.1% incidence of foot rot while vaccinated lambs had a 10.5% incidence when vaccine was administered at 4 and 21 days of age ($P = 0.024$).

This study documented mean weight gain differences in pre-weaned lambs with foot rot and their foot rot-free flock mates. It also demonstrated that twin lambs nursing foot rot-affected dams were at the highest risk for developing foot rot themselves. Vaccination of lambs at an early age appeared to be protective without producing obvious side effects.

Key **words:** lambs, foot, rot, vaccine, risk.

Introduction

Foot rot is a highly contagious disease of sheep, caused by a synergistic infection of two bacteria, *Fusobacterium necrophorum* followed by *Dichelobacter nodosus*, formerly called *Bacteroides nodosus* (Beveridge, 1941; Bailey et al., 1985; East, 1996). The weather in western Oregon is ideal for successful infections. Western Oregon has an average rain fall of 40 inches, mean daily temperature 70 °F and mean daily humidity levels of 40%, which fits within the moisture, weather and temperature parameters for foot rot (Cross, 1978a; Graham et al., 1968). Contagious foot rot may cause reduced weight gain and lowered wool production, and animals are more susceptible to fly strike and predation (Hansen, 1994; Marshall et al., 1991; Wardhaugh et al., 1989; Salman et al., 1988; Carmody et al., 1984; Hunt, 1958). Many foot rot-affected lambs appear to lose weight and are observed grazing on their knees or lying down when other lambs are grazing. There were few published reports of the effect of foot rot on pre-weaning lamb growth. Hunt (1958) and Littlejohn (1964) detected a lower growth rate in foot rot-affected weaned lambs. There have been few economic studies that determine the loss due to foot rot in lambs. Economic studies evaluated the quality and quantity of wool loss due to foot rot in mature sheep (Marshall et al., 1991; Carmody et al., 1984). The incidence and impact on production of foot rot in nursing lambs is not well described in the literature.

Foot rot is a serious drain on the health status of the sheep flock and

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control strategies have a high labor requirement. Workers have researched treatments and management procedures for decades (Cross, 1978b; Glenn et al., 1985; Bulgin et al., 1986; Bagley et al., 1987; Thompson et al., 1995). Sound management programs have been developed over time to eradicate foot rot from a flock (Beveridge, 1941; Bailey et al., 1985; East, 1996). Researchers have shown efficacy for various antimicrobial products used to treat foot rot (Salman et al., 1988; Grogono et al., 1994).

Recent development of vaccines against foot rot have added other tools to control foot rot (Glenn et al., 1985; Lewis et al., 1989; Berg, 1990; Thompson et al., 1995). Currently, there are two types of foot rot vaccines marketed in the United States. One contains *Dichelobacter nodosus* serotype antigens and the other contains a *Fusobacterium necophorum* antigen. Both vaccines have been reported as being effective against foot rot in adult sheep (Glenn et al., 1985; Bulgin et al., 1985; Bagley et al., 1987; Lewis et al., 1989; Thompson et al., 1995).

It is widely held that for complete control and eradication of foot rot in a flock the following components are essential: proper hoof trimming, appropriate foot bathing and/or foot treatment, and culling chronically infected sheep. Vaccination may add additional protection under some conditions (Bagley et al., 1987; East, 1996).

The objective of these trials was to evaluate the efficacy of a *Fusobacterium necophorum* vaccine ("Volar," a commercial vaccine produced by Bayer, Inc.) against infectious foot rot in pre-weaned lambs. Previous trials have reported efficacy in adult sheep but none have been reported for pre-weaned lambs. Secondly, investigators wanted to document the risk for and the impact of foot rot infections on pre-weaned lambs. These trials are the first published report demonstrating the efficacy of a *Fusobacterium necophorum* vaccine in pre-weaned lambs.

Materials and Methods

Trial Lambs

A commercial flock of 500 Dorset and Dorset × Suffolk cross ewes and their lambs were utilized in these trials to evaluate the efficacy of the vaccine against a field challenge of foot rot in pre-weaned lambs. The trials started in the spring during the foot rot challenge period of warm, wet weather. Ewes were not vaccinated and the lambs were assigned randomly to either a non-vaccinated (control) or a vaccinated (treated) group. Once assignments had been completed records identifying lambs by their group were kept from the flock owners and members of the evaluation team until each trial ended. This was done to safeguard against possible bias during data collection.

Trial One, 1994

Five hundred and forty-two lambs, between the age of 65 and 80 days, were identified with numbered ear tags and randomly assigned to groups of equal size (n = 271). One group was vaccinated and the other served as non-vaccinated controls. The vaccinated group was re-vaccinated 21 days after the first injection.

Weights. One of the major objectives of the trial was to measure the efficacy of complete vaccination in pre-weaned lambs. Reports on the efficacy of this vaccine on ewes and feeder lambs found no differences in infection or cure rates among vaccinates and non-vaccinates during the 21 to 30 day time period between the initial and booster dose of vaccine (Armstrong, 1994). Because the lambs were already showing signs of foot rot before the initial vaccine dose was given, it was decided to weigh the lambs on the second injection date relying on the predicted anemestic response to enhance the immune reaction and offer some protection. Final lamb weights were taken at the end of the trial for comparisons. Weight gains were calculated for each lamb as the weight difference between initial and final weights. The mean weight gains from individual lambs in each group were then calculated and used for comparison between groups.

Foot Scoring. All lambs' feet were scored at the beginning of the trial, at 21 days and again at the end of the trial. At the time of foot evaluation, lambs' feet were scored by the following criteria: 0 = no foot rot or scald; 1 = initial scald lesion of the inter-digital skin between the toes and the heel; 2 = advanced lesion with some undermining of the sole of one of the hooves; and 3 = undermining of the sole with a foul smelling exudate of one or both toes. Foot score values for all four feet were combined resulting in a single score for that lamb. The individual scores were utilized to determine foot rot status and effectiveness of the vaccine.

Management. Lambs and ewes received minimal foot trimming. Only severely lame animals were examined and foot-trimmed. All animals were foot-bathed at three-week intervals, using a 10% formaldehyde solution. All lambs remained with their dams and were pastured and managed the same. None of the lambs or ewes received extra supplemental zinc.

Comparisons. Divergences between vaccinates and non-vaccinates were compared analyzing differences in foot scores, disease rates, cure rates and average daily gains of the lambs. Comparisons were also made between single and twin lambs and between purebred and crossbred lambs within and among groups.

Trial Two, 1995.

The same flock was used; however, the first dose of vaccine was given to lambs at four days of age. The second dose was given to groups of vaccinated lambs as they reached three to four weeks of age. All single lambs were vaccinated, remained with their dams and were kept separate from the twin lambs and their dams throughout the trial. The 288 twin lambs used for this trial were identified sequentially with numbered ear tags at four days of age. Every odd-numbered lamb was vaccinated while even-numbered lambs served as non-vaccinated controls. Vaccinated lambs were given a second dose as they reached three to four weeks of age.

Foot Scoring. All ewes' feet were scored for foot rot as described for

lambs in trial one. Due to the high risk potential of injury to very young lambs as the flock was moved from pasture and into the corrals and chute system, investigators delayed foot scoring ewes until approximately 50 days after the trial began. The ambient daily temperatures had ranged between 25 °F and 40 °F during the 50-day period. Soil temperatures were still below 40 °F at the time ewes were examined. The possibility for active foot rot transmission in the flock was remote during this time period (Cross, 1978a; Graham et al., 1968). All ewes were identified by ear tag number and matched to their lambs for analysis at the end of the trial. Both ewes and lambs were foot-scored at the end of the trial. In addition, records were kept of those lambs treated for foot rot during the trial for comparison with foot-score data.

Score values for all four feet of each sheep were combined resulting in a single score for the ewe or lamb. The individual scores were utilized to determine foot rot status and effectiveness of the vaccine. All lambs with a foot score greater than zero were considered as vaccine failures and positive for foot rot. Ewes and lambs were evaluated to determine contamination rates from dam to lamb. The mean scores were utilized to compare groups at the end of the trial.

Management. This trial included 100 days of the challenge period of warm, wet spring days. Lambs were from 30 to 60 days old before the challenge period began. Ewes were not vaccinated. As in trial one, only affected lambs and ewes received foot trimming. Ewes and lambs were dewormed and put through a 10% formaldehyde foot bath every three weeks. Ewes with single lambs were kept and managed separately from the ewes with twin lambs. Lambs remained with their dams and in a pasture rotation system throughout this trial. None of the lambs or ewes received extra supplemental zinc.

Comparisons. Divergences between vaccinates and non-vaccinates were compared analyzing differences in foot scores, disease rates, cure rates and average daily gains of the twin lambs only. An analysis of risk from exposure to foot rot-affected dams was calculated for both single and twin lamb groups.

Statistical Analysis. Comparisons were made between vaccinated and non-vaccinated lambs for significant differences. Mean foot scores and mean weight gains within and between groups were compared using ANOVA, t-tests and finally, 95% confidence intervals calculated around the means. Differences in infection rates were compared using appropriate Chi-square statistics (Kleinbaum et al., 1982; Fienberg, 1983). P-values are reported. Relative risks and attributable fractions were also calculated for each group as described elsewhere (Kleinbaum et al., 1982). Attributable fractions were used to determine vaccine efficacy as described elsewhere (Martin et al., 1987).

Results and Discussion

Trial One.

Statistical comparisons were made within and between treatment groups. At the start of the trial 23% of the vaccinated lambs and 24% of the non-vaccinated lambs were affected with foot rot ($P = 0.62$). Daily temperatures had ranged between 45 °F and 60 °F in the week preceding the trial. Soil temperatures had exceeded 50 °F as evidenced by excellent grass growth. At the end of the trial, no significant differences were detected between or within treatment groups of singles and twins or of vaccinates and non-vaccinates in mean foot scores, new disease rates or cure rates ($P > 0.30$). The vaccine efficacy was rated below 45% in this trial (Table 1).

Mean beginning and ending weights were significantly different for single versus twin lambs (63.5 and 88.0 vs. 55.7 and 79.1 pounds, respectively; $P < 0.05$). The mean weight gains for the 80-day period for singles and twins were nearly equal (24.5 and 23.8 pounds; $P > 0.40$). There were no mean weight differences detected in comparisons between or among treatment groups (Table 2).

However, when comparing foot rot-affected lamb gains with non-affected lamb gains, there were significant differences between means of the two groups (18.2 vs. 25.3 pounds, respectively; $P < 0.05$). The average difference was 7.1 pounds less per case of foot rot (Table 2). Breed of the lamb was not a determinant for any of the divergence detected in trial one. Data analysis not shown but available upon request.

Trial Two.

Thirty three percent of the ewes with twin lambs exhibited signs of foot rot at the beginning of the trial versus 29.6% of ewes with single lambs ($P = 0.25$). During the trial, non-vacci-

Table 1. Mean foot scores, new infection rates, cure rates and P-values for specific treatment groups in trial 1.

Group	N	Mean foot score	P-value	New infection rate	P	Cure rate	P-value
Treated[a]	270	1.46	> 0.10	0.10	> 0.30	0.67	> 0.30
Control[b]	272	1.60		0.13		0.73	
Single	248	1.53	> 0.10	0.12	> 0.30	0.64	> 0.30
Twin	294	1.74		0.15		0.72	

[a] Treated = vaccinated lambs.
[b] Control = non-vaccinated lambs.

nated twin lambs experienced a 21.5% incidence of foot rot. Vaccinated twin lambs, by comparison, experienced a 10.6% incidence of foot rot. The difference was significant (P = 0.025). The efficacy of the vaccine was rated at 57% for this trial (Table 3).

In this trial, non-vaccinated twin lambs born to infected ewes were 3.6 times more likely to develop foot rot lesions than their non-vaccinated twin flock-mates born to non-infected dams (P = 0.006). Vaccinated twin lambs born to infected ewes were 2.8 times more likely to develop foot rot lesions than their vaccinated twin flock-mates born to non-infected dams (P = 0.025). By comparison, vaccinated single lambs born in the same season but managed separately, whose dams were foot rot infected were 1.8 times more likely to become infected than vaccinated single lambs of non-infected ewes (P = 0.10). Data analysis for all lambs demonstrated that lambs born to foot rot-affected ewes were 2.3 times more likely to develop foot rot than lambs born to foot rot-free ewes irrespective of vaccine status (P = 0.001; Table 3).

Discussion

Becoming infected with foot rot is a function of susceptibility, exposure and the correct environmental conditions. In these trials lambs were susceptible, environmental conditions for foot rot infections were optimal and the infected ewes probably served as an immediate source of exposure for the lambs.

There were no label guidelines for using this commercial vaccine on nursing lambs. Previous trials with the vaccine used weaned lambs or mature ewes for data collection. There were no data to show the margin of safety for vaccinating nursing lambs. Principles of disease prevention through vaccination would dictate that vaccines need to be administered before a disease exposure is present. However, experience with another commercial vaccine product (against *B. nodosus*) had shown a number of adverse reactions in lambs vaccinated when less than 45 days of age (Bulgin

Table 2. Mean beginning and ending weights and mean weight gains for trial 1. Standard deviations are in parentheses.

Group	N	Mean beginning weight		Mean ending weight		Mean weight gain	
Treated[a]	270	59.4	(11.2)	83.7	(12.7)	23.9	(9.2)
Control[b]	272	59.5	(11.3)	83.4	(13.0)	24.1	(8.1)
Single	248	63.5	(12.8)[c]	88.0	(11.6)[c]	24.2	(13.7)
Twin	294	55.7	(10.8)[d]	79.1	(12.1)[d]	23.8	(8.9)
Foot rot negative	354	59.2	(10.9)	84.3	(11.9)	25.3	(7.3)[c]
Foot rot positive	188	59.9	(11.4)	82.1	(12.7)	18.2	(9.7)[d]

[a] Treated = vaccinated.
[b] Control = non-vaccinated.
[c] Indicates a significant difference at the 0.05 level between that value and all others in the column.
[d] Indicates a significant difference at the 0.05 level between that value and all others in the column.

Table 3. Treatment groups, percent foot rot, relative risk and P-values for lambs only in trial 2.

Treatment group[a]	% Foot rot	Relative risk	P-value
Twin, non-vaccinated	21.5	2.3	0.024
Twin, vaccinated	10.6		
Twin, vaccinated, foot rot positive	18.6	2.8	0.025
Twin, vaccinated, foot rot negative	6.7		
Twin, non-vaccinated, foot rot positive	34.6	3.6	0.006
Twin, non-vaccinated, foot rot negative	12.8		
Single, vaccinated, foot rot positive[b]	18.3	1.8	0.10
Single, vaccinated, foot rot negative[b]	10.9		
All lambs, vaccinated, foot rot positive	26.2	2.3	0.001
All lambs, vaccinated, foot rot negative	10.5		

[a] Vaccination status of lambs, foot rot status of ewe.
[b] Data from single lambs and their dams. Shown for comparison only.

et al., 1985; Hansen, 1994). Reactions had included injection site soreness, sterile abscess formation and some general malaise in vaccinated groups of young lambs.

For these reasons, investigators choose a time when most lambs would be at least 60 days old to begin the first trial. Since they did not have other indications from the manufacturer, it was decided to utilize the same dosage as for mature sheep. Postponing vaccination of the lambs allowed optimal environmental conditions (warm, moist soil and grass) required for the foot rot infection to develop. Therefore, it was no surprise that 24% of the trial lambs had foot rot before they were completely vaccinated.

In trial 1, data analysis failed to detect a significant difference in foot rot incidence or weight gains between vaccinated and non-vaccinated lambs. However, analysis documented a continuum of weight difference between single and twin lambs throughout their growth period. Mean twin-lamb weights were significantly lower than mean single-lamb weights. The 8 to 9 pound difference was maintained throughout the trial. It was interesting to note the mean weight gains for single and twin lambs were nearly equal.

However, there was a significant difference in mean weight gains between affected and non-affected lambs. Mean weight gain for foot rot free lambs was 25.3 pounds versus 18.2 pounds for affected lambs. While others have reported weight differences in foot rot affected lambs (Hunt, 1958; Littlejohn, 1964), this is the first published report of a weight loss (or a failure to gain) associated with foot rot disease during the pre-weaning growth period. Hunt (1958) reported a 5.5 pound weight difference between foot rot infected and foot rot free lambs during an eight-week feeding period in weaned lambs. Littlejohn (1964) reported a slight compensatory gain in weaned lambs cured of foot rot compared to foot rot-free lambs.

Even though the vaccine did not appear to provide protection in trial 1, the investigators determined several important factors which lead to repeating the trial utilizing younger lambs. They did not observe adverse reactions to the vaccine such as malaise or an abscess at the injection site. The relatively high foot rot prevalence in both groups at the beginning of trial 1 pointed to the possibility that lambs needed protection earlier in the season.

Therefore, in trial 2, lambs were vaccinated at 4 days of age, and again between 21 and 28 days of age, hopefully before they were exposed to the disease. All singles were managed separately until the end of the trial. Thirty-three percent of the twin-lambs' dams were affected at the start of the trial, serving as an immediate source of exposure to the trial lambs. Non-vaccinated twin lambs had a 21.5% incidence of foot rot while vaccinated twin lambs only experienced a 10.6% foot rot incidence. Non-vaccinated twin lambs were 2.8 times more likely to experience foot rot disease than vaccinated flock mates.

In the second trial, it was documented for the first time that a lamb born to a ewe with foot rot was 2.3 times more likely to develop foot rot than a lamb born to a foot rot-free ewe irrespective of vaccination status. Another first was the increased risk of foot rot for twin lambs. Non-vaccinated twin lambs were at the highest risk with a relative risk of 3.6. Vaccinated twin lambs born to foot rot-positive ewes were 2.8 times more likely to become affected by foot rot than their vaccinated flock-mates, while vaccinated single lambs born to affected dams were 1.8 times more likely to develop foot rot. Producers could use this information to institute management changes which provide extra precautions for twin lamb groups.

Readers should note that even though vaccination at an earlier age appeared to give greater protection against foot rot in the second trial, the differences in the vaccine efficacy reported for each of these trials could have occurred because of factors involved in the dynamics of infection. Even though the ambient and soil temperatures were very similar for each trial, and the management did not change, there could have been enough dissimilarity between the disease determinants to effect the dynamics of pathogen development and spread differently from one year to the next. Finally, it should be noted that the use of formaldehyde as a foot bath has been reported to be only 45% to 50% effective in preventing foot rot.

Conclusions

In summary, there are a number of factors which should be considered when developing a plan for prevention or control of foot rot infection:

1. Twin lambs are at significantly higher risk for foot rot when their dams are affected.
2. Loss in weight gain from infection could be a serious economic drain on profit.
3. One needs to consider culling infected ewes following a management regime of foot trimming and bathing. If culling is not done immediately, then infection-free ewes and lambs should be segregated from the rest of the flock until all infected ewes can be culled. When living in an environment predisposing foot rot with sheep which are susceptible, the disease carriers must be removed.
4. At times, foot trimming and bathing may not be sufficient to prevent infection.
5. Vaccination, while providing some level of protection in its own right, may provide additional protection when combined with foot trimming and bathing.

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The Influence of Lamb Chronological Age, Slaughter Weight, and Gender on Carcass Composition[1,2]

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Summary

Lambs (N = 1,660) representative of the Canadian population of market lambs were slaughtered and separated into wholesale cuts, which were subsequently physically separated into lean, fat and bone. In addition, the total carcass lean was chemically analyzed for moisture, protein and fat. Trends observed in carcass lean content with advancing age indicate that if rams and wethers are to be marketed at light weights they should come from large late-maturing breed types and be marketed at young ages. Also, if ram lambs are to be marketed at heavy weights, they should receive a low plane of nutrition and be marketed at older ages. Negative trends in carcass lean content with increasing liveweight clearly represent an obstacle to the production and marketing of young, heavyweight lambs to increase production efficiency. Results further substantiate rams produce leaner carcasses than wethers which in turn produce leaner carcasses than ewes. Consequently the composite results, from a carcass composition perspective, indicate that lambs should be marketed at lighter weights and younger ages, which is consistent with consumer desires for a leaner product, but which may not be consistent with the economics associated with efficient lamb production.

Key words: lamb, carcass composition, chronological age, slaughter weight, gender.

Introduction

Carpenter (1966) expressed the need for definitive research to provide guidelines to optimize the balance between lamb carcass weight, quantitative yield of retail cuts and meat quality. In this regard it is evident that fatness and muscling of lamb carcasses differ a great deal due to differences in age, breed, carcass weight, gender and management (Carpenter, 1966). Many studies have evaluated the influence of factors such as age, weight, breed, gender and diet on carcass composition (Burton and Reid, 1969; Wood et al., 1980). These studies have tended only to evaluate one or two factors in isolation. To date, there has been no comprehensive study completed to examine the influence of these inherent traits on the carcass composition of a sample representative of the Canadian population of market lambs. The present study was designed to provide such an evaluation of the influences of chronological age, slaughter weight and gender on carcass composition.

Materials and Methods

A total of 1,660 commercial lambs were selected on the basis of age, slaughter weight, gender and fatness to fill specific subclasses in an experimental design grid (Table 1). The lambs evaluated were a representative sample of the entire range of lambs currently being marketed in Canada, rather than a set of animals of controlled breeding and dietary management, slaughtered at different weights and/or ages. The lambs in the present study were purchased from commercial sheep producers with breeding records and certified birth dates for the lambs purchased, so that both the breeding and chronological ages could be ascertained. The lambs were predominantly crossbreeds, involving some combination of the following breeds: Cheviot, Columbia, Dorset, Finnish/Landrace, Hampshire, Leicester, Montadale, Rambouillet, Romanoff, Romney,

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Shropshire, Southdown, Suffolk, Targhee or Texel. Breeds and breed crosses were allocated as evenly as possible among age/weight/gender subclasses and care was taken to prevent a given breed or breed-cross from constituting a majority in any given age/weight/gender subclass.

Fatness and gender were ascertained the day prior to slaughter. Fatness was ascertained both subjectively by a trained and experienced evaluator and ultrasonically. The same fatness criteria were applied to all age/slaughter weight/gender subclasses. Breed composition necessarily varied among age/slaughter weight subclasses, but was relatively constant within subclasses. Since the lambs were purchased from different producers, it is possible they were fed differently and it is possible this may have influenced compositional properties. The actual frequency distribution of lambs evaluated is presented in Table 1, by age, weight, gender and fatness subclass.

All lambs were slaughtered at the Lacombe Meat Research Center under simulated commercial conditions. Warm carcasses were weighed and chilled for 24 hours at 1 °C (±1 °C). After chilling, the left side of each carcass was weighed and divided into wholesale cuts (leg, loin, rack, shoulder, flank, breast, shank). All cuts were then weighed. The leg, loin, rack, shoulder, breast and flank were physically dissected into the following components: subcutaneous fat, intermuscular fat, lean and bone; and these components were weighed. The shank was physically separated into bone, lean and intermuscular fat and the components were weighed. The lean from all cuts was then pooled, ground twice through a 3-mm plate and subsampled for determination of moisture, fat and protein, using procedures previously described (Murray et al., 1989).

Data were analyzed using the general linear model (GLM) procedures of SAS (Statistical Analysis Systems Institute, 1985). Sources of variation were: age, slaughter weight, gender and the two-way and three-way interactions. Mean separation of significant main effects was by single degree of freedom linear contrast. Linear regression was used to detect significant trends with advancing age and increasing slaughter weight (Puri and Mullen, 1980).

Results and Discussion

A summary of the analyses of variance is presented in Table 2. Significance ($P < 0.05$) was observed in some of the main effects and two- and three-way interactions.

Table 1. Frequency of lambs by gender and age, fatness and weight group.

		Weight Group															
		1 (32-40 kg)			2 (41-49 kg)			3 (50-58 kg)			4 (59-67 kg)			5 (68-88 kg)			
		Gender[a]															
Age Group	Fatness Group	r	e	w	r	e	w	r	e	w	r	e	w	r	e	w	All
1	1 (lean)	12	12	15	15	13	14	15	14	12	13	12	12	0	0	0	159
(3-6 mo)	2 (inter)	12	13	12	13	13	12	17	22	12	21	12	12	2	0	0	173
	3 (fat)	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	2
	All	24	25	27	28	26	26	33	36	24	35	24	24	2	0	0	334
2	1 (lean)	1	0	0	15	14	21	14	12	18	13	14	15	12	12	12	173
(6-9 mo)	2 (inter)	1	1	0	12	17	15	17	5	19	14	13	14	12	12	12	174
	3 (fat)	0	0	0	12	14	12	14	14	13	14	15	13	12	12	12	157
	All	2	1	0	39	45	48	45	41	50	41	42	42	36	36	36	504
3	1 (lean)	2	0	1	12	12	12	16	16	16	13	12	12	12	12	12	160
(9-12 mo)	2 (inter)	0	0	0	13	14	14	14	16	14	17	13	13	12	12	13	165
	3 (fat)	0	0	0	12	12	12	14	12	14	13	13	14	12	12	13	153
	All	2	0	1	37	38	38	44	44	44	43	38	39	36	36	38	478
4	1 (lean)	0	1	0	0	1	1	12	12	12	12	12	12	12	13	13	113
(12-15 mo)	2 (inter)	0	0	0	1	1	1	11	11	12	12	12	14	12	14	18	119
	3 (fat)	0	0	0	0	1	0	12	12	12	12	12	12	12	12	15	112
	All	0	1	0	1	3	2	35	35	36	36	36	38	36	39	46	344
All	1 (lean)	15	13	16	42	40	48	57	54	58	51	50	51	36	37	37	605
	2 (inter)	13	14	12	39	45	42	59	64	57	64	50	53	38	38	43	631
	3 (fat)	0	0	0	24	27	24	41	38	39	40	40	39	36	36	40	424
	All	28	27	28	105	112	114	157	156	154	155	140	143	110	111	120	1660

[a] r = ram, e = ewe and w = wether.

Carcasses from ram lambs had a higher proportion ($P < 0.05$) of lean than their counterparts from ewe lambs when they were in age group 1 and weight group 2; age group 3 and weight groups 2, 3 and 4; and age group 4 and weight groups 4 and 5 (Table 3). Ram lambs also had a higher proportion ($P < 0.05$) of carcass lean than their counterparts from wether lambs when they were age group 1 and weight groups 2 and 3; age group 3 and weight groups 3 and 4; and age group 4 and weight groups 3, 4 and 5. Carcasses from wether lambs had a higher proportion of lean than their counterparts from ewe lambs when they were in age group 3 and weight groups 2, 3 and 4; and age group 4 and weight group 4. In data not presented in tabular form, significant negative trends in percent carcass lean with increasing liveweight were detected in rams in age group 1 ($r^2 = 0.67$, $P < 0.05$), ewes in age groups 1 and 2 ($r^2 = 0.98$, $P < 0.01$ and $r^2 = 0.74$, $P < 0.05$, respectively), and wethers in age group 2 ($r^2 = 0.85$, $P < 0.05$), which is in agreement with the previous report of Notter et al. (1983) and Thompson et al. (1979). Significant negative trends were also observed in the proportion of carcass lean with increasing age in rams in weight group 2 ($r^2 = 0.96$, $P < 0.01$). However, significant positive trends in the proportion of carcass lean with increasing age were detected in rams in weight groups 4 and 5 ($r^2 = 0.90$, $P < 0.01$; $r^2 = 0.72$, $P < 0.05$, respectively). These findings are in agreement with numerous reports indicating ram lambs are generally the leanest and ewe lambs are generally the fattest of the three gender classes (rams, ewes, wethers) of lambs (Andrews and Orskov, 1970; Butler-Hogg et al., 1984; Carpenter et al., 1969; Chrystall and Winger, 1986; Kemp et al., 1962; Lewezuk et al., 1980; Purchas, 1978; Walker, 1950; Wise, 1978).

The significant negative trends in carcass lean content detected with increasing liveweight in young lambs three to nine months of age (in data not shown in tabular form) suggest attempting to force young lambs to heavy weights at young ages results in lower proportions of lean in the carcass. These trends potentially represent an obstacle to the production of young heavyweight lambs. The significant negative trends in carcass lean content with advancing age in lightweight rams and wethers (in data not shown in tabular form) suggest that, if rams and wethers are to be marketed at light weights they should be marketed at young ages. In addition, the significant positive trends in carcass lean proportion (in data not shown in tabular form) with advancing age in heavyweight rams (more than 58.9 kg) clearly demonstrates the proportion of carcass lean is greater in older animals suggesting that, from a carcass composition perspective, if rams are to be marketed as heavyweights they should receive a lower plane of nutrition and be carried to older ages. These results are in general agreement with previously reported results of the effects of nutrition on body composition (Andrews and Orskov, 1970) and the effects of age (Riley et al., 1972) and slaughter weight (Steele and Hohenboken, 1972; Vesely and Peters, 1972) on carcass composition.

Rams had a higher proportion ($P < 0.05$) of carcass bone than their ewe counterparts, when they were in age group 1 and weight groups 2 and 3; age group 3 and weight groups 2, 3 and 4; and age group 4 and weight groups 4 and 5 (Table 3). They also had a higher proportion of carcass bone ($P < 0.05$) than their wether counterparts when they were in age group 1 and weight group 3; age group 2 and weight group 4; age group 3 and weight groups 2 and 3; and age group 4 and weight groups 4 and 5. Wethers also had a higher proportion of carcass bone than their ewe counterparts when they were in age group 3 and weight groups 3 and 4, which supports the previous observation of Thompson et al. (1979). Significant negative trends in the proportion of carcass bone with increasing liveweight were observed for rams in age group 1 ($r^2 = 0.94$, $P < 0.01$), ewes in age groups 1 ($r^2 = 0.94$, $P < 0.01$) and 2 ($r^2 = 0.66$, $P < 0.05$), and wethers in age groups 1 ($r^2 = 0.79$, $P < 0.05$), 2 ($r^2 = 0.96$, $P < 0.01$) and 4 ($r^2 = 0.79$, $P < 0.05$) which supports the previous observations of Thompson et al. (1979). Significant negative trends (in data not presented in tabular form) in the

Table 2. Summary of the probability estimates from the analyses of variance for carcass compositional data.

Trait	Gender (G)	Age (A)	Weight (W)	G×A	G×W	A×W	G×A×W	RMSE
Carcass tissues, g/100g^{-1}:								
Lean	0.0001	0.0152	0.0001	0.0001	0.0085	0.0006	0.0145	19.1393
Bone	0.0001	0.0001	0.0748	0.0113	0.7511	0.0251	0.0001	6.0743
Fat	0.0001	0.0013	0.0001	0.0001	0.0301	0.0009	0.0035	36.8130
Subcutaneous fat	0.0001	0.6480	0.0043	0.0001	0.0014	0.0020	0.0064	9.3493
Intermuscular fat	0.0001	0.0001	0.0001	0.0001	0.2458	0.0001	0.0005	8.8587
Body cavity fat	0.0004	0.2654	0.4108	0.0160	0.0315	0.0001	0.1931	0.3781
Chemical components, g/100g^{-1}:								
Moisture	0.0006	0.2289	0.3275	0.0205	0.0786	0.0109	0.3329	2.0034
Protein	0.5962	0.5866	0.0062	0.6834	0.0820	0.5511	0.1388	1.4734
Fat (dry matter)	0.0001	0.1431	0.6179	0.0124	0.3165	0.0001	0.4472	4.9155
Fat (wet weight)	0.0001	0.1753	0.5460	0.0084	0.2346	0.0001	0.3989	1.8306

proportion of carcass bone with advancing age were also detected for rams in weight group 2 ($r^2 = 0.86$, $P < 0.05$), and ewes in weight groups 1 ($r^2 = 0.98$, $P < 0.01$), 2 ($r^2 = 0.98$, $P < 0.01$), 4 ($r^2 = 0.81$, $P < 0.05$) and 5 ($r^2 = 0.92$, $P < 0.05$).

Because the proportion of bone in the carcass is usually inversely related to the fat content in sheep of the same genotype, age, gender and weight, rams generally had the highest proportion and ewes the lowest proportion of carcass bone. The significant negative trends in the proportion of carcass bone with increasing liveweight would also be expected, since bone increases in mass more slowly than the other carcass tissues (lean and fat). The significant negative trends in the proportion of carcass bone in lightweight lambs with advancing age reflects the fact that older lambs marketed at lightweights are proportionately fatter than their

Table 3. Least squares means and standard errors for the proportions of carcass lean, bone and fat in carcasses within various age/liveweight/gender subclasses.

		Liveweight Group									
		1 (31.8 to 40.4 kg)		2 (40.5 to 49.5 kg)		3 (50.0 to 58.6 kg)		4 (58.9 to 67.7 kg)		5 (68.2 to 76.8 kg)	
Age Group	Gender	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
						Carcass Lean, g/100g^{-1}					
1 (3-6 months)	Ram	59.49	0.93	58.27^{a}	0.86	56.25^{a}	0.77	53.35	0.74	47.30	3.09
	Ewe	59.04	0.93	54.68^{b}	0.87	52.51^{b}	0.74	52.33	0.89	–	–
	Wether	57.95	0.86	55.82^{b}	0.87	52.15^{b}	0.89	53.90	0.89	–	–
2 (6-9 months)	Ram	–	–	56.33	0.73	55.94	0.68	53.87	0.70	52.49	0.74
	Ewe	56.92	4.37	56.23	0.68	54.83	0.69	52.61	0.71	53.29	0.76
	Wether	–	–	56.44	0.63	55.25	0.62	54.35	0.68	53.11	0.71
3 (9-12 months)	Ram	50.22	3.09	55.39^{a}	0.72	57.68^{a}	0.67	55.47^{a}	0.67	52.63	0.74
	Ewe	–	–	52.08^{b}	0.71	50.53^{c}	0.66	50.81^{c}	0.72	52.31	0.74
	Wether	51.50	4.37	55.30^{a}	0.71	53.93^{b}	0.67	52.98^{b}	0.70	53.11	0.71
4 (12-15 months)	Ram	–	–	55.02	4.37	56.04^{a}	0.77	55.71^{a}	0.75	55.36^{a}	0.74
	Ewe	46.28	4.37	53.25	3.09	53.99^{ab}	0.75	50.60^{c}	0.77	50.70^{b}	0.70
	Wether	–	–	–	–	52.12^{b}	0.73	52.93^{b}	0.74	50.93^{b}	0.67
						Carcass Bone, g/100g^{-1}					
1 (3-6 months)	Ram	22.93	0.53	21.47^{a}	0.48	19.93^{a}	0.44	19.65	0.42	18.52	1.74
	Ewe	22.57	0.53	19.60^{b}	0.49	18.39^{b}	0.42	18.80	0.50	–	–
	Wether	22.08	0.48	20.83^{ab}	0.49	18.32^{b}	0.50	18.79	0.50	–	–
2 (6-9 months)	Ram	–	–	19.82	0.41	19.40	0.38	19.82^{a}	0.39	19.17	0.42
	Ewe	19.62	2.46	19.62	0.38	18.98	0.39	18.90^{ab}	0.40	18.16	0.43
	Wether	–	–	20.35	0.36	19.15	0.35	18.44^{b}	0.38	18.13	0.42
3 (9-12 months)	Ram	18.72	1.74	20.09^{a}	0.41	20.95^{a}	0.38	19.01^{a}	0.38	17.33	0.42
	Ewe	–	–	18.43^{b}	0.40	16.95^{c}	0.37	16.84^{b}	0.41	17.50	0.42
	Wether	16.74	2.46	18.81^{b}	0.40	18.67^{b}	0.38	18.82^{a}	0.39	17.96	0.40
4 (12-15 months)	Ram	–	–	18.71	0.46	19.18	0.44	20.16^{a}	0.42	19.72^{a}	0.42
	Ewe	16.76	2.46	17.35	1.74	18.21	0.43	17.29^{b}	0.44	16.71^{b}	0.39
	Wether	–	–	–	–	18.09	0.41	17.76^{b}	0.42	17.31^{b}	0.38
						Total Carcass Fat, g/100g^{-1}					
1 (3-6 months)	Ram	17.64	1.29	20.27^{b}	1.19	23.72^{b}	1.13	26.86	1.09	34.18	4.29
	Ewe	18.39	1.29	25.89^{a}	1.24	29.40^{a}	1.04	28.87	1.24	–	–
	Wether	19.97	1.19	23.35^{ab}	1.21	29.53^{a}	1.24	27.31	1.24	–	–
2 (6-9 months)	Ram	–	–	23.36	1.01	24.66	0.94	26.31	0.97	28.34	1.03
	Ewe	23.46	6.07	24.15	0.94	26.28	0.98	28.51	1.00	28.55	1.06
	Wether	–	–	23.13	0.89	25.94	0.88	27.64	0.97	30.16	1.11
3 (9-12 months)	Ram	31.06	4.29	24.52	1.00	21.51^{c}	1.03	25.51^{b}	0.95	30.04	1.03
	Ewe	–	–	24.15	0.94	32.52^{a}	0.91	32.35^{a}	1.00	30.19	1.03
	Wether	31.75	6.07	25.89	0.98	27.62^{b}	0.94	28.19^{b}	0.97	28.93	0.98
4 (12-15 months)	Ram	–	–	26.28	6.07	24.79^{b}	1.07	24.17^{b}	1.09	25.02^{b}	1.03
	Ewe	36.96	6.07	29.40	4.29	29.62^{a}	1.06	32.40^{a}	1.09	32.60^{a}	0.97
	Wether	–	–	–	–	29.91^{a}	1.03	29.56^{a}	1.07	32.46^{a}	0.96

^{a,b,c} Means in the same column and age group without a superscript or bearing a common superscript do not differ significantly ($P > 0.05$).

younger counterparts, suggesting from a carcass composition perspective that if lambs are to be marketed at a lightweight they should be marketed at young ages.

Ewe lambs had a higher proportion ($P < 0.05$) of total carcass fat than their ram lamb counterparts when they were in age group 1 and weight groups 2 and 3; age group 3 and weight groups 3 and 4; and age group 4 and weight groups 3, 4 and 5 (Table 3). They also had a higher proportion ($P < 0.05$) of total carcass fat than their wether counterparts only when they were in age group 3 and weight groups 3 and 4. Wether lambs had a higher proportion ($P < 0.05$) of total carcass fat than their ram counterparts when they were in age group 1 and weight group 3; age group 3 and weight group 3; and age group 4 and weight groups 3, 4 and 5. In data not presented in tabular form, significant positive trends in percent total carcass fat with increasing liveweight were detected in rams in age groups 1 ($r^2 = 0.76$, $P < 0.05$) and 2 ($r^2 = 0.77$, $P < 0.05$); ewes in age groups 1 ($r^2 = 0.96$, $P < 0.01$) and 2 ($r^2 = 0.77$, $P < 0.05$); and wethers in age groups 1 ($r^2 = 0.77$, $P < 0.05$) and 2 ($r^2 = 0.88$, $P < 0.05$) which is in agreement with the previous report of Thompson et al. (1979). In data not presented in tabular form, significant positive trends in percent total carcass fat with advancing age were also observed for rams in weight group 2 ($r^2 = 0.98$, $P < 0.01$); ewes in weight group 5 ($r^2 = 1.00$, $P < 0.01$); and wethers in weight group 4 ($r^2 = 0.85$, $P < 0.05$). However, a significant negative trend (in data not presented in tabular form) in total carcass fat with advancing age was detected in rams in weight groups 4 ($r^2 = 0.92$, $P < 0.01$) and 5 ($r^2 = 0.79$, $P < 0.05$).

These findings further substantiate that ram lambs are the leanest and ewe lambs are the fattest and support the previous findings of Carpenter et al. (1969), Kemp et al. (1962), Walker (1950) and Wise (1978). The significant positive trend in total carcass fat content in young lambs (less than nine months old) indicates carcass fat content increases linearly with liveweight in young lambs, which is in agreement with the previous report of Wise (1978) and Notter et al. (1983). The significant positive trends with advancing age in lightweight rams indicate carcass fatness increases proportionally with age in rams and wethers marketed at lightweights.

Carcasses from ewe lambs contained a higher proportion of subcutaneous fat ($P < 0.05$) than their counterpart ram lambs when they were in age group 1 and weight groups 2 and 3; age group 3 and weight groups 2, 3 and 4; and age group 4 and weight groups 3, 4 and 5 (Table 4). They also contained a higher proportion ($P < 0.05$) of subcutaneous fat than their counterparts from wether lambs when they were in age group 3 and weight groups 2, 3 and 4. Carcasses from wether lambs also contained a higher proportion of subcutaneous fat than their counterparts from ram lambs when they were in age group 1 and weight groups 2 and 3; age group 3 and weight group 3; and age group 4 and weight groups 3, 4 and 5. Such results are in agreement with findings in previous reports (Carpenter et al., 1969; Kemp et al., 1962; Walker, 1950). Significant positive trends in percent subcutaneous fat with increasing liveweight (in data not presented in tabular form) were detected in rams in age groups 1 ($r^2 = 0.74$, $P < 0.05$) and 2 ($r^2 = 0.77$, $P < 0.05$), ewes in age group 1 ($r^2 = 0.88$, $P < 0.05$), and wethers in age group 2 ($r^2 = 0.92$, $P < 0.01$) which is in agreement with the previous report of Thompson et al. (1979). Significant positive trends in the proportion of subcutaneous fat with advancing age (in data not presented in tabular form) were also observed in ewes in weight groups 1 ($r^2 = 0.94$, $P < 0.05$) and 4 ($r^2 = 0.90$, $P < 0.05$). However, a significant negative trend (in data not presented in tabular form) was detected in percent subcutaneous fat with advancing age in rams in weight group 4 ($r^2 = 0.92$, $P < 0.01$).

Carcasses from ewe lambs also had a higher proportion of intermuscular fat ($P < 0.05$) than their counterparts from ram lambs when they were in age group 1 and weight groups 2 and 3; age group 3 and weight groups 2, 3 and 4; and age group 4 and weight groups 4 and 5 (Table 4). Ewe lamb carcasses also had a higher proportion ($P < 0.05$) of intermuscular fat than their counterparts from wether lambs when they were in age group 3 and weight groups 3 and 4. Carcasses from wether lambs had a higher proportion ($P < 0.05$) of intermuscular fat than their counterparts from ram lambs when they were in age group 1 and weight group 3; age group 2 and weight group 5; age group 3 and weight groups 3 and 4; and age group 4 and weight groups 3, 4 and 5. In data not presented in tabular form, significant positive trends were detected in percent intermuscular fat with increasing liveweight in rams in age group 1 ($r^2 = 0.77$, $P < 0.05$), ewes in age groups 1 ($r^2 = 0.98$, $P < 0.01$) and 2 ($r^2 = 0.72$, $P < 0.05$) and wethers in age groups 1 ($r^2 = 0.85$, $P < 0.05$) and 2 ($r^2 = 0.81$, $P < 0.05$) which is in agreement with the previous report of Thompson et al. (1979). Significant positive trends in the proportion of intermuscular fat (in data not presented in tabular form) were also detected with advancing age in rams in weight group 2 ($r^2 = 0.96$, $P < 0.01$) and ewes in weight group 5 ($r^2 = 1.00$, $P < 0.01$).

In addition, carcasses from ewe lambs had a higher proportion of body cavity fat ($P < 0.05$) than their counterparts from ram lambs when they were in age group 2 and weight groups 2 and 4; age group 3 and weight groups 2, 3 and 4; and age group 4 and weight groups 3, 4 and 5 (Table 4). Ewe lamb carcasses also contained a higher proportion ($P < 0.05$) of body cavity fat than their counterparts from wether lambs when they were in age group 3 and weight groups 2 and 3, and age group 4 and weight group 4. Carcasses from wether lambs also had a higher proportion of body cavity fat ($P < 0.05$) than their counterparts from ram lambs when they were in age group 1 and weight group 3; age group 2 and weight group 2; and age group 4 and weight groups 3, 4 and 5. Such results are in agreement with previous findings (Carpenter et al., 1969; Kemp et al., 1962; Walker,

1950). In data not presented in tabular form, significant trends in proportion of body cavity fat were not observed in any age/sex subclass with increasing liveweight ($P > 0.05$). A significant negative trend in percent body cavity fat with advancing age (in data not presented in tabular form) was detected in rams in weight group 3 ($r^2 = 0.92$, $P < 0.01$).

The carcass lean from ram lamb carcasses contained a higher proportion ($P < 0.05$) of moisture than that from ewe lamb carcasses when it was from lambs in age group 2 and weight groups 2, 3 and 4; age group 3 and weight groups 2, 3 and 4; and age group 4 and weight group 4 (Table 5). Carcass lean from ram lamb carcasses also contained a higher proportion ($P < 0.05$) of moisture than its counterpart from wether lamb carcasses when the carcass lean was from lambs in age group 3 and weight groups 3 and 4, and age group 4 and

Table 4. Least squares means and standard errors for the proportions of subcutaneous, intermuscular and body cavity fat in lamb carcasses in various age/weight/gender subclasses.

		Liveweight Group									
		1 (31.8 to 40.4 kg)		2 (40.5 to 49.5 kg)		3 (50.0 to 58.6 kg)		4 (58.9 to 67.7 kg)		5 (68.2 to 76.8 kg)	
Age Group	Gender	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
						Subcutaneous Fat, g/100g^{-1}					
1 (3-6 months)	Ram	7.55	0.65	8.95^{b}	0.60	10.60^{b}	0.54	12.18	0.52	16.26	2.16
	Ewe	8.17	0.65	12.00^{a}	0.61	13.68^{a}	0.52	12.49	0.62	–	–
	Wether	8.95	0.60	10.73^{a}	0.61	13.98^{a}	0.62	12.24	0.62	–	–
2 (6-9 months)	Ram	–	–	10.53	0.51	11.22	0.47	11.82	0.49	12.91	0.52
	Ewe	11.10	3.06	11.34	0.47	12.37	0.49	12.73	0.50	12.08	0.52
	Wether	–	–	10.48	0.44	11.66	0.43	11.98	0.47	12.88	0.52
3 (9-12 months)	Ram	13.84	2.16	10.07^{b}	0.50	8.72^{c}	0.47	10.67^{b}	0.47	12.44	0.52
	Ewe	–	–	12.25^{a}	0.50	14.17^{a}	0.46	13.72^{a}	0.50	12.17	0.52
	Wether	14.36	3.06	10.53^{b}	0.50	11.39^{b}	0.47	11.68^{b}	0.49	12.29	0.50
4 (12-15 months)	Ram	–	–	10.80	3.06	10.10^{b}	0.54	10.07^{b}	0.53	10.36^{b}	0.52
	Ewe	15.51	3.06	12.20	2.16	12.20^{a}	0.52	13.99^{a}	0.54	13.52^{a}	0.49
	Wether	–	–	–	–	12.73^{a}	0.51	12.71^{a}	0.52	13.64^{a}	0.47
						Intermuscular Fat, g/100g^{-1}					
1 (3-6 months)	Ram	7.98	0.63	9.08^{b}	0.58	10.85^{b}	0.53	12.66	0.50	15.61	2.10
	Ewe	8.01	0.63	11.41^{a}	0.60	12.90^{a}	0.50	14.14	0.61	–	–
	Wether	8.83	0.58	10.23^{ab}	0.60	12.74^{a}	0.61	12.77	0.61	–	–
2 (6-9 months)	Ram	–	–	11.27	0.50	11.23	0.46	12.32	0.48	13.03^{b}	0.50
	Ewe	10.04	2.98	10.44	0.46	11.46	0.47	13.16	0.48	14.36^{ab}	0.52
	Wether	–	–	10.39	0.43	11.66	0.42	12.94	0.46	14.52^{a}	0.51
3 (9-12 months)	Ram	14.42	2.10	12.60^{b}	0.49	10.83^{c}	0.45	12.96^{c}	0.45	15.27	0.50
	Ewe	–	–	14.89^{a}	0.48	16.02^{a}	0.45	16.45^{a}	0.49	15.90	0.50
	Wether	14.24	2.98	13.54^{ab}	0.48	14.15^{b}	0.45	14.54^{b}	0.48	14.50	0.48
4 (12-15 months)	Ram	–	–	13.03	2.98	12.90^{b}	0.53	12.19^{b}	0.51	12.74^{b}	0.50
	Ewe	18.39	2.98	14.90	2.10	13.81^{ab}	0.51	15.39^{a}	0.53	16.47^{a}	0.48
	Wether	–	–	–	–	14.68^{a}	0.50	14.20^{a}	0.50	15.66^{a}	0.45
						Body Cavity Fat, g/100g^{-1}					
1 (3-6 months)	Ram	2.12	0.13	2.24	0.12	2.41^{b}	0.11	2.19	0.11	2.31	0.43
	Ewe	2.22	0.13	2.34	0.13	2.69^{ab}	0.10	2.24	0.13	–	–
	Wether	2.18	0.12	2.39	0.12	2.80^{a}	0.13	2.31	0.13	–	–
2 (6-9 months)	Ram	–	–	2.06^{b}	0.10	2.21	0.09	2.17^{b}	0.10	2.40	0.10
	Ewe	2.32	0.61	2.37^{a}	0.09	2.46	0.10	2.57^{a}	0.10	2.11	0.11
	Wether	–	–	2.36^{a}	0.09	2.32	0.09	2.31^{ab}	0.10	2.38	0.11
3 (9-12 months)	Ram	2.80	0.43	1.85^{b}	0.10	1.81^{b}	0.10	1.88^{b}	0.10	2.33	0.10
	Ewe	–	–	2.35^{a}	0.10	2.32^{a}	0.09	2.18^{a}	0.10	2.12	0.10
	Wether	3.15	0.61	1.82^{b}	0.10	1.92^{b}	0.09	1.97^{ab}	0.10	2.14	0.10
4 (12-15 months)	Ram	–	–	2.45	0.61	1.78^{b}	0.11	2.00^{c}	0.11	1.92^{b}	0.10
	Ewe	3.06	0.61	2.29	0.43	2.35^{a}	0.11	2.75^{a}	0.11	2.61^{a}	0.10
	Wether	–	–	–	–	2.40^{a}	0.10.	2.42^{b}	0.11	2.46^{a}	0.10

^{a,b,c} Means in the same column and age group without a superscript or bearing a common superscript do not differ significantly ($P > 0.05$).

Table 5. Least squares means and standard errors for the proportions of moisture, protein and intramuscular fat (wet and dry weight basis) in the carcass lean of lamb carcasses in various age/weight/gender subclasses.

		Liveweight Group									
		1 (31.8 to 40.4 kg)		2 (40.5 to 49.5 kg)		3 (50.0 to 58.6 kg)		4 (58.9 to 67.7 kg)		5 (68.2 to 76.8 kg)	
Age Group	Gender	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
					Moisture, g/100g^{-1}						
1 (3-6 months)	Ram	72.59	0.45	72.77	0.40	72.01	0.37	72.21	0.39	72.54	1.42
	Ewe	72.56	0.41	71.86	0.41	71.12	0.35	72.47	0.42	–	–
	Wether	72.72	0.39	71.80	0.39	71.01	0.41	71.93	0.41	–	–
2 (6-9 months)	Ram	74.55	1.42	72.29^{a}	0.32	72.02^{a}	0.30	72.83^{a}	0.32	72.10	0.33
	Ewe	70.35	2.00	70.92^{b}	0.31	70.84^{b}	0.32	71.41^{b}	0.31	71.52	0.33
	Wether	–	–	71.83^{a}	0.29	71.93^{a}	0.28	72.05^{ab}	0.31	71.95	0.33
3 (9-12 months)	Ram	72.58	1.42	73.11^{a}	0.34	73.65^{a}	0.31	72.99^{a}	0.32	71.39^{ab}	0.35
	Ewe	–	–	72.04^{b}	0.32	71.32^{b}	0.30	71.44^{b}	0.34	70.78^{b}	0.35
	Wether	74.52	2.00	72.62^{ab}	0.39	72.11^{b}	0.32	71.65^{b}	0.35	71.85^{a}	0.34
4 (12-15 months)	Ram	–	–	71.50	2.00	71.88	0.35	72.48^{a}	0.35	71.41	0.37
	Ewe	70.22	2.00	72.04	1.42	71.15	0.34	70.37^{b}	0.34	71.18	0.33
	Wether	–	–	70.92	2.00	70.95	0.34	71.07^{b}	0.34	70.72	0.30
					Protein, g/100g^{-1}						
1 (3-6 months)	Ram	17.04	0.33	17.11	0.29	16.30	0.27	16.64	0.28	16.50	1.04
	Ewe	17.18	0.30	17.24	0.30	16.59	0.26	16.37	0.31	–	–
	Wether	16.71	0.29	16.81	0.29	17.12	0.30	16.31	0.30	–	–
2 (6-9 months)	Ram	16.42	1.04	17.36	0.24	17.49	0.22	16.39	0.23	17.20	0.25
	Ewe	17.13	1.47	16.92	0.22	16.91	0.24	16.99	0.23	16.86	0.25
	Wether	–	–	17.21	0.21	17.07	0.21	16.73	0.23	16.85	0.25
3 (9-12 months)	Ram	17.82	1.04	16.61	0.25	16.55	0.23	16.00	0.23	16.21	0.26
	Ewe	–	–	16.76	0.24	16.78	0.22	15.98	0.25	16.25	0.26
	Wether	18.21	1.47	16.37	0.28	16.83	0.23	16.44	0.26	16.38	0.25
4 (12-15 months)	Ram	–	–	18.85	1.47	16.77	0.26	16.47	0.26	16.98	0.27
	Ewe	15.15	1.47	17.14	1.04	16.62	0.25	17.16	0.25	16.32	0.25
	Wether	–	–	15.10	1.47	17.38	0.25	16.58	0.25	16.43	0.22
					Fat (Wet Weight Basis), g/100g^{-1}						
1 (3-6 months)	Ram	7.25	0.41	6.90^{b}	0.37	7.62^{b}	0.33	7.54	0.35	6.91	1.29
	Ewe	7.18	0.37	7.97^{a}	0.37	8.89^{a}	0.32	7.24	0.38	–	–
	Wether	7.37	0.36	8.00^{a}	0.36	8.76^{a}	0.37	7.87	0.37	–	–
2 (6-9 months)	Ram	6.14	1.29	7.38^{b}	0.30	7.34^{b}	0.27	6.71^{b}	0.29	7.39	0.31
	Ewe	9.93	1.83	8.95^{a}	0.28	8.94^{a}	0.30	8.04^{a}	0.29	8.20	0.31
	Wether	–	–	7.85^{b}	0.26	7.66^{b}	0.26	7.31^{ab}	0.28	7.57	0.31
3 (9-12 months)	Ram	7.28	1.29	6.49^{b}	0.31	6.11^{c}	0.28	6.79^{b}	0.29	8.36	0.32
	Ewe	–	–	7.59^{a}	0.30	8.18^{a}	0.28	8.32^{a}	0.31	8.77	0.32
	Wether	4.62	1.83	6.82^{ab}	0.35	7.13^{b}	0.29	7.68^{a}	0.32	8.11	0.31
4 (12-15 months)	Ram	–	–	7.40	1.83	7.17^{b}	0.32	7.03^{b}	0.32	7.53^{b}	0.34
	Ewe	11.15	1.83	7.33	1.29	7.99^{ab}	0.31	9.08^{a}	0.31	8.59^{a}	0.31
	Wether	–	–	7.85	1.83	8.30^{a}	0.31	8.61^{a}	0.31	9.01^{a}	0.27
					Fat (Dry Weight Basis), g/100g^{-1}						
1 (3-6 months)	Ram	20.30^{b}	1.10	25.24^{b}	0.98	26.98^{b}	0.90	26.96	0.95	24.95	3.48
	Ewe	26.02^{a}	1.00	28.14^{a}	1.00	30.60^{a}	0.87	26.02	1.02	–	–
	Wether	26.87^{a}	0.96	28.29^{a}	0.96	30.12^{a}	1.00	27.55	1.00	–	–
2 (6-9 months)	Ram	24.13	3.48	26.47^{b}	0.80	25.98^{b}	0.73	24.48^{b}	0.78	26.26	0.82
	Ewe	33.50	4.92	30.50^{a}	0.75	30.43^{a}	0.80	27.87^{a}	0.77	28.50	0.82
	Wether	–	–	27.74^{b}	0.71	26.99^{b}	0.70	26.01^{ab}	0.76	26.84	0.82
3 (9-12 months)	Ram	25.91	3.48	23.67^{b}	0.84	22.98^{c}	0.76	24.84^{b}	0.78	28.92	0.86
	Ewe	–	–	26.72^{a}	0.80	28.32^{a}	0.74	28.96^{a}	0.83	29.83	0.87
	Wether	18.15	4.92	24.66^{ab}	0.95	25.31^{b}	0.78	26.75^{ab}	0.87	28.66	0.83
4 (12-15 months)	Ram	–	–	25.96	4.92	25.07^{b}	0.87	25.26^{b}	0.86	25.85^{b}	0.91
	Ewe	37.44	4.92	26.22	3.48	27.45^{ab}	0.84	30.43^{a}	0.84	29.56^{a}	0.82
	Wether	–	–	27.00	4.92	28.25^{a}	0.84	29.49^{a}	0.83	30.51^{a}	0.73

^{a,b,c} Means in the same column and age group without a superscript or bearing a common superscript do not differ significantly ($P > 0.05$).

weight group 4. The carcass lean from wether lamb carcasses also had a higher proportion ($P < 0.05$) of moisture than its counterpart from ewe lamb carcasses when the carcass lean was from lambs in age group 2 and weight groups 2 and 3 and age group 3 and weight group 5. Significant negative trends in percent moisture (in data not presented in tabular form) were observed with increasing liveweight in the carcass lean from rams in age group 2 ($r^2 = 0.74$, $P < 0.05$), ewes in age group 3 ($r^2 = 0.85$, $P < 0.05$) and wethers in age group 3 ($r^2 = 0.94$, $P < 0.01$). Significant negative trends in percent moisture (in data not presented in tabular form) were also detected with advancing age in the carcass lean from rams in weight group 5 ($r^2 = 0.86$, $P < 0.05$) and ewes in weight group 4 ($r^2 = 0.90$, $P < 0.05$).

Because the moisture content of the carcass lean is usually inversely related to the intramuscular fat content, these results indicate that ewe lambs have the highest and ram lambs have the lowest intramuscular fat content. Significant differences among samples of lean from carcasses from lambs of different gender in muscle protein content were not detected ($P > 0.05$) in any age/weight subclass (Table 5). In data not presented in tabular form, significant negative trends in the proportion of protein in the carcass lean with increasing liveweight were observed in samples from ram lamb carcasses in age groups 3 ($r^2 = 0.92$, $P < 0.01$) and 4 ($r^2 = 0.85$, $P < 0.05$), samples from ewe lamb carcasses in age group 2 ($r^2 = 0.76$, $P < 0.05$) and samples from wether lamb carcasses in age group 3 ($r^2 = 0.83$, $P < 0.05$). Significant negative trends in the percent protein of the carcass lean (in data not presented in tabular form) were also detected with advancing age in ewes ($r^2 = 0.86$, $P < 0.05$) and wethers ($r^2 = 0.86$, $P < 0.05$) in weight group 5.

The negative trends in the protein content of carcass lean observed with increasing liveweight and advancing age also indicate the fat content within the muscle increases as animals become older and heavier, since the protein content of the carcass lean is usually inversely related (modestly but not strongly) to the intramuscular fat content.

The carcass lean from ewe lambs contained more fat on a wet weight basis ($P < 0.05$) than did carcass lean from ram lambs when they were in age group 1 and weight groups 2 and 3; age group 2 and weight groups 2, 3 and 4; age group 3 and weight groups 2, 3 and 4; and age group 4 and weight groups 4 and 5 (Table 5). Carcass lean from ewe lambs also contained more ($P < 0.05$) fat on a wet weight basis than its counterpart from wether lambs when they were in age group 2 and weight groups 2 and 3, and age group 3 and weight group 3. The carcass lean of wether lambs also contained more fat on a wet weight basis ($P < 0.05$) than its counterpart from ram lambs when they were in age group 1 and weight groups 2 and 3; age group 3 and weight groups 3 and 4; and age group 4 and weight groups 3, 4 and 5. Significant positive trends in the proportion of fat on a wet weight basis in the carcass lean with increasing liveweight (in data not presented in tabular form) were observed in ewes in age group 3 ($r^2 = 0.92$, $P < 0.05$) and wethers in age groups 3 ($r^2 = 1.00$, $P < 0.01$) and 4 ($r^2 = 0.86$, $P < 0.05$). However, a significant negative trend in the proportion of fat of the carcass lean on a wet weight basis with increasing liveweight (in data not presented in tabular form) was detected in ewes in age group 2 ($r^2 = 0.90$, $P < 0.01$). Significant negative trends in the proportion of fat in the carcass lean on a wet weight basis with advancing age were also detected in ewes in weight groups 3 ($r^2 = 0.77$, $P < 0.01$) and 4 ($r^2 = 0.98$, $P < 0.01$), possibly as a result of differences in nutritional regimes and/or genotype (Notter et al., 1983).

The carcass lean of ewe lambs also contained a higher proportion of fat on a dry weight basis ($P < 0.05$) than did carcass lean from ram lambs when they were in age group 1 and weight groups 1, 2 and 3; age group 2 and weight groups 2, 3 and 4; age group 3 and weight groups 2, 3 and 4; and age group 4 and weight groups 4 and 5 (Table 5). Carcass lean from ewe lambs also had a higher proportion of fat on a dry weight basis ($P < 0.05$) than did carcass lean from wether lambs when they were in age group 2 and weight groups 2 and 3 and age group 3 and weight group 3. The carcass lean from wether lambs contained a higher proportion of fat on a dry weight basis than did carcass lean from ram lambs when they were in age group 1 and weight groups 1, 2 and 3; age group 3 and weight group 3; and age group 4 and weight groups 3, 4 and 5. In data not presented in tabular form, significant positive trends in the proportion of fat content of the carcass lean on a dry weight basis with increasing liveweight were observed in rams in age group 1 ($r^2 = 0.71$, $P < 0.05$), ewes in age group 3 ($r^2 = 0.96$, $P < 0.01$) and wethers in age groups 3 ($r^2 = 1.00$, $P < 0.01$) and 4 ($r^2 = 0.86$, $P < 0.05$). However, a significant negative trend in the fat content of the carcass lean of ewes in age group 2 on a dry weight basis (in data not presented in tabular form) was observed with increasing liveweight ($r^2 = 0.90$, $P < 0.01$), possibly as a result of differences in nutritional regime and/or genotype (Notter et al., 1983).

In data not presented in tabular form, significant positive trends in the fat content of the carcass lean on a dry weight basis with advancing age were also detected in ewes in weight group 4 ($r^2 = 1.00$, $P < 0.01$) and wethers in weight group 5 ($r^2 = 0.74$, $P < 0.05$). However, significant negative trends in the proportion of fat in carcass lean on a dry weight basis with advancing age were also detected in ewes in weight group 3 ($r^2 = 0.86$, $P < 0.05$).

Conclusions

These results clearly substantiate the fact that ewe lambs have the highest and ram lambs have the lowest intramuscular fat content. However, it should be noted that fat on the surface of the dissected lean may have contributed to this difference. The significant trends observed in the intramuscular fat content of carcass lean with advancing age and increasing liveweight undoubtedly

reflect differences in animal type and/or physiological maturity.

The composite results indicate that lambs should be marketed at lighter weights and younger ages, which is consistent with consumer desires for a leaner product but may not be consistent with the economics associated with efficient lamb production.

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The Influence of Lamb Chronological Age, Slaughter Weight and Gender on Yield and Cutability[1,2]

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Summary

A total of 1,660 lambs of three genders in four chronological age groups and five slaughter weight groups were evaluated for antemortem preslaughter shrink, dressing yield and cutability. Ram lambs were most susceptible to antemortem preslaughter shrink but became more resistant with advancing age. Dressing yields decreased as slaughter weight increased and were lowest for ram lambs. Ram lambs had the lowest proportions of loin, rack and flank and the highest proportions of shank, while ewe lambs had the highest proportion of rack. Proportion of leg decreased with advancing age in heavyweight ram and ewe lambs (more than 68.2 kg). Proportion of loin decreased with advancing age in heavyweight lambs (more than 50 kg) and increased with slaughter weight in young rams (less than nine months). Proportion of rack decreased with advancing age in lightweight lambs (less than 58.9 kg). Proportion of breast was not influenced by either slaughter weight or chronological age, but proportion of flank increased with advancing age. Proportion of shoulder increased with advancing age, particularly in rams over 40 kg at the time of slaughter. Proportion of shank decreased with slaughter weight in young lambs (less than 12 months) and increased in older lambs (more than 12 months). Proportion of shank also decreased with advanced age in lightweight lambs (less than 50 kg) and increased in heavyweight wether lambs (more than 68.2 kg). Consequently, the results from the present study indicate that to obtain the highest yield of high value cuts, lambs should be marketed at younger ages and at lighter weights; and to obtain the greatest dressing yields, lambs, and particularly ram lambs, should be marketed at lighter weights. However, to prevent excessive preslaughter shrink, young ram lambs (less than 12 months of age) should be shielded from antemortem stress.

Key words: chronological age, slaughter weight, gender, preslaughter shrinkage, dressing yield, cutability.

Introduction

Various criteria have been suggested as measures of ultimate lamb carcass desirability. Most of these criteria are based on the fact that the ultimate desirability of lamb carcasses is determined by the yield of edible portion and the quality of the muscle which comprises this portion. Some criteria which have been suggested include: carcass value (Carpenter et al., 1964), total retail cuts (Oliver et al., 1967; Ringkob et al., 1964), trimmed primal or retail cuts (Spurlock and Bradford, 1965; Spurlock et al., 1966; Zinn, 1961; Cunningham et al., 1967; Carpenter et al., 1964; Hoke, 1961), weight of edible meat per day of age (Carpenter et al., 1965), edible portion (Judge and Martin, 1963; Johnston et al., 1967), separable physical components (Moody et al., 1965; Judge et al., 1966; Field et al., 1963; Hankins, 1947; Palsson, 1939; Kirton and Barton, 1958; Ringkob et al., 1964; Timon and Bichard, 1965; Walker and McKeekan, 1944) and chemical composition (Hankins, 1947; Khandikar et al., 1965; Pradham et al., 1966; Munson et al., 1966; Adams et al., 1970). However, Carpenter (1966) expressed the need for definitive research to provide guidelines to optimize the balance between carcass weight, quantitative yield of retail cuts and meat quality. In this regard, fatness and muscling of

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lamb carcasses differ considerably due to differences in age, weight, breed, gender and management (Carpenter et al., 1965). Although many studies have evaluated the influence of such factors on carcass composition and meat quality (Burton and Reid, 1969; Jeremiah et al., 1997; Wood et al., 1980), those studies have tended only to evaluate one or two factors in isolation. There have been no comprehensive studies to examine the influence of such traits on the yield and cutability of a sample representative of the Canadian market lamb population. The present study was designed to provide an evaluation of the influences of chronological age, slaughter weight and gender on dressing yields, carcass yields and cutability of Canadian market lambs.

Materials and Methods

A total of 1,660 commercial lambs were selected on the basis of age, slaughter weight, gender and fatness to fill specific subclasses in an experimental design grid (Jeremiah et al., 1997). The lambs evaluated were a representative sample of the entire range of lambs currently being marketed in Canada, rather than a set of animals of controlled breeding and dietary management, slaughtered at different weights and/or ages. The lambs in the present study were purchased from commercial sheep producers with breeding records and certified birthdates for the lambs purchased, so that both the breeding and chronological ages could be ascertained. The lambs were predominantly crossbreds, involving some combination of the following breeds: Cheviot, Columbia, Dorset, Finnish/Landrace, Hampshire, Leicester, Montadale, Rambouillet, Romanoff, Romney, Shropshire, Southdown, Suffolk, Targhee or Texel. Breeds and breed-crosses were allocated as evely as possible among age/slaughter weight/gender subclasses and care was taken to prevent a given breed or breed-cross from constituting a majority in any given age/slaughter weight/gender subclass.

Fatness and gender were ascertained the day prior to slaughter. Fatness was ascertained both subjectively by a trained and experienced evaluator and ultrasonically. The same fatness criteria were applied to all age/slaughter weight subclasses, but was relatively constant within subclasses. Since the lambs were purchased from different producers, it is possible that they were fed differently and this may have influenced compositional properties. The actual frequency distribution of lambs evaluated is presented by age, weight, gender and fatness subclass (Jeremiah et al., 1997). Lambs were selected from four chronological age groups (3 to 6, 6 to 9, 9 to 12, 12 to 15 months), five slaughter weight groups (31.8 to 40.4, 40.5 to 49.5, 50.0 to 58.6, 58.9 to 67.7, 68.2 to 76.8 kg), three gender groups (rams, ewes, wethers), and three fatness groups (fat, intermediate, lean).

All lambs were delivered to the Lacombe Meat Research Center 20 hours prior to slaughter and slaughtered under simulated commercial conditions. All animals were weighed upon receipt the day prior to slaughter and reweighed immediately prior to slaughter to facilitate calculation of antemortem shrinkage. Warm carcasses were weighed to facilitate calculation of dressing yields and then chilled for 24 hours at 1 °C (±1 °C).

After chilling the carcasses were weighed and split. The left side of each carcass was then weighed and divided into wholesale cuts (leg, loin, rack, shoulder, flank, breast, shank). All cuts were then weighed to facilitate calculation of individual cut yields.

Data were analyzed using the general linear model (GLM) procedures of SAS (1985). Sources of variation were: age, slaughter weight, gender and the two-way and three-way interactions. Mean separation of significant main effects was by single degree of freedom linear contrast. Linear regression was used to detect significant trends with advancing age and increasing slaughter weight (Puri and Mullen, 1980).

Results and Discussion

By design, both receiving weight and slaughter weight increased progressively with slaughter weight group ($P < 0.001$). They were also related to each other ($r^2 = 0.97$, $P < 0.0001$). Although a positive trend in the receiving weight of rams in weight group 3 was observed with advancing age ($r^2 = 0.90$, $P < 0.01$), a negative trend was detected in rams in weight group 4 ($r^2 = 0.82$, $P < 0.05$) with advancing age. Positive trends in slaughter weights with advancing age were detected in rams in weight group 3 ($r^2 = 0.63$, $P < 0.05$), ewes in weight group 5 ($r^2 = 0.91$, $P < 0.05$) and wethers in weight groups 4 ($r^2 = 0.81$, $P < 0.05$) and 5 ($r^2 = 0.94$, $P < 0.01$). These results imply chronological age was not related to receiving weight, but was positively related to slaughter weight, particularly in heavyweight ewe and wether lambs.

Preslaughter antemortem shrinkage during overnight lairage is a concern to packers who purchase live lambs. Consequently, the effects of gender, chronological age and slaughter weight on this parameter is of interest. Both receiving weight and slaughter weight were negatively related to preslaughter antemortem shrinkage ($r = -0.10$ and -0.26, respectively; $P < 0.0001$).

Ram lambs sustained higher antemortem shrinkage between receipt and slaughter ($P < 0.05$) than ewe lambs when they were in age group 1 and weight group 4, age group 2 and weight groups 2 and 3 and age group 3 and weight group 3 (Table 1). Ram lambs also sustained higher antemortem shrinkage than wether lambs when they were in age group 1 and weight groups 1, 2 and 3 and age group 3 and weight group 3 ($P < 0.05$). Ewe lambs also sustained greater preslaughter shrinkage than wether lambs when they were in age group 1 and weight group 1 and age group 2 and weight groups 2, 4 and 5, and age group 3 and weight group 5 ($P < 0.05$). However, wether lambs sustained greater preslaughter shrinkage than both ram and ewe lambs ($P < 0.05$) when they were in age group 4 and weight group 5. These results demonstrate, in general, that ram lambs up to 12 months of age were most susceptible to antemortem preslaughter shrinkage and

wether lambs up to 12 months of age were most resistant to such shrinkage. However, when lambs were between 12 and 15 months of age and at heavy weights (more than 68.2 kg), wethers were more susceptible to preslaughter shrinkage than both ram and ewe lambs. Such results undoubtly are a result of reactions to preslaughter stress and have important implications for the preslaughter handling of lambs to prevent antemortem shrinkage.

Positive trends in antemortem, preslaughter shrinkage were observed in rams in age group 1 ($r^2 = 0.91$, $P < 0.01$) and ewes in age group 4 ($r^2 = 0.85$, $P < 0.01$) with increasing liveweight, indicating preslaughter

Table 1. Least squares means and standard errors (SE) for antemortem shrinkage, dressing yields and cold carcass weights for lambs of different ages, slaughter weights and genders.

		Slaughter Weight Group									
		1 (31.8 to 40.4 kg)		2 (40.5 to 49.5 kg)		3 (50.0 to 58.6 kg)		4 (58.9 to 67.7 kg)		5 (68.2 to 76.8 kg)	
Age Group	Gender	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
					Antemortem Shrinkage, g/kg^{-1}						
1 (3 to 6 mo.)	Ram	6.0^{a}	0.57	6.3^{a}	0.53	6.3^{a}	0.48	6.6^{a}	0.47	6.6	1.97
	Ewe	6.6^{a}	0.56	5.9^{a,b}	0.55	4.9^{a,b}	0.46	4.8^{b}	0.58	–	–
	Wether	3.3^{b}	0.54	5.0^{b}	0.55	4.2^{b}	0.57	5.9^{a,b}	0.57	–	–
2 (6 to 9 mo.)	Ram	4.6	1.97	5.5^{a}	0.45	5.9^{a}	0.42	5.6^{a}	0.44	4.8^{a}	0.46
	Ewe	5.1	2.79	4.4^{b}	0.42	4.9^{b}	0.44	6.4^{a}	0.44	4.6^{a}	0.46
	Wether	–	–	3.0^{c}	0.40	4.7^{b}	0.39	4.5^{b}	0.43	3.6^{b}	0.46
3 (9 to 12 mo.)	Ram	3.3	1.97	3.1	0.46	4.6^{a}	0.42	3.5	0.43	2.9^{a,b}	0.46
	Ewe	–	–	2.8	0.45	2.4^{b}	0.42	2.6	0.47	3.4^{a}	0.46
	Wether	5.3	2.79	3.3	0.45	2.4^{b}	0.42	3.2	0.45	2.2^{b}	0.46
4 (12 to 15 mo.)	Ram	–	–	5.8	2.79	3.0	0.48	3.7	0.47	3.0^{b}	0.52
	Ewe	1.4	2.79	2.0	1.61	2.7	0.47	3.5	0.46	3.2^{b}	0.46
	Wether	–	–	3.1	1.97	2.1	0.47	3.4	0.45	4.2^{a}	0.41
					Dressing Yield, g/kg^{-1}						
1 (3 to 6 mo.)	Ram	50.9	2.29	50.9^{b}	2.12	51.5	2.08	51.3	1.95	48.6	7.93
	Ewe	48.9	2.29	56.6^{a}	2.29	53.7	1.95	49.8	2.39	–	–
	Wether	50.5	2.16	50.6^{b}	2.29	51.4	2.29	48.4	2.34	–	–
2 (6 to 9 mo.)	Ram	43.8	11.21	60.0^{a}	2.05	45.9^{b}	1.84	45.2^{b}	2.05	44.6	2.39
	Ewe	50.7	11.21	47.3^{b}	1.98	50.3^{a}	1.90	51.0^{a}	1.98	45.6	2.05
	Wether	–	–	50.1^{b}	1.90	47.5^{a,b}	1.87	50.1^{a}	1.92	42.4	2.29
3 (9 to 12 mo.)	Ram	64.1	11.21	58.4^{b}	1.90	48.6^{b}	1.71	47.0^{a,b}	1.80	46.3	1.95
	Ewe	–	–	63.3^{a}	1.98	56.0^{a}	1.84	50.4^{a}	1.90	45.2	1.92
	Wether	61.4	11.21	61.0^{a,b}	1.87	51.6^{a,b}	1.75	46.3^{b}	1.82	42.9	2.01
4 (12 to 15 mo.)	Ram	–	–	78.0	11.21	54.2	2.12	44.5	2.24	40.8^{b}	2.12
	Ewe	63.3	11.21	–	–	53.5	2.05	47.2	2.29	43.8^{a,b}	2.01
	Wether	–	–	–	–	54.1	1.98	47.8	2.08	45.1^{a}	2.01
					Cold Carcass Weight, kg						
1 (3 to 6 mo.)	Ram	17.5	1.20	21.8^{b}	1.11	25.7	1.09	30.3^{a}	1.02	33.1	4.14
	Ewe	16.7	1.20	24.5^{a}	1.20	27.6	1.02	28.9^{a,b}	1.22	–	–
	Wether	18.1	1.13	21.5^{b}	1.20	26.7	1.20	27.4^{b}	1.22	–	–
2 (6 to 9 mo.)	Ram	16.0	5.85	26.3^{a}	1.07	23.6^{b}	0.96	26.9^{b}	1.07	31.2	1.25
	Ewe	19.0	5.85	20.7^{b}	1.03	25.9^{a}	0.99	29.7^{a}	1.03	30.4	1.07
	Wether	–	–	22.5^{b}	0.99	24.8^{a,b}	0.98	29.8^{a}	1.00	29.4	1.20
3 (9 to 12 mo.)	Ram	23.6	5.85	26.7	0.99	25.1^{b}	0.89	28.2^{b}	0.93	32.9^{a}	1.02
	Ewe	–	–	27.7	1.03	29.4^{a}	0.96	30.5^{a}	0.99	31.1^{a,b}	1.00
	Wether	21.8	5.85	26.6	0.98	27.2^{a}	0.90	27.9^{b}	0.95	30.4^{b}	1.05
4 (12 to 15 mo.)	Ram	–	–	32.0	5.85	28.9	1.11	26.3^{b}	1.17	28.3^{b}	1.11
	Ewe	22.8	5.85	–	–	28.2	1.07	26.6^{b}	1.20	30.9^{a}	1.05
	Wehter	–	–	–	–	28.3	1.03	29.3^{a}	1.09	32.7^{a}	1.05

^{a,b,c} Means in the same column and trait and age group without a superscript or bearing a common superscript do not differ significantly ($P > 0.05$).

shrinkage increased as ewe lambs became heavier in this age group (in data not presented in tabular form). However, negative trends with increasing liveweight were observed in ewes in age group 1 ($r^2 = 0.88$, $P < 0.05$) and rams in age group 4 ($r^2 = 0.87$, $P < 0.01$) indicating preslaughter shrinkage decreased as liveweight increased in these groups. The general lack of consistent trends, however, would tend to negate the relationship of liveweight with preslaughter shrinkage.

Negative trends in antemortem preslaughter shrinkage with advancing age were detected in rams in weight groups 1 ($r^2 = 0.99$, $P < 0.01$), 3 ($r^2 = 0.89$, $P < 0.05$), 4 ($r^2 = 0.87$, $P < 0.05$) and 5 ($r^2 = 0.91$, $P < 0.05$); in ewes in weight groups 2 ($r^2 = 0.87$, $P < 0.05$) and 5 ($r^2 = 0.98$, $P < 0.01$); and in wethers in weight groups 4 ($r^2 = 0.89$, $P < 0.05$). Such findings indicate lambs, particularly ram lambs, become more resistant to factors producing antemortem preslaughter shrinkage as they become older. Therefore, these findings have important implications in the management of preslaughter shrink in market lambs.

Ewe lambs gernerally produced the heaviest warm carcasses (in data not presented in tabular form). By design, warm carcass weights increased progressively ($P < 0.001$) with slaughter weight group in all age/gender subgroups. Negative trends in warm carcass weight with advancing age were detected only in wether lambs in weight group 3 ($r^2 = 0.99$, $P < 0.001$) and ram lambs in weight group 4 ($r^2 = 0.95$, $P < 0.01$), indicating chronological age generally was not related to warm carcass weight.

Dressing yields are of concern to meat processors when they pruchase live lambs. Both slaughter weight and warm carcass weight were related to dressing yields ($r^2 = 0.32$ and 0.57, respectively, $P < 0.0001$).

Ram lambs had higher dressing yields ($P < 0.05$) than both ewe and wether lambs when they were in age group 2 and weight group 2 (Table 1). However, ewe lambs had higher dressing yields than ram lambs ($P < 0.05$) when they were in age group 1 and weight group 2, age group 2 and weight groups 3 and 4, and age group 3 and weight groups 2 and 3. Ewe lambs also had higher dressing yields than wether lambs ($P < 0.05$) when they were in age group 1 and weight group 2, age group 2 and weight group 4 and age group 3 and weight group 4; wether lambs had higher dressing yields than ram lambs ($P < 0.05$) when they were in age group 2 and weight group 4 and age group 4 and weight group 5. Such results indicate ram lambs had lower dressing yields than ewe and wether lambs, probably because they were leaner.

Negative trends in dressing yields were observed in rams in age groups 3 and 4 ($r^2 = 0.88$, $P < 0.01$, and $r^2 = 0.99$, $P < 0.001$, respectively), ewes in age groups 3 ($r^2 = 0.89$, $P < 0.05$) and 4 ($r^2 = 0.99$, $P < 0.01$) and wethers in age groups 3 and 4 ($r^2 = 0.74$ and 0.93, respectively, $P < 0.05$), indicating dressing yields decreased with slaughter weight in all genders once they reached nine months of age, probably reflecting increased leanness, which is in agreement with numerous previous reports.

Trends in dressing yield with advancing age were not detected ($P > 0.05$) in any of the slaughter weight/gender subgroups, indicating dressing yield was not related to chronological age.

Cold ram lamb carcasses were heavier than cold ewe lamb carcasses ($P < 0.05$) when they were in age group 2 and weight group 2 and cold wether lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 4, age group 2 and weight group 2 and age group 3 and weight group 5 (Table 1). However, cold ewe lamb carcasses were heavier than cold ram lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 2, age group 2 and weight groups 3 and 4, age group 3 and weight groups 3 and 4 and age group 4 and weight group 5. Cold ewe lamb carcasses also were heavier than cold wether lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 2 and age group 3 and weight group 4. However, cold wether lamb carcasses were heavier than cold ewe lamb carcasses ($P < 0.05$) when they were in age group 4 and weight group 4. Cold wether lamb carcasses were also heavier than cold ram lamb carcasses ($P < 0.05$), when they were in age group 2 and weight group 4, age group 3 and weight group 3, and age group 4 and weight groups 4 and 5. Therefore, consistent differences in cold carcass weights attributable to gender were not observed.

As expected by design, positive trends in cold carcass weight with increasing liveweight were observed in ram lambs in age groups 1 and 2 ($r^2 = 0.89$ and 0.89, respectively, $P < 0.01$), ewe lambs in age groups 1 ($r^2 = 0.99$, $P < 0.01$), 2 ($r^2 = 0.81$, $P < 0.05$) and 3 ($r^2 = 0.95$, $P < 0.01$) and wether lambs in age groups 1 ($r^2 = 0.87$, $P < 0.05$), 2 ($r^2 = 0.78$, $P < 0.05$) and 3 ($r^2 = 0.97$, $P < 0.001$). These findings indicate cold carcass weights increased with slaughter weight in lambs up to 12 months of age. Since the only trends in cold carcass weights with advancing age were positive trends observed in ewe lambs in weight group 1 ($r^2 = 0.94$, $P < 0.05$) and ram lambs in weight group 2 ($r^2 = 0.92$, $P < 0.01$), it does not appear cold carcass weights are related to chronological age.

Notter et al. (1983) demonstrated the yield of carcass and trimmed cuts was influenced by both breed and feeding regime and indicated the slaughter weights which optimized yield of trimmed cuts from ram lambs of three early-maturing breeds.

In the present study, consistent differences attributable to gender were not observed in the proportion of hindsaddle and longsaddle ($P > 0.05$, in data not presented in tabular form). These findings appear contrary to the previous report of Carpenter et al. (1969) that ewe and wether lamb carcasses produced higher hindsaddle yields than ram lamb carcasses, probably as a result of ram lambs having heavier shoulders and ewe and wether lambs having more subcutaneous and body cavity fat. This disparity in findings can likely be explained by the fact that kidney and pelvic fat was removed prior to cutting in the present study. Carpenter et al. (1969)

concluded that if hindsaddle yield was adjusted to a constant level of body cavity fat, carcasses of different gender would likely be similar in hindsaddle yield.

Negative trends in the proportion of longsaddle with increasing slaughter weight were observed in ram lambs in age group 1 ($r^2 = 0.87$, $P < 0.01$) and wether lambs in age group 2 ($r^2 = 0.77$, $P < 0.05$). Such trends indicate the proportions of longsaddle decreased with increases in slaughter weight in young ram and wether lambs (six to nine months). Negative trends in the proportion of longsaddle were also observed with advancing age in ram lambs in weight groups 2 ($r^2 = 0.96$, $P < 0.01$) and 3 ($r^2 = 1.00$, $P < 0.001$), ewe lambs in weight group 5 ($r^2 = 0.94$, $P < 0.01$), and wether lambs in weight group 5 ($r^2 = 0.97$, $P < 0.01$). Therefore, the proportion of longsaddle appeared to decrease with advancing age.

The only trend observed in the proportion of hindsaddle was a negative trend observed in ewe lambs in age group 1 ($r^2 = 0.98$, $P < 0.01$). Therefore, the proportion of hindsaddle generally was not related to slaughter weight. Negative trends in the proportion of hindsaddle with advancing age were detected in ram lambs in weight groups 1 ($r^2 = 0.99$, $P < 0.001$), 2 ($r^2 = 0.99$, $P < 0.001$), and 3 ($r^2 = 0.99$, $P < 0.001$), and ewe lambs in weight groups 1 ($r^2 = 0.96$, $P < 0.01$). Therefore, the proportion of hindsaddle decreased with advancing age in lightweight ram (less than 58.6 kg) and ewe (less than 40.4 kg) lambs.

Proportion leg was positively related to proportion longsaddle ($r^2 = 0.59$), hindsaddle ($r = 0.79$) and shank ($r = 0.33$) and negatiely related to proportion loin ($r = -0.26$), rack ($r = -0.20$), shoulder ($r = -0.14$), breast ($r = -0.48$) and flank ($r = 0.42$) ($P < 0.0001$; Table 2).

Ram lamb carcasses had a greater proportion of leg than ewe lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 3, age group 3 and weight groups 2, 3 and 4, and age group 4 and weight groups 4 and 5 (Table 3). Ram lamb carcasses also had a higher proportion of leg than wether lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 3, age group 3 and weight groups 2, 3 and 4, and age group 4 and weight groups 4 and 5. However, ewe lamb carcasses had a greater proportion of leg than ram lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 1 and age group 3 and weight group 5. Ewe lamb carcasses also had a greater proportion of leg than wether lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 1. However, wether lamb carcasses had a greater proportion of leg than did ewe lamb carcasses ($P < 0.05$), when they were in age group 1 and weight group 4 and age group 2 and weight group 5. Wether lamb carcasses also had a higher proportion of leg than ram lamb carcasses ($P < 0.05$) when they were in age group 3 and weight group 5. Therefore, consistent differences attributable to gender were not observed in the proportion of leg.

Negative trends in the proportion of leg with increasing slaughter weight were detected only in ewe lambs in age group 1 ($r^2 = 0.97$, $P < 0.01$) and ram lambs in age group 2 ($r^2 = 0.87$, $P < 0.01$). Therefore, the proportion of leg was not related to slaughter weight. Significant trends in proportion of leg with advancing age were not observed ($P > 0.05$), indicating the proportion of leg was not related to advancing age.

Proportion of loin was positively related to proportion of longsaddle ($r = 0.54$), hindsaddle ($r = 0.38$), rack ($r = 0.51$, $P < 0.0001$), and breast ($r = 0.05$, $P < 0.05$), and negatively related to proportion of leg, shoulder and shank ($r = -0.26$, -0.46 and -0.21, respectively; $P < 0.0001$; Table 2).

Ram lamb carcasses had a greater proportion of loin than carcasses from both ewe and wether lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 4 (Table 3). However, ewe lamb carcasses had a greater proportion of loin than ram lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 1, age group 2 and weight group 3, age group 3 and weight groups 2, 3 and 4 and age group 4 and weight groups 4 and 5. Ewe lamb carcasses also had a greater proportion of loin

Table 2. Pearson correlation coefficient for relationships among the proportions of various cuts.

Cut	Long-saddle	Hind-saddle	Leg	Loin	Rack	Shoulder	Breast	Flank	Shank
Longsaddle	1.00	–	–	–	–	–	–	–	–
Hindsaddle	0.91[b]	1.00	–	–	–	–	–	–	–
Leg	0.59[b]	0.79[b]	1.00	–	–	–	–	–	–
Loin	0.54[b]	0.38[b]	−0.26[b]	1.00	–	–	–	–	–
Rack	0.53[b]	0.13[b]	−0.20[b]	0.51[b]	1.00	–	–	–	–
Shoulder	−0.47[b]	−0.43[b]	−0.14[b]	−0.46[b]	−0.25[b]	1.00	–	–	–
Breast	−0.39[b]	−0.41[b]	−0.48[b]	0.05[a]	−0.11[b]	−0.41[b]	1.00	–	–
Flank	−0.43[b]	−0.39[b]	−0.42[b]	0.02	−0.24[b]	−0.20[b]	0.57[b]	1.00	–
Shank	0.11[b]	0.19[b]	0.33[b]	−0.21[b]	−0.11[b]	−0.11[b]	−0.28[b]	−0.45[b]	1.00

[a] $P < 0.05$
[b] $P < 0.0001$

Table 3. Least squares means and standard errors (SE) for cold carcass weight and the proportions of the cold carcass in various untrimmed primal cuts from lambs in various age/weight/gender subclasses.

		Slaughter Weight Group									
		1 (31.8 to 40.4 kg)		2 (40.5 to 49.5 kg)		3 (50.0 to 58.6 kg)		4 (58.9 to 67.7 kg)		5 (68.2 to 76.8 kg)	
Age Group	Gender	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
						Proportion Leg, g/kg^{-1}					
1 (3 to 6 mo.)	Ram	31.5^{b}	0.33	31.7	0.31	31.4^{a}	0.28	30.7^{a,b}	0.28	29.3	1.15
	Ewe	32.7^{a}	0.33	31.2	0.32	30.5^{b}	0.27	30.5^{b}	0.33	–	–
	Wether	31.5^{b}	0.31	31.8	0.32	30.7^{b}	0.33	31.2^{a}	0.33	–	–
2 (6 to 9 mo.)	Ram	31.8	1.63	31.3	0.26	31.2	0.25	31.1	0.25	30.7^{a,b}	0.28
	Ewe	31.7	1.63	31.8	0.25	31.3	0.26	30.6	0.26	30.4^{b}	0.27
	Wether	–	–	31.4	0.24	31.4	0.23	31.1	0.25	31.2^{a}	0.28
3 (9 to 12 mo.)	Ram	31.2	1.15	31.6^{a}	0.27	32.0^{a}	0.25	31.3^{a}	0.25	29.8^{b}	0.27
	Ewe	–	–	30.7^{b}	0.27	30.3^{b}	0.25	30.2^{b}	0.26	30.5^{a}	0.28
	Wether	31.7	1.63	30.5^{b}	0.26	30.6^{b}	0.25	30.2^{b}	0.26	30.4^{a}	0.26
4 (12 to 15 mo.)	Ram	–	–	30.1	1.63	30.9	0.29	31.3^{a}	0.28	30.9^{a}	0.28
	Ewe	29.4	1.63	30.3	1.15	30.7	0.28	30.2^{b}	0.28	29.9^{b}	0.26
	Wether	–	–	–	–	30.4	0.27	30.5^{b}	0.27	29.8^{b}	0.25
						Proportion Loin, g/kg^{-1}					
1 (3 to 6 mo.)	Ram	8.6^{b}	0.22	9.4	0.20	9.5	0.19	10.0^{a}	0.18	10.3	0.76
	Ewe	9.4^{a}	0.22	9.4	0.21	9.7	0.18	8.7^{c}	0.22	–	–
	Wether	8.7^{b}	0.21	9.3	0.21	9.5	0.22	9.1^{b}	0.22	–	–
2 (6 to 9 mo.)	Ram	7.7	1.07	9.0	0.17	9.1^{b}	0.17	9.3	0.17	9.3	0.18
	Ewe	8.7	1.07	9.3	0.17	9.5^{a}	0.17	9.4	0.17	9.0	0.18
	Wether	–	–	9.3	0.15	9.2^{a,b}	0.15	9.2	0.17	9.3	0.18
3 (9 to 12 mo.)	Ram	8.0	0.76	7.9^{b}	0.18	8.0^{b}	0.16	8.1^{b}	0.16	8.7	0.18
	Ewe	–	–	8.4^{a}	0.18	8.9^{a}	0.16	8.7^{a}	0.17	8.8	0.18
	Wether	9.4	1.07	8.4^{a}	0.17	8.6^{a}	0.16	8.8^{a}	0.17	8.9	0.17
4 (12 to 15 mo.)	Ram	–	–	8.8	1.07	8.6^{b}	0.19	8.6^{b}	0.18	8.3^{c}	0.18
	Ewe	8.8	1.07	9.6	0.76	8.8^{a,b}	0.18	9.4^{a}	0.19	8.7^{b}	0.17
	Wether	–	–	–	–	9.1^{a}	0.18	9.3^{a}	0.18	9.1^{a}	0.16
						Proportion Rack, g/kg^{-1}					
1 (3 to 6 mo.)	Ram	7.3^{a,b}	0.16	7.3	0.15	7.4	0.14	7.2^{a}	0.13	7.2	0.56
	Ewe	7.6^{a}	0.16	7.6	0.15	7.5	0.13	6.7^{b}	0.16	–	–
	Wether	7.1^{b}	0.15	7.6	0.15	7.3	0.16	6.9^{a,b}	0.16	–	–
2 (6 to 9 mo.)	Ram	7.9	0.79	6.9^{b}	0.13	7.0^{b}	0.12	6.8^{b}	0.12	7.0	0.13
	Ewe	8.3	0.79	7.5^{a}	0.12	7.4^{a}	0.12	7.1^{a}	0.12	6.8	0.13
	Wether	–	–	7.4^{a}	0.11	6.9^{b}	0.11	7.1^{a}	0.12	6.8	0.13
3 (9 to 12 mo.)	Ram	5.6	0.56	6.2^{b}	0.13	6.3^{b}	0.12	6.1^{b}	0.12	6.5	0.13
	Ewe	–	–	6.6^{a}	0.13	6.7^{a}	0.12	6.5^{a}	0.13	6.3	0.13
	Wether	6.5	0.79	6.3^{b}	0.13	6.6^{a}	0.12	6.6^{a}	0.13	6.5	0.13
4 (12 to 15 mo.)	Ram	–	–	6.5	0.79	6.2^{b}	0.14	6.7	0.13	6.5	0.13
	Ewe	6.0	0.79	6.4	0.56	6.5^{a}	0.13	6.7	0.14	6.4	0.13
	Wether	–	–	–	–	6.4^{a,b}	0.13	6.6	0.13	6.6	0.12
						Proportion Shoulder, g/kg^{-1}					
1 (3 to 6 mo.)	Ram	26.2	0.41	25.5^{a}	0.38	24.9	0.35	24.7^{b}	0.34	25.0	1.42
	Ewe	25.6	0.41	25.1^{a,b}	0.39	25.0	0.33	26.3^{a}	0.41	–	–
	Wether	25.6	0.39	24.6^{b}	0.39	24.9	0.41	25.0^{b}	0.41	–	–
2 (6 to 9 mo.)	Ram	27.4	2.01	26.3^{a}	0.32	25.7^{a}	0.31	25.8	0.31	25.1^{b}	0.34
	Ewe	24.8	2.01	25.4^{b}	0.31	24.9^{b}	0.32	25.3	0.32	26.5^{a}	0.33
	Wether	–	–	25.8^{a,b}	0.29	25.6^{a}	0.28	25.7	0.31	26.0^{a}	0.34
3 (9 to 12 mo.)	Ram	26.0	1.42	27.0^{b}	0.33	27.0^{a}	0.31	26.9	0.31	26.9^{a}	0.33
	Ewe	–	–	26.6^{b}	0.33	25.8^{b}	0.31	26.7	0.33	27.3^{a}	0.34
	Wether	27.4	2.01	28.1^{a}	0.33	27.7^{a}	0.31	27.3	0.32	26.2^{b}	0.33
4 (12 to 15 mo.)	Ram	–	–	27.2	2.01	28.3^{a}	0.36	27.5^{a}	0.34	27.6^{a}	0.34
	Ewe	24.8	2.01	24.3	1.42	26.3^{b}	0.34	25.5^{b}	0.35	25.6^{b}	0.32
	Wether	–	–	–	–	26.0^{b}	0.33	25.4^{b}	0.33	25.4^{b}	0.31

than wether lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 1. However, wether lamb carcasses had a greater proportion of loin than ewe lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 4 and age group 4 and weight group 5. Wether lamb carcasses also had a greater proportion of loin than ram lamb carcasses ($P < 0.05$) when they were in age group 3 and weight groups 2, 3, and 4 and age group 4 and weight groups 3, 4 and 5. These findings indicate among gender classes, ram lamb carcasses had the lowest proportion of loin.

Positive trends in the proportion of loin with increasing slaughter weight were observed in ram lambs in age

Table 3. ***(Continued.)***

		Slaughter Weight Group									
		1 (31.8 to 40.4 kg)		2 (40.5 to 49.5 kg)		3 (50.0 to 58.6 kg)		4 (58.9 to 67.7 kg)		5 (68.2 to 76.8 kg)	
Age Group	Gender	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
						Proportion Breast, g/kg^{-1}					
1 (3 to 6 mo.)	Ram	12.8	0.27	13.2^{b}	0.25	13.7^{b}	0.23	14.0	0.23	15.0	0.95
	Ewe	12.3	0.27	13.8^{a}	0.26	14.2^{a}	0.22	14.4	0.27	–	–
	Wether	13.4	0.26	13.3^{a,b}	0.26	14.5^{a}	0.28	14.1	0.27	–	–
2 (6 to 9 mo.)	Ram	13.6	1.34	13.5^{a}	0.21	13.8	0.21	13.8	0.21	14.8^{a}	0.23
	Ewe	13.5	1.34	13.6^{a}	0.21	13.8	0.21	14.1	0.21	13.9^{b}	0.22
	Wether	–	–	12.8^{b}	0.19	13.8	0.19	14.0	0.21	14.1^{b}	0.23
3 (9 to 12 mo.)	Ram	15.6	0.95	13.8^{b}	0.22	13.1^{b}	0.20	13.8^{b}	0.20	14.8^{a}	0.22
	Ewe	–	–	14.5^{a}	0.22	14.9^{a}	0.20	14.6^{a}	0.22	13.9^{b}	0.23
	Wether	13.7	1.34	13.3^{c}	0.22	13.5^{b}	0.20	13.7^{b}	0.21	14.5^{a}	0.22
4 (12 to 15 mo.)	Ram	–	–	15.3	1.34	13.3^{b}	0.24	13.3^{b}	0.23	13.7^{b}	0.23
	Ewe	16.3	1.34	16.0	0.95	14.5^{a}	0.23	14.8^{a}	0.23	13.5^{b}	0.21
	Wether	–	–	–	–	14.7^{a}	0.22	14.6^{a}	0.22	15.2^{a}	0.20
						Proportion Flank, g/kg^{-1}					
1 (3 to 6 mo.)	Ram	4.2	0.19	4.4	0.18	4.7^{b}	0.16	5.0^{b}	0.16	4.9	0.67
	Ewe	4.2	0.19	4.7	0.18	5.2^{a}	0.16	5.9^{a}	0.19	–	–
	Wether	4.5	0.18	4.5	0.18	5.1^{a,b}	0.19	5.2^{b}	0.19	–	–
2 (6 to 9 mo.)	Ram	4.9	0.94	4.9	0.15	5.0	0.15	5.0	0.15	5.0^{b}	0.16
	Ewe	5.0	0.94	4.8	0.15	4.9	0.15	5.1	0.15	5.8^{a}	0.16
	Wether	–	–	4.7	0.14	5.1	0.13	5.2	0.15	5.8^{a}	0.16
3 (9 to 12 mo.)	Ram	5.8	0.67	5.4^{b}	0.16	5.1^{b}	0.14	5.7^{b}	0.14	5.9^{b}	0.16
	Ewe	–	–	5.8^{a}	0.16	5.1^{b}	0.14	6.5^{a}	0.15	6.3^{a}	0.16
	Wether	5.0	0.94	5.5^{a,b}	0.15	5.6^{a}	0.14	5.9^{b}	0.15	6.1^{a,b}	0.15
4 (12 to 15 mo.)	Ram	–	–	4.9	0.94	5.3^{b}	0.17	4.9^{b}	0.16	5.5^{b}	0.16
	Ewe	6.9	0.94	6.0	0.67	5.5^{a,b}	0.16	5.6^{a}	0.16	6.5^{a}	0.15
	Wether	–	–	–	–	5.9^{a}	0.16	5.8^{a}	0.16	6.2^{a}	0.14
						Proportion Shank, g/kg^{-1}					
1 (3 to 6 mo.)	Ram	6.0^{a}	0.14	5.9^{a}	0.13	5.6^{a}	0.12	5.4^{a}	0.12	5.2	0.50
	Ewe	5.5^{b}	0.15	5.3^{c}	0.14	5.3^{b}	0.12	5.0^{b}	0.15	–	–
	Wether	6.0^{a}	0.14	5.6^{b}	0.14	5.0^{c}	0.15	5.4^{a}	0.15	–	–
2 (6 to 9 mo.)	Ram	5.6	0.71	5.3	0.11	5.3	0.11	5.2	0.11	5.2^{a}	0.12
	Ewe	5.0	0.71	5.2	0.11	5.2	0.11	5.1	0.11	4.9^{b}	0.12
	Wether	–	–	5.3	0.10	5.2	0.10	5.0	0.11	4.9^{b}	0.12
3 (9 to 12 mo.)	Ram	5.6^{a}	0.50	5.3^{a}	0.12	5.5^{a}	0.11	5.3^{a}	0.11	5.0^{a}	0.12
	Ewe	–	–	5.0^{b}	0.12	4.9^{b}	0.11	4.7^{c}	0.12	4.7^{b}	0.12
	Wether	3.9^{b}	0.71	5.0^{b}	0.12	4.9^{b}	0.11	5.0^{b}	0.11	5.0^{a}	0.12
4 (12 to 15 mo.)	Ram	–	–	4.9	0.71	5.2	0.13	5.3^{a}	0.12	5.3^{a}	0.12
	Ewe	4.5	0.71	5.1	0.50	5.2	0.12	5.1^{a,b}	0.12	4.8^{b}	0.11
	Wether	–	–	–	–	5.0	0.12	5.0^{b}	0.12	5.1^{a}	0.11

^{a,b,c} Means in the same column and trait and age group without a superscript or bearing a common superscript do not differ significantly ($P > 0.05$).

groups 1 ($r^2 = 0.96$, $P < 0.001$) and 2 ($r^2 = 0.94$, $P < 0.01$), indicating the proportion of loin increased with slaughter weight in young ram lambs (less than nine months). Negative trends in the proportion of loin with advancing age were detected in ram lamb carcasses in weight group 5 ($r^2 = 0.99$, $P < 0.01$) and ewe lamb carcasses in weight group 3 ($r^2 = 0.91$, $P < 0.05$), indicating the proportion of loin decreased with advancing age in lambs in these subclasses.

Proportion of rack was positively related to proportion of longsaddle ($r = 0.53$), hindsaddle ($r = 0.13$) and loin ($r = 0.51$), and negatively related to proportion of leg ($r = -0.20$), shoulder ($r = -0.25$), breast ($r = -0.11$), flank ($r = -0.24$) and shank ($r = -0.11$, $P < 0.0001$; Table 2).

Ram lamb carcasses had a greater proportion of rack than ewe lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 4 (Table 3). However, ewe lamb carcasses had a greater proportion of rack than ram lamb carcasses ($P < 0.05$) when they were in age groups 2 and 3 and weight groups 2, 3 and 4 and age group 4 and weight group 3. Ewe lamb carcasses also had a greater proportion of rack than wether lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 1, age group 2 and weight group 3, and age group 3 and weight group 2. Wether lamb carcasses also had a higher proportion of rack than ram lamb carcasses ($P < 0.05$) when they were in age group 2 and weight groups 2 and 4 and age group 3 and weight groups 3 and 4. Such findings indicate ewe lamb carcasses had the highest and ram lamb carcasses had the lowest proportion of rack.

A negative trend in the proportion of rack observed in ewe lambs in age group 2 was the only significant trend detected with increasing slaughter weight ($r^2 = 0.99$, $P < 0.001$). Negative trends in the proportion of rack with advancing age were detected in ram lamb carcasses in weight group 3 ($r^2 = 0.94$, $P < 0.01$), ewe lamb carcasses in weight groups 2 ($r^2 = 0.85$, $P < 0.05$) and 3 ($r^2 = 0.87$, $P < 0.05$) and wether lamb carcasses in age group 3 ($r^2 = 0.99$, $P < 0.01$). These findings indicate the proportion of rack decreased with advancing age in lightweight lambs (less than 58.6 kg).

Due to the fact that consistent differences attributable to gender were not observed in the present study in the proportion of leg and because ram lamb carcasses generally had the lowest proportion of loin and rack, present findings fail to support previous reports that ram lamb carcasses had higher yields of preferred cuts than ewes and wethers (Carpenter et al., 1969; Oliver et al., 1967; Cunningham et al., 1967; Ray and Mandigo, 1966). However, it should be noted that wholesale cuts were not trimmed in the present study but were trimmed in previous studies.

Proportion of shoulder was negatively related to proportion of longsaddle ($r = -0.47$), hindsaddle ($r = -0.43$) and all other cuts ($P < 0.0001$; leg: $r = -0.14$; loin: $r = -0.46$; rack: $r = -0.25$; breast: $r = -0.41$; flank: $r = -0.20$; and shank: $r = -0.11$; Table 2), indicating increases in the proportion of shoulder decreased as the proportion of all other cuts increased.

Ram lamb carcasses had a greater proportion of shoulder than ewe lamb carcasses ($P < 0.05$) when they were in age group 2 and weight groups 2 and 3, age group 3 and weight group 3, and age group 4 and weight groups 3, 4 and 5 (Table 3). Ram lamb carcasses also had a greater proportion of shoulder than wether lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 2, age group 3 and weight group 5, and age group 4 and weight groups 3, 4 and 5. However, ewe lamb carcasses had a greater proportion of shoulder than ram lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 4 and age group 2 and weight group 5. Ewe lamb carcasses also had a greater proportion of shoulder than wether lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 4 and age group 3 and weight group 5. However, wether lamb carcasses had a greater proportion of shoulder than ewe lamb carcasses ($P < 0.05$) when they were in age group 2 and weight group 3 and age group 3 and weight groups 2 and 3. Wether lamb carcasses also had a greater proportion of shoulder than ram lamb carcasses ($P < 0.05$) when they were in age group 2 and weight group 3 and age group 3 and weight groups 2 and 3. Therefore, consistent differences in the proportion of shoulder attributable to gender were not observed. Such findings fail to support a previous report that ram lamb carcasses had a higher proportion of shoulder (Carpenter et al., 1969).

A negative trend in the proportion of shoulder was observed in ram lamb carcasses in age group 2 ($r^2 = 0.93$, $P < 0.01$) was the only significant trend detected with increasing slaughter weight. Positive trends in the proportion of shoulder with advancing age were observed in ram lamb carcasses in weight groups 2 ($r^2 = 0.97$, $P < 0.01$), 3 ($r^2 = 0.96$, $P < 0.01$), 4 ($r^2 = 0.99$, $P < 0.001$), and 5 ($r^2 = 0.85$, $P < 0.05$) and wether lamb carcasses in weight group 2 ($r^2 = 0.92$, $P < 0.05$). Therefore, the proportion of shoulder increased with advancing age, particularly in carcasses from ram lambs weighing over 40 kg live.

Proportion of breast was positively related to proportion of flank ($r = 0.57$, $P < 0.0001$) and loin ($r = 0.05$, $P < 0.0001$), but negatively related to the proportion of all other cuts (longsaddle: $r = -0.39$, hindsaddle: $r = -0.41$; leg: $r = -0.48$; rack: $r = -0.11$; shoulder: $r = -0.41$; shank: $r = -0.28$; Table 2).

Ram lamb carcasses had a higher proportion of breast than ewe lamb carcasses ($P < 0.05$) when they were in age group 2 and weight group 5 and age group 3 and weight group 5 (Table 3). Ram lamb carcasses also had a greater proportion of breast than wether lamb carcasses ($P < 0.05$) when they were in age group 2 and weight groups 2 and 5 and age group 3 and weight group 2. However, ewe lamb carcasses had a greater proportion of breast than ram lamb carcasses ($P < 0.05$) when they were in age group 1 and weight groups 2 and 3, age group 3 and weight groups 2, 3 and 4, and age group 4 and weight groups 3 and 4. Ewe lamb carcasses

also had a higher proportion of breast than wether lamb carcasses ($P < 0.05$) when they were in age group 2 and weight group 2 and age group 3 and weight groups 2, 3 and 4. However, wether lamb carcasses had a greater proportion of breast than ewe lamb carcasses ($P < 0.05$) when they were in age group 3 and weight group 5 and age group 4 and weight group 5. Wether lamb carcasses also had a greater proportion of breast than ram lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 3 and age group 4 and weight groups 3, 4 and 5. Consequently, consistent differences in the proportion of breast attributable to gender were not observed.

Although positive trends in the proportion of breast with increasing slaughter weight were observed in ram lamb carcasses in age group 1 ($r^2 = 0.84$, $P < 0.05$), ewe lamb carcasses in age group 1 ($r^2 = 0.99$, $P < 0.001$) and wether lamb carcasses in age group 2 ($r^2 = 0.99$, $P < 0.001$), a negative trend in the proportion of breast with increasing slaughter weight was detected in ewe lamb carcasses in age group 4 ($r^2 = 0.74$, $P < 0.05$). Such inconsistency in trends indicates the proportion of breast was not related to slaughter weight. A negative trend in the proportion of breast in ram lamb carcasses in weight group 5 was the only significant trend observed with advancing age ($r^2 = 0.67$, $P < 0.05$), suggesting the proportion of breast was not related to chronological age.

Proportion of flank was positively related to proportion of breast ($r = 0.57$) but negatively related to the proportion of all other cuts, except proportion of loin (longsaddle: $r = -0.43$; hindsaddle: $r = -0.39$; leg: $r = -0.42$; rack: $r = -0.24$; shoulder: $r = -0.20$; shank: $r = -0.28$; Table 2).

Ewe lamb carcasses had a greater proportion of flank than ram lamb carcasses ($P < 0.05$) when they were in age group 1 and weight groups 3 and 4, age group 2 and weight group 5, age group 3 and weight groups 2, 4 and 5 and age group 4 and weight groups 4 and 5 (Table 3). Ewe lamb carcasses also had a greater proportion of flank than wether lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 4 and age group 3 and weight group 4. However, wether lamb carcasses had a greater proportion of flank than ewe lamb carcasses ($P < 0.05$) when they were in age group 3 and weight group 3. Wether lamb carcasses also had a greater proportion of flank than ram lamb carcasses ($P < 0.05$) when they were in age group 2 and weight group 5, age group 3 and weight group 3 and age group 4 and weight groups 3, 4 and 5. Such findings indicate that among gender classes, ram lamb carcasses generally had the lowest proportion of flank.

Positive trends in the proportion of flank with increasing slaughter weight were observed only in ewe carcasses in age group 1 ($r^2 = 0.83$, $P < 0.05$) and wether carcasses in age group 3 ($r^2 = 0.96$, $P < 0.001$), indicating the proportion of flank was not related to slaughter weight. However, positive trends in the proportion of flank with advancing age were detected in ram lamb carcasses in weight groups 1 ($r^2 = 097$, $P < 0.01$) and 3 ($r^2 = 0.99$, $P < 0.001$), ewe lamb carcasses in weight group 2 ($r^2 = 0.85$, $P < 0.05$) and wether lamb carcasses in weight groups 3 ($r^2 = 0.87$, $P < 0.05$) and 5 ($r^2 = 0.99$, $P < 0.001$), indicating the proportion of flank increased with advancing age.

Proportion of shank was positively related ($P < 0.0001$) to proportion of longsaddle ($r = 0.11$), hindsaddle ($r = 0.19$) and leg ($r = 0.33$), and negatively related ($P < 0.001$) to proportion loin ($r = -0.21$), rack ($r = -0.11$), shoulder ($r = -0.11$), breast ($r = -0.28$) and flank ($r = -0.45$; Table 2).

Ram lamb carcasses had a higher proportion of shank than ewe lamb carcasses ($P < 0.05$) when they were in age group 1 and weight groups 1, 2, 3 and 4, age group 2 and weight group 5, age group 3 and weight groups 2, 3, 4 and 5, and age group 4 and weight group 5 (Table 3). Ram lamb carcasses also had a higher proportion of shank than wether lamb carcasses ($P < 0.05$) when they were in age group 1 and weight groups 2 and 3, age group 2 and weight group 5, age group 3 and weight groups 1, 2, 3 and 4, and age group 4 and weight group 4. Ewe lamb carcasses also had a greater proportion of shank than wether lamb carcasses ($P < 0.05$) when they were in age group 1 and weight group 3. However, wether lamb carcasses had a greater proportion of shank than ewe lamb carcasses ($P < 0.05$) when they were in age group 1 and weight groups 1, 2 and 4, age group 3 and weight groups 4 and 5, and age group 4 and weight group 5. These findings suggest ram lamb carcasses had the greatest proportion of shank.

Although negative trends in the proportion of shank with increasing slaughter weight were observed in ram lamb carcasses in age group 1 ($r^2 = 0.80$, $P < 0.05$), ewe lamb carcasses in age groups 1 and 3 ($r^2 = 0.77$ and 0.80, respectively, $P < 0.05$) and wether lamb carcasses in age group 2 ($r^2 = 0.78$, $P < 0.05$), a positive trend in the proportion of shank with increasing slaughter weight was detected in ram lamb carcasses in age group 4 ($r^2 = 0.98$, $P < 0.001$). Such findings indicate the proportion of shank decreased with slaughter weight in young lambs (less than 12 months) and increased with slaughter weight in older ram lambs (more than 12 months).

Although negative trends in the proportion of shank with advancing age were detected in ram lamb carcasses in weight group 2 ($r^2 = 0.92$, $P < 0.01$) and wether lamb carcasses in weight group 2 ($r^2 = 0.99$, $P < 0.01$), a positive trend in the proportion of shank was observed in wether lamb carcasses in weight group 5 ($r^2 = 0.94$, $P < 0.05$). Such findings suggest the proportion of shank decreased with advancing age in lightweight lambs (less than 50.0 kg live) and increased with advancing age in heavyweight wether lambs (more than 68.2 kg live).

Present findings fail to support a previous report that ram lambs were higher yielding than ewes and wethers (Carpenter et al., 1969) and reports that ewes and wethers differed in cutability (Boylan and Seale, 1965; Oliver et al., 1967; Field et al., 1963). These findings, however, are consistent with previous reports that ewes and wethers were similar in cutability

(Carpenter et al., 1969; Judge et al., 1966; Knight and Foote, 1965).

Conclusions

To obtain the highest yield of high value cuts, lambs should be marketed at younger ages and lighter weights; and to obtain the greatest dressing yields, lambs, and particularly ram lambs, should be marketed at lighter weights. However, to prevent excessive preslaughter shrink, young ram lambs (less than 12 months of age) should be shielded from antemortem stress.

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Research Briefs

Responses in Wool and Live Weight when Different Sources of Dietary Protein are Given to Pregnant or Lactating Ewes

D.G. Masters, C.A. Stewart, G. Mata and N.R. Adams

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Cited from: Animal Science 62:497-506 (1996).

During late pregnancy, nutrients are required for foetal growth and udder development as well as growth of wool and other maternal tissues. Priorities for nutrients favor the foetus for most breeds. A severe nutritional deficit is necessary to cause a serious decline in foetal growth. In contrast, wool growth may be drastically reduced during late pregnancy. Also, quality traits such as length or strength may also be affected. A study (involving 200 ewes) was conducted to evaluate the response in wool growth, ewe live weight and lamb birth weight and growth to different types of dietary protein. Only ewes with a single foetus were used in the experiment, which lasted from 122 days of gestation through 21 days of lactation. Diets were formulated to contain equal amounts of Metabolizable Energy (ME) and protein, but differing protein solubility. The three sources of protein were Lupineseed (highly soluble), fish meal or formaldehyde-treated egg albumin (protected). The ewes were fed to maintain conceptus-free live weight. Both fish meal and treated eggwhite increased fleece growth and staple strength (reduced breakage), but did not significantly increase lamb growth rate. The authors conclude that benefits were obtained from an increased supply of protein available for absorption in the small intestines rather than the provision of specific amino acids.

– Prepared by Maurice Shelton

Analysis of the Genetic Relationship between Litter Size and Weight Traits of Segurena Sheep

M. Analla, A. Munoz-Serrano and J.M. Serradilla

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Cited from: Canadian Journal of Animal Science. 77:17-21 (1996)

The Segurena is a hardy breed, well adapted to the harsh environments and extensive production systems prevailing in this region of Spain. Improvement of litter size is considered to be the first goal in improving meat production from this breed. The authors suggest approximately 30% reduction in production costs if twin-producing ewes are substituted for single-producing ewes. The lambs are weaned at about 45 days and slaughtered at around 90 days. Data were analyzed from 8,117 animals to estimate the genetic parameters related to reproductive and growth traits (at these early ages). The heritability of litter size was estimated at 0.08 which is very similar to other estimates in the literature. The heritability of weaning weight (45 days) and slaughter weight (90 days) was estimated to be 0.34 and 0.28, respectively. The authors estimated a genetic correlation of 0.18, 0.48 and 0.36 between litter size and birth weight, weaning weight and slaughter weight, respectively. The authors failed to find an environmental correlation (near zero) between litter size and the weight traits. This is somewhat surprising and might bring into question the other parameter estimates. The authors conclude that it is possible to select for litter size without bringing about deterioration in breeding values for the weight traits. In this reviewer's opinion, the results may not have been the same if gain or body size later in life formed the basis of comparison or selection. Other studies have suggested that early (sexual) maturity and reproductive rate may be positively related.

– Prepared by Maurice Shelton

News and Notes

Larry D. Young, 1950–1997

Larry Young was a native of Indiana, earning a BS degree in animal science from Purdue University in 1972. He received MS and PhD degrees in animal breeding from Oklahoma State University in 1973 and 1975, respectively. He served as a postdoctoral research associate at the University of Nebraska during part of 1976. Larry joined the staff of the U.S. Meat Animal Research Center in 1976 where he conducted breeding and genetics research in sheep and swine with particular emphasis on the genetics of reproduction. He was also an Adjunct Associate Professor in the Department of Animal Science at the University of Nebraska. Larry Young died on March 3, 1997, after battling cancer for over three years.

Larry served on the Genetics Review Panel of the Sheep and Goat Research Journal since 1985. He participated in various activities of the U.S. sheep industry and made many significant contributions as a scientist. Larry will be greatly missed by all who had the privilege of calling him their colleague and friend.

Memorials in his name may be made to the Larry Young Memorial Fund, 839 N. Lexington Ave., Hastings, NE 68901. The money will be used to support cancer research.

Sheep & Goat Research Journal
Guidelines for Authors

Objective

The aim of the Sheep & Goat Research Journal is to provide a publication of sheep and goat research findings which can be used by scientists, educators, Extension agents and sheep and goat producers alike. The specific goal of the Journal is to gather and distribute current research information on all phases of sheep and goat production and to encourage producer use of research which has practical application. The Journal is published three times each year.

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We are most interested in publishing articles of research relating to all aspects of sheep and goat production and marketing. Articles should relate and contribute to the advancement of the American sheep and goat industries and/or their products. All research manuscripts must represent unpublished original research. The submission of review articles is encouraged but will require review as well as those reporting original research. Articles which promote commercial products or services will not be approved for publication. Conclusions reached must be supported by research results. An orientation to practical applied research which may be useful to the sheep and goat industries is encouraged. At least one author of each manuscript must subscribe to the Journal.

Review Process

Manuscripts will be subject to critical review by an editorial board or others designated by the editor. Authors will be notified of acceptance or rejection of papers by mail. Manuscripts needing revision will be returned to authors and should be revised and returned by the deadline indicated. When papers are accepted for publication, the authors must send a floppy disk with the manuscript in the ASCII file format along with two hard copies. Papers not suitable for publication will be returned to the authors with a statement of reasons for rejection. Consult the Sheep & Goat Research Journal Editorial Policy and Procedures for details of the technical requirements for manuscripts submitted to the Journal.

Guidelines

Several sources were consulted, including the Journal of Animal Science and the Council of Biology Editors, Inc., when preparing these guidelines. Though the nature of the Journal is such that relatively few regulations are needed on style and form, we have attempted to standardize the manner in which the material is published as a service to Journal subscribers. Following are general guidelines for style and form.

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Manuscripts must be typed and double-spaced; five copies must be submitted. The lines on all pages including those pages for Literature Cited and Figure Legends must be numbered in the left margin beginning with the numeral one (1) at the top of the page. Tables should be as few and as simple as is feasible for presentation of the essential data; tables should be typed and double-spaced. Each table should be on a separate sheet. All figures used in the text must be camera-ready. The author will be billed at full cost if figure preparation is required.

Research manuscripts should follow the format of:

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2nd	**Key Words** (up to 6)
3rd	**Introduction**
4th	**Materials and Methods**
5th	**Results and Discussion**
6th	**Conclusions**
7th	**Literature Cited**

In citing literature in the text, use both authors if there are only two. If there are more than two, use the first author and "et al." Authors are asked to provide "interpretive summaries" for use by the sheep and goat industries in other media.

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Primary authors will receive galley proofs of articles. Corrected proofs should be returned by the deadline indicated. Failure to do so will result in delay of article publication.

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The publication charge for the Sheep & Goat Research Journal is $60.00 per page and position announcements are $30.00 per quarter-page or less. Contributors will be billed following publication. All manuscripts and correspondence should be addressed to: Sheep & Goat Research Journal, 6911 South Yosemite Street, Englewood, CO 80112-1414; unless noted otherwise on materials received from the editorial staff.

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Volume 13, Number 2: 1997

Contents:

American Sheep Industry Association

Feed Intake and Digestion by Different Breeds of Ewes in Early- to Mid-Gestation Consuming Different Hay Harvests of Two Tropical Grasses[1,2]

A.L. Goetsch[3,4], G.E. Aiken[3], M.A. Brown[3] and Z.B. Johnson[5]

Summary

Twenty-four ewes (21 months old) of four breed groups (St. Croix, S; St. Croix × Romanov, SR; St. Croix × Texel, ST; Gulf Coast Native, N) in early- to mid-gestation were used in an experiment (4-by-2-by-3 factorial) to determine effects and interactions in feed intake and digestibility of breed group, tropical grass source (Eastern gamagrass, GG; switchgrass, SG) and hay-cutting treatment (1 = primary growth harvested on June 12, 1995; 2 = primary growth harvested on August 14, 1995; 3 = regrowth from June 12 to August 14, 1995). Three ewes of each breed group consumed the hay-cutting treatments of GG or SG in eight simultaneous 3-by-3 Latin squares. Soybean meal was supplemented and body weight (BW) was 39, 49, 46 and 59 kg (SE = 2.5) for S, SR, ST and N, respectively. Interactions between breed groups and dietary forage treatments (grass source and hay-cutting treatment) did not occur ($P > 0.10$). Hay dry matter intake ranked ($P < 0.05$) hay-cutting treatment 3 > 2 > 1 for GG and 2 < 1 and 3 for SG (59, 50, 67, 49, 38 and 46 g/kg $BW^{0.75}$ for GG-1, GG-2, GG-3, SG-1, SG-2 and SG-3, respectively; SE = 1.5) and was 60, 57, 48 and 40 g/kg $BW^{0.75}$ for S, SR, ST and N, respectively (SE = 2.6). Hay organic matter digestibility was greater ($P < 0.05$) for GG versus SG and for cuttings 1 and 3 versus 2 (52, 41, 53, 36, 22 and 34% for GG-1, GG-2, GG-3, SG-1, SG-2 and SG-3, respectively; SE = 2.1). Digestible hay organic matter intake differed among treatments as noted for hay intake (28.1, 20.1, 32.8, 16.8, 8.0 and 14.8 g/kg $BW^{0.75}$ for GG-1, GG-2, GG-3, SG-1, SG-2 and SG-3, respectively; SE = 1.22) and was 23.1, 23.5, 19.0 and 14.9 g/kg $BW^{0.75}$ (SE = 1.63) for S, SR, ST and N, respectively. In conclusion, effects on intake and digestibility of grass source and hay-cutting treatment were similar among breed groups, and grass characteristics impacting feed intake were affected by hay-cutting treatment differently between GG and SG. S and SR may be better suited for early- to mid-gestation consumption of such tropical grass hay sources compared with ST, and need for or importance of supplementation for BW maintenance may be greatest for N.

Key words: ewe, breed, feed intake, digestibility, grass.

Introduction

Eastern gamagrass (GG; *Tripsacum dactyloides* L.) and switchgrass (SG; *Panicum virgatum* L.) are tropical grasses grown in the midwestern and eastern United States (Hitchcock, 1951). Forage quality can be high for both Eastern gamagrass (Horner et al., 1985; Kalmbacher et al., 1991; Burns et al., 1992) and switchgrass (Twidwell et al., 1988; George and Obermann, 1989). However, little knowledge exists regarding nutritive value for sheep of these grasses in the midsouthern or southcentral U.S., and little information regarding feed intake is available. Although grazing obviously offers advantages over

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feeding harvested forage (for example, equipment costs), in some areas of the U.S. such as the mid-south, moderate- to low-quality hay is fed by many livestock producers for a major portion of the year when tropical grasses are not actively growing. Thus, information regarding differences among potential tropical grasses and various hay harvesting schemes in nutritive value for gestating ruminants is desirable.

Environmental conditions in the southern and southcentral U.S. dictate consideration of breeds tolerant of heat and humidity, examples of which are the St. Croix (S) and Gulf Coast Native (N; Fernandez et al., 1994; Brown and Jackson, 1995; Fernandez and Pond, 1995). While these breeds are heat tolerant, they typically do not excel in litter size and are lightly muscled. In order to take advantage of the heat tolerance of these breeds, they can be crossed with breeds that excel in reproductive and growth traits. However, abilities of various sheep breeds and crosses to consume high quantities of digestible nutrients with low-quality tropical grasses, which frequently are consumed in gestation, are unknown.

Feed intake may be physiologically controlled (Ketelaars and Tolkamp, 1992; Leng et al., 1993; Goetsch and Patil, 1997) and sheep breeds and crosses vary physiologically in attributes such as mature size, rate of maturation, body composition and potentials for nutrient use in accretion of protein and fat (Foote, 1983; Notter et al., 1983; Fahmy et al., 1992; Burleigh et al., 1994; Fernandez et al., 1994; Fernandez and Pond, 1995; Freetly et al., 1995). Hence, interactions between breed groups and dietary forage treatments are possible. Knowledge of such interactions would facilitate improved matching of particular genotypes to specific forage environments and would enable proper supplementation of biological types when inappropriately matched with nutritional settings. Therefore, the objectives of this experiment were to determine differences in feed intake and digestibility among six tropical grass treatments and four sheep breed groups and to assess interactions between dietary forage and breed group treatments.

Materials and Methods

Animals

Twenty-four ewes approximately 21 months in age, in early- to mid-gestation and with one previous lambing, were used in an experiment (4-by-2-by-3 factorial arrangement of treatments) with eight simultaneous 3-by-3 Latin squares. Animals were cared for in accordance with guidelines of Consortium (1988), with approval of the experimental protocol by the Institutional Animal Care and Use Committee of the Dale Bumpers Small Farms Research Center (Booneville, AR). The experiment began on October 26, 1995, with breeding in September. Ewes were of four breed groups (St. Croix, S; St. Croix × Romanov, SR; St. Croix × Texel, ST; Gulf Coast Native, N [six per breed]) and had been managed similarly before the experiment. Ewes were dewormed at initiation of the experiment, and during the trial resided in 1.2-by-1.2 m lambing pens. Prior to the experiment ewes had grazed common bermudagrass (*Cynodon dactylon* L., Pers.) pasture during the day. Approximately 0.45 kg (air-dry) of ground corn was supplemented for two weeks prior to and during the 35-day breeding period.

Diets

Six diets consisted of three hay cuttings of Eastern gamagrass (*Tripsacum dactyloides* L.) and three of switchgrass (*Panicum virgatum* L.). One hectare plots for hay harvest were of similar soil type and fertilized with nitrogen (86 kg/hectare), phosphorus (33 kg/hectare) and potassium (63 kg/hectare) on April 14, 1995. Primary growth was harvested on June 12 and August 14, 1995 (hay-cutting treatments 1 and 2, respectively). Hay-cutting treatment 3 was regrowth from June 12 to harvest on August 14, 1995. Hay was ground to pass a 1.9-cm screen. Growth stage for hay-cutting treatment 1 was late-boot and mid- to late-boot for GG and SG, respectively; the growth stage of hay-cutting treatments 2 and 3 was anthesis.

Four Latin squares entailed feeding of GG hay-cutting treatments and four were with those of SG. Three ewes of each breed group consumed GG hay-cutting treatments in the three 21-day periods of each square and the other three ewes consumed SG hay cuttings. Hay was fed once daily (0700 hours) ad libitum (105 to 110% of consumption on the preceding few days). Refused hay was removed and weighed immediately preceding 0700 hours. To avoid ruminal nitrogen deficiencies, soybean meal was top-dressed on hay (0.18, 0.44, 0.32, 0.34, 0.51 and 0.40% of initial body weight for GG-1, GG-2, GG-3, SG-1, SG-2 and SG-3, respectively; as-fed basis) and consumed completely. In addition, 4 g/day of a mixture of NaCl (42.9%), dicalcium phosphate (34.3%), trace mineral premix (14.3%; contained at least 12% Zn, 10% Fe, 8% Mn, 1.5% Cu, 0.3% I, 0.1% Co and 0.02% Se; air-dry basis) and vitamin premix (8.6%; contained at least 8.8 million IU vitamin A, 1.8 million IU vitamin D_3 and 1,100 IU vitamin E per kg; air-dry basis) was top-dressed on hay.

Sampling and Analyses

Hay and soybean meal composite samples were created by sampling on days 16 to 21. Fecal grab samples were obtained on the last four days of each period at 12-hour intervals advancing 3 hours daily. Ewes were weighed at the end of each period. Hay samples were ground to pass a 1-mm screen. Fecal samples were dried at 55 °C and ground to pass a 2-mm screen; composite fecal samples were then constructed (air-dry basis) and ground to pass a 1-mm screen. Feed and fecal samples were analyzed for dry matter (DM; 100 °C), ash, Kjeldahl nitrogen (N; AOAC, 1984), neutral detergent fiber (NDF; filter bag technique; ANKOM Technology Corp., Fairport, NY) and acid insoluble ash (2*N*-HCl; Van Keulen and Young, 1977). Hay samples also were analyzed for acid detergent fiber and lignin (filter bag technique; ANKOM Technology Corp., Fairport, NY), with cellulose determined as loss in weight upon sulfuric acid treatment and hemicellulose as the difference between NDF and acid detergent fiber concentrations.

Calculations

Feed intake was determined as the average of intake on the two days preceding and four days of fecal sampling. Acid-insoluble ash was used as an inert, internal marker to estimate digestibilities. To estimate digestibility of hay organic matter (OM), an apparent total tract digestibility of soybean meal OM of 88% (total digestible nutrient concentration; NRC, 1985) was assumed. The net energy for maintenance requirement was calculated as 56 kcal/kg of body weight$^{0.75}$ (NRC, 1985). Digestible energy intake was estimated assuming 4.547 kcal/g of digestible OM intake (Goetsch and Patil, 1997), metabolizable energy intake as 82% of digestible energy intake (NRC, 1985) and net energy intake as 60% of metabolizable energy intake (Tolkamp and Ketelaars, 1994).

Statistical Analyses

Data were analyzed as a split-plot by General Linear Models procedures of SAS (1990), with a model consisting of breed group, grass source (GG or SG), breed group-by-grass source, animal within breed group-by-grass source (error term for previous variation sources), period, hay cutting or harvest, breed group-by-hay cutting, grass source-by-hay cutting and breed group-by-grass source-by-hay cutting. The latter term was not significant ($P > 0.05$) for any variable; nor were two-way interactions involving breed group significant ($P > 0.05$). Differences among means (breed group, grass source, hay cutting and/or grass source-by-hay cutting) were determined by least significant difference procedures when the treatment F-test was significant ($P < 0.05$). Means for grass source-by-hay cutting are presented for all variables regardless of significance; whereas, tabular presentation of breed group means occurs only when the breed group effect was significant ($P < 0.05$). Regression procedures of SAS (1990) were used to determine standardized partial regression coefficients.

Results and Discussion

Forage Composition

As expected, crude protein concentration was lowest among hay-cutting treatments for treatment 2 (Table 1). Within all hay-cutting treatments, crude protein concentration was slightly greater for GG than for SG, with differences between grass sources ranking hay-cutting treatment 2 < 3 < 1. Neutral detergent fiber concentration did not markedly differ between grass sources or among hay cuttings. Acid detergent lignin concentration was greatest among hay-cutting treatments for cutting 2 and slightly greater for SG-2 versus GG-2.

Feed Intake

Body weight was lower ($P < 0.05$) for S than for SR and N, and BW for N was greatest ($P < 0.05$) among breed groups (Table 2). Body weight was less ($P < 0.05$) for hay-cutting treatment 2 than for cuttings 1 and 3. Hay DM intake was greater ($P < 0.05$) for SR than for ST and N, and hay DM intake for S was intermediate ($P > 0.05$). Hay DM intake in g/day was greater ($P < 0.05$) for GG versus SG within hay-cutting treatments and was less ($P < 0.05$) for hay-cutting treatment 2 than for hay-cuttings 1 and 3. Hay DM intake for GG-3 was greatest ($P < 0.05$) among GG hay-cutting treatments; whereas, hay DM intake for SG-3 tended ($P = 0.10$) to be less than for SG-1. Probabilities of breed group effects were 0.0584 and 0.0566 for total DM and OM intakes, respectively.

Digestion

Breed did not alter total dietary or hay OM digestibility ($P > 0.10$; Table 2). Digestibilities of total and hay OM and NDF were greater ($P < 0.05$) for GG than for SG and less ($P < 0.05$) for hay-cutting treatment 2 versus hay-cuttings 1 and 3. Hay OM digested daily in g/day was greater for SR than for S ($P = 0.08$), ST and N ($P < 0.05$). Relative to BW$^{0.75}$, digestible hay OM intake was greater for S and SR than for ST ($P = 0.09$ and 0.07, respectively) and N ($P < 0.05$), and was less ($P = 0.09$) for N versus ST. Digestible hay OM intake was greater ($P < 0.05$) for GG than for SG within hay-cutting treatments. With GG, hay digestible OM intake ranked ($P < 0.05$) hay-cutting treatment 2 < 1 < 3; whereas, the ranking ($P < 0.05$) was cutting 2 < 1 and 3 with SG.

Dietary crude protein concentration averaged 11.9, 13.2, 11.7, 13.4, 16.3 and 13.7% of DM for GG-1, GG-2, GG-3, SG-1, SG-2 and SG-3, respectively. Differences between breed groups and among dietary treatments in nitrogen intakes and digestibilities

Table 1. Feedstuff composition as a percentage of dry matter.

	Gamagrass[a]			Switchgrass[a]			
Item	1	2	3	1	2	3	Soybean meal
Ash	6.5	5.3	6.6	6.5	4.4	6.0	8.1
Crude protein	8.7	4.3	6.8	6.5	3.4	5.1	53.6
Neutral detergent fiber	78.0	77.9	73.5	73.5	77.9	77.1	13.9
Acid detergent fiber	45.2	48.1	41.1	43.9	50.7	45.8	
Acid detergent lignin	5.1	6.5	4.6	5.2	8.7	5.6	
Cellulose	40.0	40.6	35.6	38.3	41.7	39.5	
Hemicellulose	32.8	29.8	32.5	29.6	27.2	31.3	

[a] 1 = primary growth harvested on June 12, 1995; 2 = primary growth harvested on August 14, 1995; 3 = regrowth between June 12 and August 14, 1995.

in part reflect those in soybean meal intake, particularly for breed groups because of differences in BW (Table 2). However, assuming constant soybean meal nitrogen digestibility (i.e., 90%), apparent hay nitrogen digestibility was greater ($P < 0.05$) for GG than for SG (44 vs. 19%) and ranked ($P < 0.05$) hay-cutting treatment 2 < 3 < 1 (14, 35 and 44%, respectively).

Breed Groups

Ewes of all breed groups behaved similarly, with no observed stress from confinement that could have impacted feed intake. Feed intake was expressed relative to $BW^{0.75}$ at period end, although small biases probably resulted from differences among diets in feed intake and gut digesta fill. However, use of initial or average period BW would entail influences of prior treatments and differences in BW among hay-cutting treatments were of relatively small magnitude. Body weight did not appreciably change during the experiment (initial and final BW of 47.7 [SE = 1.06] and 49.3 kg [SE = 1.9], respectively); initial BW was 38, 48, 46 and 59 kg, and final BW was 39, 51, 47 and 60 kg for S, SR, ST and N, respectively. At this age, breed group BW can be largely attributed to mature weight.

The lack of interactive effects of dietary treatment and breed in feed intake may be due, in part, to the fact that no breed group was extremely large in stature or possessed rapid potential growth rate, and ewes were in early- to mid-gestation when nutrient requirements are relatively low. Although differences in hay OM

Table 2. Feed intake and digestion in sheep consuming gamagrass or switchgrass hay.

	Breed[a]					Gamagrass[b]			Switchgrass[b]				
Item	S	SR	ST	N	SE	1	2	3	1	2	3	SE	Effect[c]
Body weight (at period end):													
kg	38.8^{e}	48.9^{f}	45.9^{ef}	58.6^{g}	2.54	48.9	47.9	49.1	48.1	46.8	47.4	0.30	2<1,3
$kg^{0.75}$	15.5^{e}	18.5^{f}	17.5^{ef}	21.2^{g}	0.71	18.4	18.1	18.5	18.2	17.8	18.0	0.08	2<1,3
Dry matter intake:													
SBM, g/day	130^{e}	161^{f}	155^{f}	197^{g}	7.8	81^{e}	195^{h}	140^{f}	148^{f}	227^{i}	173^{g}	2.9	
Hay, g/day	931^{ef}	1,062^{f}	851^{e}	851^{e}	51.4	1,075^{h}	898^{g}	1,216^{i}	882^{fg}	660^{e}	812^{f}	29.3	
Total, g/day	1,061	1,223	1,006	1,048	54.5	1,156^{h}	1,093^{gh}	1,356^{i}	1,030^{fg}	887^{e}	986^{f}	29.3	
Hay, g/kg $BW^{0.75}$	60.2^{g}	57.1^{g}	48.2^{f}	40.4^{e}	2.56	58.9^{g}	50.3^{f}	66.8^{h}	49.3^{f}	37.6^{e}	46.0^{f}	1.53	
Total, g/kg $BW^{0.75}$	68.5^{f}	65.9^{f}	57.0^{e}	49.7^{e}	2.51	63.2^{h}	60.9^{gh}	74.3^{i}	57.4^{fg}	50.3^{e}	55.6^{f}	1.52	
Total organic matter:													
Intake, g/day	994	1,146	942	981	50.9	1,080^{h}	1,029^{gh}	1,265^{i}	961^{fg}	840^{e}	923^{f}	27.5	
Digestion:													
%	46.8	49.9	49.7	48.2	1.55	54.9	50.5	57.3	43.8	40.2	45.3	1.57	T;2<1,3
g/day	474	580	473	483	32.3	590	521	727	423	338	415	19.7	T;2<1<3
g/kg $BW^{0.75}$	30.6^{f}	31.2^{f}	26.7^{ef}	22.9^{e}	1.62	32.3^{g}	29.2^{g}	39.6^{h}	23.6^{f}	19.0^{e}	23.4^{f}	1.13	
Hay organic matter digestion[d]:													
%	40.4	43.3	41.9	37.8	1.78	52.4	42.2	53.7	36.2	24.3	36.3	1.88	T;2<1,3
g/day	369^{ef}	450^{f}	348^{e}	323^{e}	30.5	524^{h}	363^{g}	614^{i}	304^{fg}	155^{e}	275^{f}	20.0	
g/kg $BW^{0.75}$	23.8^{f}	23.2^{f}	19.6^{ef}	15.3^{e}	1.65	28.7^{h}	20.6^{g}	33.5^{i}	17.1^{fg}	8.7^{e}	15.7^{f}	1.12	
Neutral detergent fiber:													
Intake, g/day	727^{ef}	832^{f}	669^{e}	675^{ef}	40.3	850	726	914	669	546	651	22.1	T;2<1,3
Digestion:													
%	41.5	44.2	43.8	39.6	1.69	55.4	43.8	55.2	35.7	24.5	39.2	1.62	T;2<1,3
g/day	316	383	303	283	26.2	469	320	507	242	135	253	15.3	T;2<1,3
Nitrogen:													
Intake, g/day	20.1^{e}	24.1^{fg}	21.4^{ef}	25.1^{fg}	0.98	21.7^{e}	23.0^{f}	25.1^{g}	21.8^{e}	23.1^{f}	21.5^{e}	0.40	
Digestion:													
%	65.6^{e}	69.2^{ef}	68.8^{ef}	72.4^{f}	1.33	65.8	72.7	66.8	65.9	74.1	68.7	1.27	2<1,3
g/day	13.2^{e}	16.6^{fg}	14.8^{ef}	18.3^{g}	0.81	14.3^{e}	16.8^{f}	16.8^{f}	14.4^{e}	17.2^{f}	14.8^{e}	0.37	

[a] S = St. Croix; SR = St. Croix × Romanov; ST = St. Croix × Texel; N = Gulf Coast Native.
[b] 1 = primary growth harvested on June 12, 1995; 2 = primary growth harvested on August 14, 1995; regrowth between June 12 and August 14, 1995.
[c] T = gamagrass versus switchgrass ($P < 0.05$); < denotes a difference between hay cuttings ($P < 0.05$).
[d] Calculated assuming 88% digestibility of soybean meal organic matter.
[e-i] Means in a row within breed or hay source treatment without a common superscript differ ($P < 0.05$).

and dietary NDF digestibilities indicate a considerable range in tropical grass quality, hay harvests were not at high-quality growth stages. In contrast to results of the present experiment, an interaction occurred in a subsequent study with mature, nonpregnant ewes of three of the four same breed groups and two grass sources that differed in digestibility (our unpublished observations). Digestible OM intake with mature bermudagrass hay (49% total tract OM digestibility) was 28, 30, 30 and 27 g/kg $BW^{0.75}$ and with endophyte-free fescue hay (*Festuca arundinacea*; late-boot; 62% total tract OM digestibility) was 39, 50, 47 and 39 g/kg $BW^{0.75}$ for S, ST, Polypay × Texel and N, respectively (SE = 1.5). Perhaps greater OM digestibility for fescue compared with forages used in the present experiment may have been responsible for the disparity in results.

The absence of interactions between breed group and dietary treatment indicates that no breed group was notably more or less adept at ingesting high quantities of digestible nutrients with forages highest or lowest in quality. Because a supplement was provided to avoid ruminal deficiencies of nitrogenous compounds for microbial digestion and growth, these results do not encompass effects of potential differences among breed groups in ruminal nitrogen recycling.

Estimated total net energy intake was 1.29, 1.58, 1.29 and 1.32 Mcal/day (SE = 0.088) and net energy required for maintenance was 0.87, 1.03, 0.99 and 1.18 Mcal/day (SE = 0.040) for S, SR, ST and N breed groups, respectively. Therefore, total net energy intake was greater than required for maintenance of all breed groups (149, 152, 130 and 111% for S, SR, ST and N, respectively; SE = 7.9%). By assuming 2.18 Mcal/kg of net energy for maintenance in soybean meal (NRC, 1985), hay provided 116, 118, 96 and 75% (SE = 8.0) of net energy required for BW maintenance of S, SR, ST and N, respectively. Hence, under these experimental conditions and assuming that maintenance energy requirement related linearly to $BW^{0.75}$ regardless of breed group, the degree to which maintenance energy requirement could be met and/or energy accreted ranked S and SR > ST > N. This suggests that for maintenance of BW with such low-quality forage supplementation would be of greatest concern or importance for N. However, unpublished results outlined earlier imply that conditions with higher quality forage may be dissimilar, as digestible OM intake relative to $BW^{0.75}$ was similar between S and N ewes with both mature bermudagrass hay and higher quality fescue hay.

Comparisons of N with similar breed groups and forage treatments are lacking. However, in experiments with diets higher in quality than in the present experiment, feed intake and/or BW change was less for N versus Suffolks (Burleigh et al., 1994; Fernandez et al., 1994; Forbes et al., 1995). Mann et al. (1987) noted similar intake relative to $BW^{0.75}$ of Coastal bermudagrass pellets among Barbados Blackbelly (hair breed), Dorset (wool breed) and Blackbelly × Dorset ram lambs, although in a separate experiment intake of orchardgrass-alfalfa (*Dactylis glomerata* L.-*Medicago sativa* L.) hay was greater for Blackbelly than for Dorset ram lambs and intermediate for Blackbelly × Dorsets. In vivo DM digestibility of orchardgrass-alfalfa hay was approximately 12 percentage units greater than that for bermudagrass pellets (i.e., 54 vs. 42%) and intakes were appreciably greater (i.e., treatment mean range of 77 to 100 g of DM/kg $BW^{0.75}$) than in the present experiment.

It appeared that greater BW for SR versus S, because of factors including heterosis and potential differences in mature size of parent St. Croix and Romanov breed groups, was accompanied by ability of SR to ingest digestible nutrients from these low-quality grasses only to an extent necessary for BW maintenance. Intake of a high concentrate diet by S, SR and ST wether lambs (initial BW of 22.2, 25.7 and 25.9 kg, respectively) was similar among S, SR and ST breed groups (1.36, 1.35 and 1.45 kg/day, respectively), although BW gain (187, 227 and 238 g/day, respectively) and gain:DM intake (0.138, 0.168 and 0.164, respectively) were less for S than for SR and ST (Phillips et al., 1995). Ability of SR to ingest adequate digestible nutrients with low-quality forages, as used in the present experiment, to support greater nutrient demands associated with greater prolificacy compared with S is unknown, although presumably diet quality would be greater during periods of high nutrient demands such as in late gestation and early lactation. In this regard, aforementioned unpublished results entailed greater digestible OM intake with relatively high-quality fescue hay by crossbred versus purebred ewes but similar digestible OM intake with mature bermudagrass hay.

The increase in BW through crossbreeding of St. Croix and Texel compared with S was not accompanied by like change in capacity for digestible nutrient ingestion, thereby resulting in lower feed intake relative to maintenance energy requirement. Therefore, the ST breed group may be less suited for rearing on these low-quality forages, compared with S and SR. How these breed groups compare in maintenance energy requirements, however, is unknown. Freetly et al. (1995) noted that fasting heat production for Texel and Suffolk ewes related directly to percentage of mature weight rather than simply to $BW^{0.75}$, with considerably slower maturation for Texel versus Suffolk ewes.

Reasons for lower DM intake relative to $BW^{0.75}$ for ST versus S and SR cannot be discerned from these data, and relevant literature is presently lacking. Unpublished results presented earlier imply that similar differences may not exist with higher quality forage. Perhaps an observation that Texels exhibit few but long meals of a pelleted diet compared with other breeds (K.A. Leymaster, personal communications) is involved. Also, prolific breeds such as the Romanov have greater internal fat depots than nonprolific breeds (Fahmy et al., 1992). Notter et al. (1983) observed greater gastrointestinal tract tissue mass for Finns than for Rambouillets and Dorsets. It is possible that such

factors contributed to intake differences in the present experiment and perhaps to disparate maintenance energy requirements relatively to $BW^{0.75}$ among breed groups as well. For example, high gastrointestinal tract tissue mass for Romanovs implies elevated potential acetate metabolism for energy (Annison, 1984) but also is associated with greater energy use in tissue maintenance (Ferrell, 1988). Relatedly, variation in hepatic oxygen consumption of liver mass not attributable to digestible energy intake with forage-based diets has been accounted for by portal-drained viscera oxygen consumption or gastrointestinal tract tissue mass (Goetsch and Patil, 1997; Kouakou et al., 1997a,b), perhaps because of interrelationships between gut and liver metabolism.

In contrast to results of the present experiment, yearling wether intake of a mixture of alfalfa-smooth bromegrass (*Medicago sativa* L.-*Bromus inermis* L.) was greater for wool sheep (Targhee × Dorset) than for S (3.17 vs. 2.66% of BW; Quick and Dehority, 1986). Although similar to results of the present experiment, breed groups did not differ in digestibilities, and intakes and digestibilities differed among forage forms (pelleted, chopped, long-stemmed) similarly between breed groups. Greater intake by the wool versus hair breed in this experiment, and the aforementioned results of Mann et al. (1987), in contrast to breed group differences in feed intake noted in the present experiment, may partially relate to experiment differences in diet quality and body composition. St. Croix deposit less subcutaneous fat than wool breeds (Foote, 1983; McClure et al., 1991). Perhaps with high-quality forage-based diets characterized by greater propionate absorption and peripheral tissue energy availability than with diets such as used in the present experiment (Goetsch and Patil, 1997), greater potential for fat deposition of common wool breeds, and the associated more rapid rate of acetate clearance from blood with minimal heat generation, may facilitate greater feed intake. Conversely, with low-quality forage this difference in propensity for fattening could have little or no impact on feed intake. Such an interaction seems supported by a comparison of findings of the present expeirment with previously outlined unpublished results

Dietary Treatments

Before the experiment began, hay samples were collected and analyzed for nitrogen to determine levels of supplemental soybean meal. Levels were chosen to ensure adequate ruminal concentrations of nitrogenous compounds for normal microbial digestion and growth and so that dietary nitrogen intake would not differ markedly among diets. Soybean meal was supplemented alone to avert potential confounding that would occur with inclusion of other supplemental feedstuffs.

Hay OM and dietary NDF digestibilities appeared slightly lower than expected based on acid detergent lignin as a percentage of DM and relative to NDF concentration, although Rees and Little (1980) noted lower digestibility of tropical grass hay sources consumed ad libitum by sheep than cattle. Nonetheless, it is conceivable that factors such as unrepresentative hay sampling and/or incomplete accounting for feed spillage contributed to slight underestimation of digestibility. Thus, intakes and digestibilities perhaps should be viewed primarily in the context of within-experiment comparisons.

Grass source and hay-cutting treatment interacted in total and hay net energy intakes in Mcal/day and are expressed as a percentage of maintenance energy requirement. Total net energy intake was 157, 142, 193, 115, 93 and 114% of that required (SE = 5.50), and that for hay alone was 140, 101, 164, 84, 43 and 77% (SE = 5.50) for GG-1, GG-2, GG-3, SG-1, SG-2 and SG-3, respectively. Thus, with nitrogen supplementation all hay cuttings of GG yielded adequate net energy intake for BW maintenance of these ewes in early- to mid-gestation, although appreciable differences among hay-cutting treatments in BW change would be expected. Conversely, no hay cutting of SG provided ample net energy intake for BW maintenance without consideration of supplemental soybean meal, with lowest BW gain or greatest loss expected for hay-cutting treatment 2. Thus, dependent on method of nitrogen supplementation (true vs. nonprotein nitrogen sources), particularly for SG-2, energy supplementation may be necessary with SG to maintain BW of this animal class even with the relatively low-energy requirement.

With the same times of hay harvests and in this region of the U.S., GG was of appreciably greater nutritive value than SG for gestating ruminants, which would largely relate to earlier maturation of SG. The decrease in nutritive value with delayed harvest of primary growth, as assessed by digestible hay OM intake relative to $BW^{0.75}$, was of similar absolute magnitude for GG and SG (hay-cutting treatment 3 vs. 1), although quality of the early harvest of SG primary growth was appreciably lower than that of GG. Highest nutritive value among dietary treatments was for regrowth of GG, whereas SG regrowth yielded digestible hay OM intake only similar to that for the first cutting of SG primary growth. Presumably the marked decline in intake and digestibility with delayed SG primary growth harvest relates to an increased proportion of stem, decreased digestion rate, potential digestibility of cell walls and to relatively smaller changes in rate and potential extent of digestion of leaf sheath cell walls (Twidwell et al., 1988).

Effects of dietary treatments on hay intake differed from those on hay OM and dietary NDF digestibilities. Also, differences among dietary treatments in hay digestibilities were greater than expected based on concentrations of chemical constituents. Most likely, these findings depict effects of grass tissue proportions and their arrangements on digestibility, as well as physiological intake control rather than regulation via physical means or gut capacity (reticulo-ruminal digesta mass or fill). Factors responsible for the greater difference in feed intake than in digestion between hay-cutting treatment 2 versus hay-cuttings 1 and 3 for GG yet similar change for SG

cuttings are unclear. However, Goetsch and Patil (1997) noted differences among dietary forage treatments in gut and liver energy expenditures apart from change expected based on digestibility, and with causal effects on ad libitum feed intake postulated. In this regard, perhaps the physical nature of hay-cutting treatment 3 (regrowth) of GG resulted in less energy consumed by splanchnic tissues relative to that absorbed than elicited by other hay-cuttings, thereby allowing greater peripheral tissue energy availability and a higher level of feed intake at which a threshold of efficiency of metabolism was reached (Tolkamp and Ketelaars, 1994).

For all data, standardized partial regression coefficients indicated that hay OM intake and digestibility accounted for 49 and 51% of variation in digestible hay OM intake, respectively. Although, as implied previously, intake accounted for relatively more variation in digestible hay OM intake with GG (50%) than with SG (41%), it is unknown whether this difference was attributable to grass source per se or to the lower quality of SG than of GG hay-cuttings because of different growth patterns and the same hay harvest dates.

Conclusions

Digestibilities were similar among breed groups, and dietary forage treatment and breed group did not interact in any variables. Hay DM intake relative to $BW^{0.75}$ ranked S and SR > ST > N. With supplemental soybean meal, average grass intake provided adequate energy intake for BW maintenance of ewes in all breed groups. However, greater BW for SR versus S was accompanied by a coincident difference in ability to ingest digestible nutrients from these tropical grass sources relative to maintenance energy requirement. Conversely, lower hay intake relative to $BW^{0.75}$ for ST than for S implies lower suitability of ST for rearing during early- and mid-gestation on such forage, dependent on supplementation. Lowest feed intake relative to maintenance energy requirements among breed groups existed for N, suggesting greatest need for or importance of supplementation for BW maintenance.

With hay harvests on the same days and soybean meal supplementation, hay OM digestibility was greater for GG than for SG and lower for the late harvest of primary growth compared with early primary growth and regrowth harvests. Differences in hay intake among SG hay-cutting treatments resembled those in hay OM digestibility, although for GG, intake was greater for regrowth than for the early primary growth harvest. In accordance, digestible hay OM intake ranked hay-cutting treatment 3 > 1 > 2 for GG and cutting 1 and 3 > 2 for SG. Thus, differences among hay-cutting treatments in characteristics affecting ruminal microbial digestion and animal metabolism were dissimilar between GG and SG, with relatively greater effect of differences between regrowth and primary growth cuttings on intake than on digestibility with GG but similar differences in intake and digestion with SG.

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Performance, Intake and Digestibility of Lambs Fed Alfalfa Hay and Various Levels of Barley

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Summary

Two trials were conducted to evaluate the effects of increasing levels of rolled barley supplementation on the utilization of chopped alfalfa hay by lambs. In Trial 1, 96 white-face weaned ewe lambs (33.3 ± 2.9 kg) were randomly assigned to one of four treatments for a 63-day trial. Treatments were 0, 0.3, 0.6 or 0.9% of body weight (BW) of barley. Barley was fed at 0600 hours each day. After barley was consumed, chopped (5-cm screen) alfalfa hay (crude protien [CP] = 15.4%; in vitro dry matter digestability [IVDMD] = 54.0%) was offered at approximately 15% above the estimated previous day's intake. Linear ($P < 0.001$) and quadratic ($P = 0.079$) effects were detected for lamb average daily gain (ADG; 142, 180, 187 and 201 ± 6 g/day for 0, 0.3, 0.6 and 0.9% BW barley, respectively). Feed efficiency increased linearly ($P < 0.01$) as level of barley supplementation increased (111, 129, 133 and 138 ± 5 g gain/kg feed for 0, 0.3, 0.6 and 0.9% BW barley, respectively). In Trial 2, eight fine-wool wether lambs were arranged in a replicated 4-by-4 Latin square to determine intake and digestibility of alfalfa hay when supplemented with increasing levels of barley. Average initial BW of the wethers was 55.6 ± 0.6 kg. Wethers were housed in metabolism crates for the duration of the experiment. Barley, fed at the same levels as in Trial 1, was offered at 0700 hours each day. After the barley was consumed, ground (5-cm screen) alfalfa hay was offered at 20% above the previous day's intake. A linear response was observed ($P < 0.001$) with lamb intake of alfalfa hay (3.03, 2.87, 2.88 and 2.33 ± 0.09% BW for 0, 0.3, 0.6 and 0.9% BW barley, respectively) and total intake (3.03, 3.17, 3.49 and 3.24 ± 0.09% BW for 0, 0.3, 0.6 and 0.9% BW barley, respectively) as lambs consumed increasing levels of barley. Dry matter, neutral detergent fiber (NDF) and starch digestibilities increased linearly ($P < 0.001$) as lambs were fed increasing levels of barley. Digestible dry matter intake increased linearly ($P<.001$) as level of barley in the diet increased (1.65, 1.82, 2.07 and 2.03 ± 0.05% BW for 0, 0.3, 0.6 and 0.9% BW barley, respectively). These data suggest that barley supplementation of lambs consuming chopped alfalfa hay as a base diet will improve ADG, feed efficiency and digestible dry matter intake.

Key words: barley, alfalfa, lambs, intake.

Introduction

Concentrate supplementation of livestock consuming forage is a common practice. Supplementation of ruminants is often utilized to stretch an existing forage supply or to improve the nutrient content of the diet in order to achieve a desired level of animal performance. Intake and digestibility of a forage are affected by the quality of the forage and the type and level of supplement used (Bowman and Sanson, 1996). As forage quality changes so do rumen characteristics, resulting in varying effects of supplements on digestibility, rate of passage and intake (Ruder et al., 1996). High-protein supplements generally increase low-quality (less than 7% CP) forage intake and utilization. However, starch-based energy supplements decrease forage intake and may negatively impact digestibility, depending on feeding level and composition (Goetsch et al., 1991; Mertens and Loften, 1980).

Substitution of concentrate for forage intake is often observed in supplementation studies (Matejovsky and Sanson, 1995). The amount of substi-

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tution of concentrate for forage depends on the amount of available forage, the quality of the forage and the limits of feed intake. Substitution can be either desirable or undesirable depending on the situation. A decrease in forage intake may be desirable when attempting to stretch an existing forage supply. On the other hand, if the goal is to maximize forage utilization, the effect of some supplements may be negative.

The effects of cereal grains on utilization of alfalfa hay have been characterized in moderate- to high-concentrate diets. Data on the effect of starch-based supplements at lower percentages of the diet when fed as a supplement are limited, especially with barley supplements. The objective of this study was to evaluate levels of barley supplementation on performance, intake and digestion in weaned lambs fed free-choice, chopped alfalfa hay.

Materials and Methods

Trial 1

Ninety-six fine-wool weaned ewe lambs, approximately four months of age (BW = 33.3 ± 2.9 kg), were used to evaluate the effects of level of barley supplementation on forage intake and animal growth. Lambs were stratified into three groups by weight, with lambs from each weight class subsequently randomized into four groups of eight lambs. This resulted in three replicates for each of the four treatments. Treatments were 0, 0.3, 0.6 and 0.9% BW of barley as a supplement (Table 1). Treatment levels were assigned based on the initial body weight of the ewe lambs and were not adjusted during the trial. Barley was processed with a roller mill with the majority of the barley cracked into two to three pieces. Lambs were housed in partially-covered pens. Adequate bunk space was available for all lambs. Procedures used in this trial were approved by the University of Wyoming Animal Care and Use Committee.

Lambs were fed at 0600 each morning. Prior to feeding forage, the appropriate level of barley was fed in a concrete bunk to each treatment. After supplements were consumed, ground alfalfa hay (5-cm screen; Table 1) was weighed and offered daily to each pen at approximately 15% above the previous day's estimated intake in separate bunks. The daily feeding of alfalfa was placed on top of the previous day's refusal. Alfalfa refusals were measured weekly to determine intake. Bunks used to feed alfalfa were located under the covered portion of the pen, while bunks used to feed supplements were located outside the shed. Water and trace mineralized block salt (95 to 98% NaCl, ≥ 0.350% Zn, ≥ 0.280% Mn, ≥ 0.175% Fe, ≥ 0.035% Cu, ≥ 0.007% I, ≥ 0.007% Co) were available free choice.

Lambs were weighed on two consecutive days at the beginning and end of the 63-day study. Prior to the onset of the study, lambs were given a 1-ml intramuscular injection of Ivomectin (Merck & Co, Inc., Rahway, NJ).

Barley and alfalfa samples were collected daily and composited across week. Refusal sample was collected from each pen at the end of each week. A representative 10% subsample of weekly hay, barley and refusal were dried in a forced air oven at 55 °C for 48 hours, allowed to air equilibrate for 24 hours, ground with a Wiley mill to pass a 2-mm screen and stored at room temperature until the end of the trial. Additional subsamples were dried in a forced air oven at 100 °C to determine absolute dry matter. At the termination of the study, weekly alfalfa and barley samples were compiled across week by sample type. Weekly refusal samples were also compiled across week by pen and stored at room temperature until chemical analysis.

Trial 2

Eight fine-wool wether lambs were used to determine intake and digestibility of alfalfa hay when supplemented with increasing levels of barley. Levels of supplementation (0.0, 0.3, 0.6 and 0.9% BW of barley) and type of barley and hay used in this trial were from the same source as Trial 1. Lambs (BW = 55.6 ± 0.6 kg) were arranged in two 4-by-4 Latin squares, with four collection periods conducted with two lambs on each treatment during each collection period. Each period consisted of a 16-day diet adjustment period and a 5-day collection period. Wethers were housed in metabolism crates for the duration of the trial. Lambs were individually weighed at the beginning of each period to determine level of barley supplement. Animal care and other procedures used in this trial were approved by the University of

Table 1. Chemical composition (DM basis) of barley and alfalfa fed to lambs in a performance trial (Trial 1) and a digestion trial (Trial 2).

	Trial 1		Trial 2	
Item %	Barley	Alfalfa	Barley	Alfalfa
Dry matter	88.13	88.80	88.99	90.70
Ash	3.47	10.73	3.35	10.84
CP[a]	11.21	15.38	10.75	16.54
IVDMD[b]	–	54.00	–	54.00
NDF[c]	27.35	53.72	27.35	54.86
ADF[d]	8.60	44.29	9.20	46.54
ADL[e]	3.27	10.27	3.27	10.27
AIA[f]	0.41	0.41	0.41	0.41
ADIN[g]	0.04	0.07	0.04	0.07

[a] CP = crude protein.
[b] IVDMD = in vitro dry matter digestibility.
[c] NDF = neutral detergent fiber.
[d] ADF = acid detergent fiber.
[e] ADL = acid detergent lignin.
[f] AIA = acid insoluble ash.
[g] ADIN = acid detergent insoluble nitrogen.

Wyoming Animal Care and Use Committee.

Lambs were fed at 0700 each day. Prior to feeding supplements, the previous day's alfalfa refusal was removed from the feed bunk. At this time, lambs assigned to receive a supplement were given their respective level of barley. As lambs consumed the barley, daily refusal was measured, after which ground alfalfa hay (Table 1) was offered at approximately 20% above the previous day's intake to each lamb. Wethers had ad libitum access to water and trace mineralized salt. Salt blocks were identical in composition to those used in Trial 1.

Alfalfa and barley samples were collected daily during the last six days of each period. Samples were composited across day. Alfalfa refusal samples were also collected during this time and composited within animal across day. On days 17 through 21, total fecal and urine output were collected and measured. Fecal bags were placed on the lambs on day 16 at 0700, with bags emptied and feces discarded at 0700 on day 17. Subsequently, bags were emptied at 1900 and 0700. Feces removed from bags at 1900 were stored in individual pails at room temperature until the next morning, when daily fecal output for each wether was weighed, mixed and a representative 10% aliquot was collected and stored at 2 °C until the end of the collection period. Urine was diverted into plastic pails with the use of metal shields attached to the bottom of the crates. Urine was emptied from pails at 0700 and 1900 each day into large plastic storage jugs and stored at room temperature until the end of the collection. The storage jug contained 100 ml H_2SO_4. Every morning and evening after urine was transferred to the storage jug, 20 ml of H_2SO_4 was put into each individual collection bucket.

Alfalfa, barley, refusal, feces and urine samples were processed for analysis at the completion of each collection period. Composite alfalfa, barley, refusal and fecal samples were mixed and a representative sub-sample was withdrawn and dried in a forced air oven (55 °C) for 48 hours, allowed to air equilibrate for 24 hours, ground with a Wiley mill to pass a 2-mm screen and stored at room temperature until analysis. Additional subsamples of each were dried in a forced-air oven at 100 °C to determine absolute DM. Urine samples were measured and diluted to the nearest liter with distilled water. A sub-sample was drawn, placed in airtight containers and stored in the freezer until lab analysis could be performed.

Chemical Analysis

Alfalfa, barley and refusal samples from both trials and fecal samples from Trial 2 were analyzed for DM, CP (Kjeldahl N × 6.25), ash (AOAC, 1990), acid detergent fiber (ADF) and NDF (Goering and Van Soest, 1970). Barley samples were incubated in amylase before NDF analysis (McQueen and Nicholson, 1979). Alfalfa and barley samples from both trials were also analyzed for acid detergent lignin, acid insoluble ash (determined as the ash fraction of acid detergent lignin) and acid detergent insoluble nitrogen (Goering and Van Soest, 1970). In vitro DM digestibility was determined on alfalfa samples from both trials using procedures of Tilley and Terry (1963). Trial 2 alfalfa, barley, refusal and fecal samples were analyzed for starch using procedures of MacRae and Armstrong (1968) as modified by Matejovsky and Sanson (1995). Urine samples were analyzed for Kjeldahl N (AOAC, 1990).

Statistical Analysis

Weight, weight gain, ADG and feed efficiency data from Trial 1 were analyzed as a one-way analysis of variance using GLM procedures of SAS (1985) with "pen" as the experimental unit. Forage intake, supplement intake and total DM intake were analyzed using GLM procedures of SAS (1985) with a split-plot in time

Table 2. Performance and intake of ewe lambs fed increasing levels of barley supplement with alfalfa hay (Trial 1).

	Level of barley supplementation, % BW					Model[a]	Contrast P-value		
	0.0	0.3	0.6	0.9	SE[b]	P	Linear	Quadratic	0 vs. 0.9%[c]
Initial BW, kg	33.4	33.3	33.3	33.3	2.85	0.999	0.990	0.977	0.985
Final BW, kg	42.4	44.6	45.1	46.0	3.03	0.851	0.423	0.828	0.851
Weight gain, kg	8.9	11.3	11.8	12.7	0.37	< 0.001	< 0.001	0.074	< 0.001
ADG, g/day	142	180	187	201	6	< 0.001	< 0.001	0.079	< 0.001
Diet intake, kg/day	1.27	1.40	1.41	1.46	0.06	0.227	0.066	0.552	0.056
Diet intake, % BW	3.26	3.47	3.52	3.58	0.15	0.482	0.163	0.626	0.160
Alfalfa intake, kg/day	1.27	1.30	1.20	1.16	0.05	0.240	0.080	0.489	0.139
Alfalfa intake, % BW	3.26	3.22	3.01	2.84	0.15	0.234	0.057	0.660	0.079
Feed efficiency[d]	111	129	133	138	5	0.015	0.003	0.186	0.003

[a] Probability of a significant effect due to treatment.
[b] Standard error of means, N = 3.
[c] Contrast of no barley versus 0.9% BW of barley supplement.
[d] Grams of weight gain per kilogram of total feed consumed.

(week) design with "pen" as the experimental unit and treatment tested using "pen within treatment" as the error term. When barley supplement effects were discovered, contrast analysis was used to separate linear, quadratic and no-supplement versus 0.9%-BW-barley effects.

Intake, digestion and nitrogen balance data were analyzed to test the main effect of increasing levels of barley using a GLM procedure of SAS (1985) appropriate for a replicated 4-by-4 Latin square design, with animal, period, treatment and replicate included in the model. When treatment effects were significant, contrast analysis was used to evaluate the linear, quadratic and no-supplement versus 0.9%-BW-barley effects.

Results and Discussion

Trial 1

Initial and final body weights of lambs were not influenced ($P > 0.851$) by level of barley (Table 2). Weight gain and ADG of ewe lambs responded in both a linear ($P < 0.001$) and a quadratic ($P < 0.08$) fashion as level of barley supplementation increased. Lambs supplemented with 0.3% BW of barley gained 26% more weight than lambs that received only alfalfa hay, while lambs that were supplemented with 0.6 and 0.9% barley gained 4 and 12% more weight, respectively, than lambs that received 0.3% BW of barley supplementation. Lambs that received 0.9% BW of barley gained more weight than lambs that received only alfalfa hay.

An effect of supplementation on diet intake in kilograms per day was not detected by the analysis of variance model ($P = 0.227$); however, contrast analysis indicated a linear increase in diet intake as level of supplementation increased. It should be noted that since pen was used as the experimental unit, there were only three observations per treatment per week. There were significant week-to-week variations ($P < 0.05$) in diet intake, although there was no week-by-treatment interaction ($P = 0.467$). Although analysis indicates a linear effect of supplementation on diet intake, numerically it appears that there was an increase in diet intake with the first level of barley supplementation and little effect with the additional levels of barley supplementation. When intake was adjusted for body weight, there was no effect ($P > 0.160$) of supplementation level on diet intake. Lambs consuming the barley supplements gained more weight ($P < 0.001$) than non-supplemented lambs; when intake was corrected for body size there was no effect of supplementation on intake. This observation agrees with others (Pasiley, et al., 1995; Matejovsky and Sanson, 1995) who have reported that cereal grain supplementation of medium- to high-quality forage has little effect on total intake, and that the substitution of grain for forage appears to be 1:1.

Differences in alfalfa intake were not detected by the analysis of variance model ($P > 0.240$); however, contrast analysis indicated alfalfa intake increased linearly ($P = 0.080$) as level of barley supplement increased. When intake was corrected for BW, intake also decreased linearly ($P = 0.057$) as level of supplementation increased, implying a 1:1 substitution rate of barley for alfalfa. In addition, alfalfa intake as percentage of body weight tended to be lower ($P = 0.079$) for lambs that received 0.9% barley supplementation compared to lambs that received only alfalfa hay.

Feed efficiency of ewe lambs increased ($P = 0.003$) linearly as level of barley supplement increased. Lambs fed 0.3% BW of barley gained 16% more weight per kilogram of feed than lambs that received only alfalfa. Although the increase in feed efficiency was linear, increasing levels of barley supplementation above 0.3% of BW resulted in increases in BW gain per kilogram of feed of only 3%. Feed efficiency data supports ADG data in that the largest increase in lamb performance comes at the lower level of barley supplementation. Contrast analysis revealed that feed efficiency was approaching a quadratic effect ($P = 0.186$).

Performance data implies that a "true" linear effect of barley supplementation did not occur. For example, ADG increased 38 g between lambs fed no supplement and 0.3% BW barley. Under the "true" linear conditions, the increase in ADG should have been 114 g between the no-supplement and the 0.9%-BW-barely treatments. In actuality, ADG increased only 59 g between the no-supplement and the 0.9%-BW-barley

Table 3. Intake of wether lambs fed increasing levels of barley with alfalfa hay (Trial 2).

	Level of barley supplementation, % BW					Model[a]	Contrast P-value		
	0.0	0.3	0.6	0.9	SE[b]	P	Linear	Quadratic	NS vs. 0.9%[c]
Diet, kg/day	1.70	1.76	1.91	1.79	0.04	0.012	0.027	0.043	0.116
Diet, % BW	3.03	3.17	3.49	3.24	0.09	0.011	0.024	0.038	0.104
Alfalfa, kg/day	1.70	1.59	1.58	1.29	0.04	< 0.001	< 0.001	0.056	< 0.001
Alfalfa, % BW	3.03	2.87	2.88	2.33	0.09	< 0.001	< 0.001	0.037	< 0.001
Digestible diet, kg/day	0.93	1.01	1.13	1.13	0.02	< 0.001	< 0.001	0.068	< 0.001
Digestible diet, % BW	1.65	1.82	2.07	2.03	0.05	< 0.001	< 0.001	0.062	< 0.001

[a] Probability of a significant effect due to treatment.
[b] Standard error of means, N = 8.
[c] Contrast of no barley versus 0.9% BW of barley supplement.

treatments in this study. These data suggest a diminishing value of barley supplementation as level of barley in the diet increases. Others have observed similar responses. Paisley et al. (1995) reported a decrease in energy value of corn as the level of supplementation fed to heifers consuming alfalfa cubes increased. Matejovsky and Sanson (1995) reported a diminishing energy value of corn with lambs consuming medium- and high-quality grass hays supplemented with increasing levels of corn.

Trial 2

Diet intake as a percentage of BW increased both linearly ($P = 0.024$) and quadratically ($P = 0.038$) as level of barley supplementation increased (Table 3). Intake increased 5% with the first level of barley supplementation, increased an additional 10% as level of barley supplementation increased from 0.3 to 0.6% BW, then declined by 7% when the high level of barley supplement was fed. These data contrast research reported by Paisley et al. (1995) with yearling heifers fed alfalfa cubes and supplemented with increasing levels of corn; they reported that level of supplementation had no effect on diet intake. These data also contrast intake results in Trial 1, where diet intake was not affected by level of barley supplementation when diet intake was corrected for body weight.

Alfalfa intake by lambs decreased in both a linear ($P < 0.001$) and a quadratic ($P = 0.037$) fashion as level of barley in the diet increased (Table 3). The first level of supplementation (0.3% BW) resulted in a decrease in forage intake of 5%. This decrease equaled 0.36% of BW of the lambs, indicating a 1:1 substitution rate. There was no difference in alfalfa intake between lambs fed 0.3 and 0.6% BW of barley; however, as level of supplemental barley increased from 0.6 to 0.9% BW, alfalfa intake decreased 19%. Alfalfa intake by lambs receiving 0.9% BW as supplemental barley was 23% lower ($P < 0.001$) than lambs that received only alfalfa.

Digestible DM intake increased linearly ($P < 0.001$) and quadratically ($P = 0.062$) as level of barley increased in the diet (Table 3). Intake of digestible DM increased by 10 to 14% with the first two levels of barley supplementation; however, there was little change in digestible DM intake with the last increase in barley supplementation. Lambs that received 0.9% BW of barley supplementation had higher ($P < 0.001$) total digestible dry matter intake than lambs that received no supplementation. These data support the conclusion from Trial 1 that the response to barley supplementation on diet utilization or animal performance is not linear.

DM and organic matter digestibilities increased ($P < 0.001$) linearly as level of supplemental barley increased (Table 4). Barley is a more digestible feed than alfalfa; thus increases in diet DM digestibility were expected. Matejovsky and Sanson (1995) reported similar results when supplementing increasing levels of corn to sheep consuming forages of different qualities.

Digestibility of NDF increased linearly ($P < 0.001$) as level of barley increased in the diet; however, level of barley had no effect ($P = 0.718$) on ADF digestion (Table 4). The reason for the increase in NDF digestion is not clear. Most research evaluating the effects of cereal grains on NDF digestion either indicate no effect or a negative effect of supplements high in soluble carbohydrates on NDF digestion of the diet (Amos and Evans, 1980; Chase and Hibberd, 1987; Sanson et al., 1990; Sanson, 1993; Matejovsky and Sanson, 1995); however, Paisley (1995) observed an increase in NDF digestion with steers fed alfalfa cubes and corn as level of corn increased in the diet.

Starch digestibility increased linearly ($P < 0.001$) as level of barley in the supplement increased (Table 4). Apparently, this is a response to the increased amount of starch in the diets as the level of barley increases. Similar results were observed by Matejovsky and Sanson (1995) when lambs were fed low-, medium- and high-quality grass hays and received increasing levels of corn supplementation.

Nitrogen (N) intake (Table 5) increased quadratically ($P = 0.044$) as level of barley supplement increased. There was little difference in N intake between lambs that received 0 and 0.3% BW of barley supplementation; however, N intake increased by 6% with lambs supplemented with 0.6% BW of barley compared to lambs that received 0.3% BW of barley in their diet. Nitrogen intake decreased with lambs fed 0.9% BW of barley to levels

Table 4. Digestibility of diets with increasing levels of barley with alfalfa hay fed to wether lambs (Trial 2).

	Level of barley supplementation, % BW					Model[a]	Contrast P-value		
	0.0	0.3	0.6	0.9	SE[b]	P	Linear	Quadratic	0 vs. 0.9%[c]
Dry matter	54.4	57.3	59.4	62.7	0.5	< 0.001	< 0.001	0.613	< 0.001
Organic matter	55.6	58.7	60.8	64.2	0.5	< 0.001	< 0.0012	0.751	< 0.001
ADF	39.2	39.7	39.8	40.7	1.0	0.718	0.290	0.810	0.269
NDF	41.6	42.9	43.9	45.5	0.7	0.009	< 0.001	0.839	< 0.001
Starch	88.9	93.6	94.3	96.7	0.8	< 0.001	< 0.001	0.202	< 0.001

[a] Probability of a significant effect due to treatment.
[b] Standard error of means, N = 8.
[c] Contrast of no barley versus 0.9% BW of barley supplement.

numerically lower than lambs that received only alfalfa, however, there was no difference (P = 0.106) in N intake between lambs fed no barley and those supplemented with 0.9% BW of barley. N absorbed followed a similar trend except lambs that received 0.9% BW of barley in the diet tended (P = 0.062) to have lower absorption of N than lambs that received only alfalfa hay. Digestion of N tended to decrease (P = 0.071) linearly as level of supplemental barley increased. Retained N tended (P = 0.076) to respond in a quadratic fashion as level of barley in the diet increased. N retained increased from 1.4 g/day with lambs receiving only alfalfa hay to a high of 2.6 g/day with lambs supplemented with 0.6% BW of barley, then decreased to 1.7 g/day with lambs that received 0.9% BW of barley. There was no difference (P = 0.359) in N retained between lambs that received no barley and lambs that received 0.9% BW of barley.

Nitrogen retention data indicate that 0.6% BW barley may be the optimum to maximize the energy to nitrogen ratio for fermentation. This is also the level where diet intake tended to be the highest in both trials. Increased levels of non-structural carbohydrates in the diet have been reported to decrease the roughage passage rate (Campling and Murdoch, 1966; Chase and Hibberd, 1987). Orskov and Fraser (1975) suggested that the increased rate of fermentation due to the structural carbohydrates results in unfavorable conditions for cellulolytic bacteria and is a major factor in depressing forage intake. Arias et al. (1951) reported that small quantities of starch improved digestion of forage cellulose but larger amounts decreased its digestibility. It is believed that cellulose digestion is inhibited because starch supplements result in competition for nutrients in the rumen between cellulolytic and non-cellulolytic bacteria (El-Shazly et al., 1961). Rumen pH may also be involved in the depression of fiber utilization (Horn and McCollum, 1987).

Data from the performance trial indicate that the largest improvement in weight gain and feed efficiency occurred when ewe lambs were supplemented with 0.3% BW of barley. In contrast, data from the digestion trial tend to indicate that the optimum level of barley supplementation was 0.6% BW. Feedstuffs used in both trials were the same. In addition, lambs in both trials were fed at similar levels as a percentage of BW. The percentage of total diet that was made up of barley was also similar (8.6, 17.0 and 25.1% barley for ewe lambs compared to 9.5, 17.2 and 27.8% barley for wether lambs). The reason for the differences in the two trials is not clear. Others have reported similar conflicting data between digestion and performance trials (Paisley, 1995).

Conclusions

Data from the two trials indicate that supplemental barley will increase animal performance and increase digestibility of the diet. The two trials are somewhat conflicting in which level of barley will give optimum performance. In Trial 1, lambs supplemented with barley at 0.3% of BW had 27% higher ADG compared to lambs fed only alfalfa hay. Performance continued to increase with additional barley; however, the increases were much lower than with the first increment of supplementation. Data from Trial 2 indicate that the greatest retention of N and the largest digestible DM intake occurred when lambs were supplemented with 0.6% BW of barley. Both of these studies indicate that supplementation rates higher than 0.6% BW of barley for lambs consuming alfalfa hay will not result in as large as an improvement in performance per unit of supplement as will lower levels.

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Table 5. Nitrogen intake, absorption, and retention in wether lambs fed increasing levels of barley with alfalfa hay (Trial 2).

	Level of barley supplementation, % BW					Model[a]	Contrast P-value		
	0.0	0.3	0.6	0.9	SE[b]	P	Linear	Quadratic	0 vs. 0.9%[c]
Intake, g/day	17.8	17.6	18.7	16.7	0.4	0.035	0.304	0.044	0.106
Absorbed, g/day	12.2	12.2	12.8	11.3	0.3	0.033	0.160	0.036	0.062
Digestion	68.7	68.9	68.2	67.6	0.5	0.216	0.071	0.328	0.112
Retained, g/day	1.4	1.6	2.6	1.7	0.3	0.043	0.119	0.076	0.359

[a] Probability of a significant effect due to treatment.
[b] Standard error of means, N = 8.
[c] Contrast of no barley versus 0.9% BW of barley supplement.

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Feeding to Heavy Weights Reduces Shear Values of Lambs Expressing the Calipyge Gene

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Summary

Eight extremely heavy carcasses (46 kg) and eight lighter carcasses (33 kg) from Columbia-type ewe lambs expressing the callipyge gene were compared to eight normal carcasses (33 kg) from black-faced lambs to determine if feeding callipyge lambs to extremely heavy weights would increase tenderness of their muscles. A loin roast 10 cm thick was removed posterior to the 12th rib of each carcass after 14 days aging at 2 to 4 °C. After three to six months frozen storage at -30 °C, Warner-Bratzler (WB) shear analyses were conducted. Chops cut 3.2 cm thick from each frozen roast were thawed overnight at 4 °C and roasted at 177 °C in a convection oven to an internal temperature of 74 °C. Moisture and fat percentages of longissimus muscle trimmed of all epimysial tissue and subcutaneous fat were similar for 46 and 33 kg callipyge carcasses but fat content was lower in samples from the callipyge carcasses when compared to those from normal lambs. Shear values on 1.27 cm diameter cores of cooked loin samples from heavy and lighter callipyge and normal lambs were all different ($P < 0.03$) at 5.31, 7.65 and 3.40 kg, respectively. Reduced shear values for loin samples from extremely heavy carcasses when compared to those from lighter carcasses are probably a result of slower chilling because of greater amounts of subcutaneous fat and a greater muscle mass.

Key words: lambs, tenderness, callipyge, composition.

Introduction

As long as consumers request leaner lamb there will be a need for genetically improved sheep. Lambs expressing the callipyge gene have the genetic potential to satisfy the consumer demand for leaner meat because of their extensive muscle hypertrophy and reduced fat levels (Koohmaraie et al., 1995, 1996; Carpenter et al., 1996; Jackson et al., 1997). Cockett et al. (1996) suggested that polar overdominance is the mode of inheritance of the callipyge gene characteristics.

Koohmaraie et al. (1995) found a higher calpastatin activity in callipyge lambs and suggested that the increased muscling may be related to higher calpastatin activity and concomitantly reduced protein degradation in callipyge lambs. The researchers believe the reduced rate of protein degradation and/or higher capacity for protein synthesis results in the increased muscling. Carpenter et al. (1996) further explained that hypertrophy in callipyge lambs was, at least in part, a result of fiber type changes and muscle cell enlargement; hypertrophy was strongly associated with changes in fast glycolytic fibers, the only fiber type that increased in both proportion and average diameter. These findings are in agreement with other research showing an increase in fast glycolytic fiber diameter in other muscle hypertrophy conditions (Ashmore et al., 1974; Swatland, 1984; Field et al., 1985).

The major problem associated with meat from callipyge lamb is lack of tenderness (Koohmaraie et al., 1995). Field et al. (1996) concluded that much higher shear values in longissimus muscle from callipyge lambs when compared to normal lambs could not be explained by the amount of collagen or collagen crosslinking and that attempts to make loin chops from callipyge lambs more acceptable should continue to focus on the myofibrillar fraction of muscle.

Heavier carcasses with more subcutaneous fat chill slower (Smith et al., 1976) and maintain muscle temperatures conducive to high levels of calpain activity for greater periods of time postmortem than lighter carcasses. Based on these facts, we hypothesized that heavier callipyge

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lamb carcasses would have lower shear values than lighter callipyge carcasses. The purpose of the present study was to test this hypothesis.

Materials and Methods

Loins of eight extremely heavy carcasses (46 kg) from Columbia-type ewe lambs expressing the callipyge gene were compared to loins from eight lighter Columbia-type callipyge carcasses (33 kg) and to loins from eight normal carcasses (33 kg) from black-faced lambs. The lambs obtained from mating rams known to be carriers of the callipyge gene with ewes believed to be non-carriers were born at the U.S. Sheep Experiment Research Station (Dubois, ID). Phenotypic expression of muscle hypertrophy was subjectively scored by multiple evaluators on each individual lamb at approximately 8 and 16 weeks of age. Phenotypic scores were used to distinguish carrier individuals for the callipyge gene. Further verification of classification was accomplished by genotyping animals with DNA markers (Cockett et al., 1994).

Callipyge ewe lambs from the U.S. Sheep Experiment Research Station were transported to the sheep facility at the University of Wyoming shortly after weaning when they were about five months of age and weighed about 49 kg. Lambs were adapted to experimental diets over a four-week period and randomly assigned to one of the two weight groups. They were individually fed in 1.2-by-2.4 m slotted floor pens, allowed ad libitum access to water and fed an 85% concentrate diet that included heat-treated soybean meal, corn and 15% alfalfa hay. The black-faced lambs were born and raised at the University of Wyoming sheep facility and were approximately the same age at slaughter as callipyge lambs producing 33 kg carcasses. Normal and callipyge carcasses weighing 33 kg were from lambs that were on feed approximately two months while 46 kg carcasses were from callipyge lambs fed up to five months to attain the required weight.

Fat depth over the center of the longissimus muscle at the 12th rib, marbling score, longissimus area, leg score and metacarpal length were recorded on each chilled carcass. Percentages of moisture by oven drying and of fat by the Goldfisch method (AOAC, 1990) were obtained on portions of longissimus muscle trimmed of all epimysial tissue and subcutaneous fat.

A loin roast 10 cm thick was removed posterior to the 12th rib from each carcass after 14 days aging at 2 to 4 °C. The roasts were frozen and stored at -30 °C for three to six months before WB shear analyses were conducted. The loin was used because unpublished data from our laboratory and the data of Kerth et al. (1995) show that tenderness is a greater problem in loin chops of callipyge lambs than it is in other cuts.

Chops were cut 3.2 cm thick from the cranial end of loin roasts, thawed at 4 °C and roasted at 177 °C in a convection oven to an internal temperature of 74 °C. Cooked chops were then cooled, wrapped in freezer paper and held overnight at 4 °C before WB shear values were obtained on three 1.27 cm-diameter cores cut parallel to the muscle fibers. Each core was sheared three times at a crosshead speed of 230 mm/minute. The average of nine shear values was used for subsequent statistical analysis. Data were analyzed by one-way ANOVA using the GLM procedure of SAS (1987).

Table 1. Means and standard errors for characteristics of extremely heavy lambs expressing the callipyge gene (heavy callipyge lambs) when compared to those from lighter lambs expressing the callipyge gene (lighter callipyge lambs) and normal lambs.

	Callipyge			
Item	Heavy	Lighter	Normal	SEM
Number	8	8	8	
Slaughter weight, kg	75.0[c]	57.4[e]	62.7[d]	0.85
Hot carcass weight, kg	45.6[d]	33.3[e]	32.5[e]	0.70
Fat depth, cm	0.70[d]	0.35[e]	0.39[e]	0.06
Marbling score[a]	3.59[e]	3.31[e]	4.32[d]	0.18
Longissimus fat, %	2.1[e]	1.6[e]	3.6[d]	0.23
Longissimus moisture, %	74.1[d]	74.3[d]	73.5[e]	0.21
Longissimus area, cm	27.1[d]	25.7[d]	15.1[e]	0.83
Leg score[b]	14.8[d]	14.5[d]	12.8[e]	0.20
Metacarpal length, cm	12.1[d]	11.5[e]	12.8[e]	0.20
Warner-Bratzler shear, kg	5.31[d]	7.65[c]	3.40[e]	0.59

[a] 3.59 = Slight[59], 4.32 = Small[32]. The superscript after degree of marbling is the percentage increase in marbling above the minimum for that degree.

[b] 14.8 = Prime[80], 12.8 = Choice[80]. The superscript after leg score is the percentage increase in leg conformation above the minimum for the grade.

[c,d,e] Means on the same line with different superscripts differ ($P < 0.01$) except for means for Warner-Bratzler shear where the difference was $P < 0.03$.

Results and Discussion

Means and standard errors for characteristics of extremely heavy lambs expressing the callipyge gene (heavy callipyge lambs) when compared to those from lighter lambs expressing the callipyge gene (lighter callipyge lambs) and normal lambs are found in Table 1. Although carcass weights for lighter callipyge and normal lambs were comparable ($P < 0.01$), slaughter weights were lower ($P < 0.01$) for lighter callipyge lambs. When carcass weights and live weights were used to calculate dressing percentages for heavy callipyge, lighter callipyge and normal lambs, the values were 60.8, 58.0 and 51.8%, respectively (data not presented in tabular form). Higher dressing percentages for heavy and lighter callipyge lambs when compared to normal lambs have been reported previously (Snowder et al., 1994a,b; Koohmaraie et al., 1995; Field et al., 1996). The higher carcass yield by 2.8 percentage points for heavier than for lighter callipyge lambs is probably a reflection of greater fat depths in the heavier lambs. Generally, lambs with fatter carcasses dress higher than leaner lambs (Kirton et al., 1984). The large difference of 6.2 percentage points between lighter callipyge lambs and normal lambs of similar weight and fat depth is probably a result of greater muscle mass in the callipyge lambs because no difference in fat depth ($P > 0.01$) between the two groups existed. Differences in organ weights between lambs with the callipyge gene and normal lambs are small at the same live weight (Koohmaraie et al., 1995; Kucuk, 1996; Jackson et al., 1997).

Marbling scores and longissimus fat percentages were lower ($P < 0.01$) when callipyge muscle was compared to normal muscle but muscle from heavy versus lighter callipyge lambs did not differ in intramuscular fat content (Table 1). These findings confirm the work of Koohmaraie et al. (1995) and Jackson et al. (1997) who reported higher marbling scores in longissimus muscle for normal lambs when compared to callipyge lambs. Fat content of muscle from 46-kg heavy callipyge carcasses when compared to 33-kg lighter carcasses has not previously been reported. Lawrie et al. (1964) studied chemical composition of 14 different normal and hypertrophied muscles of heifers. With the exception of the digital flexor superficialis muscle, intramuscular fat content was lower in all hypertrophied muscles. Our longissimus fat percentages of 1.6 and 2.1% in the present study for callipyge longissimus muscles from 33- and 46-kg carcasses, respectively, when compared to 3.6% for muscle from normal carcasses, support their findings. Differences in longissimus moisture content of callipyge and normal lambs were inversely proportional to the figures for fat; muscle from normal lambs possessed the most fat and the least moisture.

Differences in longissimus muscle area between callipyge and normal lambs are similar to those reported by Koohmaraie et al. (1995), Carpenter et al. (1996) and Jackson (1997). The lack of a significant ($P > 0.01$) difference between area of longissimus muscle from 33- and 46-kg callipyge carcasses indicates that very little longissimus muscle development occurs after lamb carcasses reach 33 kg. Crouse et al. (1978) reported that longissimus muscle areas in normal lambs with 24- and 28-kg carcasses were similar. The findings of Crouse et al. (1978) with normal lambs and those in the current study with callipyge lambs support the work of Butterfield et al. (1984) showing that the longissimus is a relatively early maturing muscle when compared to most other muscles in sheep. Leg scores of heavy and lighter callipyge lambs, like longissimus muscle areas, were similar and both scores were higher ($P < 0.01$) than leg scores for normal lambs. Therefore, differences in leg scores between normal and callipyge lambs support differences observed in longissimus muscle area. The longest metacarpal bones were present in normal lambs (Table 1) and this finding, along with longer carcasses (Field et al., 1996) and less muscular leg conformation scores of normal lambs, attests to a blockier conformation in callipyge lambs. Significantly ($P < 0.01$) longer metacarpals in carcasses from 46-kg heavy callipyge lambs when compared to those from 33-kg lighter callipyge lambs was somewhat surprising because the metacarpal epiphyseal cartilage (growth plate) of the extremely heavy ewe lambs had ossified, and ossification would be expected to stop bone growth (Ho et al., 1989). The extremely heavy ewe lambs were slaughtered at approximately one year of age, so ossified epiphyseal plates are an indication of earlier skeletal maturity for callipyge ewe lambs when compared to normal ewe lambs. Ho et al. (1989) reported that all ewe lambs in their study had growth plates at 361 days of age while by 459 days of age, some ewe lambs had ossified epiphyseal plates. It is clear that bone growth in normal ewe lambs continues after that in callipyge ewe lambs has ceased. Therefore, callipyge ewe lambs would be classified as yearlings at younger ages than normal ewe lambs.

Warner-Bratzler shear values were different ($P < 0.03$) for muscles from all three groups of lambs in Table 1. Loin chops from normal lambs were more tender, followed by loin chops from heavy callipyge lambs, then loin chops from lighter callipyge lambs. These findings confirm results of several other studies reviewed by Field et al. (1996) showing that loin chops from normal lambs are more tender than those from callipyge lambs. Lower, more desirable shear values for chops from heavy callipyge lambs when compared to lighter callipyge lambs is probably a reflection of differences in chilling rate between carcasses in the two weight groups (Smith et al., 1976). Greater muscle mass and greater fat depths in 46-kg heavy carcasses when compared to 33-kg lighter callipyge carcasses resulted in the heavier carcasses maintaining muscle temperatures conducive to higher levels of activity for calpain and other autolytic enzymes for greater periods of time postmortem. Nevertheless, loin chops from 46-kg heavy callipyge carcasses still lacked the tenderness possessed by loin chops from normal lambs.

Conclusions

Reduced shear values for loin samples from extremely heavy carcasses of callipyge lambs when compared to those from lighter carcasses are probably a result of slower chilling because of greater amounts of subcutaneous fat and greater muscle mass in heavier lambs. Attempts to modify shear values and make chops from callipyge lambs more tender by feeding them to heavier weights probably isn't feasible because it would result in increased fatness. Other possible disadvantages of feeding lambs to extremely heavy weights might be extended feeding periods and decreased feed efficiencies.

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Lamb Performance on Seedling Alfalfa with Differing Alfalfa/Weed Biomass Availabilities in the Irrigated Sonoran Desert

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Summary

A 28-day winter grazing trial in 1994 and in 1995 evaluated lamb (*Ovis aries* L.) performance on seedling alfalfa (*Medicago sativa* L.) with differing alfalfa/weed biomass availabilities. Crossbred commercial wethers grazed on four alfalfa/weed biomass availability levels: 1) entire 0.04-hectare paddock sprayed with herbicides, Weed-0; 2) two-thirds of the paddock sprayed so that one-third of the paddock would be weed infested, Weed-1/3; 3) one-third of the paddock sprayed so that two-thirds of the paddock would be weed infested, Weed-2/3; and 4) paddock not sprayed so that entire paddock was weed infested, Weed-100. Each year, each weed standing crop level had three replications. Four wethers with an initial mean weight of 39 kg grazed each experimental 0.04-hectare paddock. To maintain constant grazing pressure in paddocks with varying weed densities, additional lambs were added or taken from the experimental paddocks (put-and-take grazing). Four wethers were fitted with esophageal canulas to determine lamb forage preferences.

Neither year ($P = 0.19$) nor treatment ($P = 0.23$) affected lamb average daily gain (ADG). Year ($P = 0.02$) and treatment ($P < 0.01$) affected production per hectare (kg lamb per hectare). Year did not affect lamb grazing days per hectare ($P = 0.17$); however, treatment did affect ($P < 0.01$) grazing days per hectare. Treatment did not affect the percentage of alfalfa ($P = 0.49$) or broadleaf weeds ($P = 0.49$) in lamb esophageal extrusa. The varying availability of weeds in experimental paddocks affected ($P = 0.08$) the percentage of grasses in lamb esophageal extrusa.

We conclude that lamb grazing on weedy seedling alfalfa contributes to sustainable agriculture production practices. Alfalfa growers would benefit from this practice because less herbicides would be required for alfalfa production and weeds could be marketed through lambs.

Key words: sheep, grazing, weeds, alfalfa, sustainability.

Introduction

In 1994 and 1995, 339,806 and 225,000 lambs (*Ovis aries* L.), respectively, grazed alfalfa (*Medicago sativa* L.) during the winter in Imperial County (Imperial County Agricultural Commissioner, 1995) in southeastern California. Graziers pay alfalfa growers on a head-per-day basis for grazing privileges during the winter grazing season. Alfalfa is fall-planted in the irrigated Sonoran Desert so winter annual weeds are often a problem. Lamb grazing of seedling alfalfa has been practiced in the Imperial Valley as a weed control measure (Mitich et al., 1987) for many years.

Olson and Lacey (1994) described the effectiveness of sheep for weed control on both croplands and range. Ely (1994) described how sheep reduce herbicide usage by controlling weeds and therefore contribute to sustainable agricultural production. Sharrow et al. (1989) portrayed how sheep control brush in coniferous forests. In Montana, sheep are used to control leafy spurge (*Euphorbia esula*; Landgraf et al., 1984). Sheep have also proven useful in controlling globemallow (*Sphaeralcea* spp.; Rumbaugh et al., 1993). In the Imperial Valley, grazing lambs control weeds in seedling alfalfa as effectively as herbicides (Bell et al., 1996). Little published research exists regarding lamb weight gain on weedy seedling alfalfa.

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Ruminant performance usually increases as the percentage of legumes in pasture increases (Crowder, 1985). Reid et al. (1987) fed varying mixtures of ground legume/grass hays to lambs and found that as the fraction of legume hay increased, lamb dry matter (DM) intake increased. The chemical analyses and percent in vitro dry matter disappearance (%IVDMD) of various weeds (Marten and Andersen, 1975; Marten et al., 1987; Bosworth et al., 1985; Bell et al., 1996) illustrate that weeds are high-quality feed at certain times.

We evaluated lamb weight gain and total gain per hectare on weedy seedling alfalfa for two 28-day grazing trials during the winter grazing seasons of 1994 and 1995 in the irrigated Sonoran Desert. We treated portions of the experimental grazing paddocks with herbicides so that various levels of alfalfa and weeds would be available to the grazing lambs. Using a constant grazing pressure, we then could determine the relative worth of our alfalfa/weed mixtures for lamb weight gain and total lamb gain per hectare. The purpose of our grazing trials was to determine lamb weight gain and total lamb gain per hectare on seedling alfalfa with various availabilities of weedy plants in the irrigated Sonoran Desert.

Materials and Methods

Grazing trials were conducted in 1994 and 1995 at the University of California Desert Research and Extension Center, 11.3 km east of El Centro, CA. Protocols for this experiment were approved by the Animal Use Care Advisory Administrative Committee of the University of California. In 1994 we used 68 wethers and in 1995 we used 78 wethers from similar origins and from the same local grazier. The five- to seven-month-old lambs were 25 to 50% Suffolk and 50 to 75% undistinguishable white-faced breeds with initial weights of 39 kg. Prior to initiation of the study, all lambs were treated with anthelmintics and vaccinated against *Clostridium perfringens* Types C and D.

Historical weather data were obtained from the local irrigation district (Imperial Irrigation District, 1996). Weather data during the trials were obtained from the research location's meteorological station.

The experimental paddocks were planted with "CUF-101" alfalfa at a rate of 33.6 kg/hectare of seed on October 10, 1993, and October 5, 1994, on a Glenbar clay loam (fine, silty, mixed calcareous) hypothermic Typic Torrifluvents soil and was flood irrigated. Three 20.1-m wide lands (the area between raised irrigation borders) were used as blocks in this experiment.

Two 0.04-hectare experimental paddocks were randomly allocated to each of four weed control treatments within each block: 1) entire 0.04 hectare paddock sprayed with herbicides, November 29, 1993, and November 22, 1994, in an attempt to remove weeds and have as clean an alfalfa stand as possible, Weed-0; 2) two-thirds of the paddock sprayed so that one-third of the paddock would be weed infested, Weed-1/3; 3) one-third of the paddock was sprayed so that two-thirds of the paddock would be weed infested, Weed-2/3; and 4) paddock not sprayed so that entire paddock was weed infested, Weed-100. We applied the following herbicide mixture: Imazethapyr at 100 g active ingredient (ai)/hectare, 2,4-DB amine at 1.12 kg ai/hectare, ammonium nitrate at 2.5 kg/hectare and crop oil 1% volume-to-volume (v/v). Herbicide was applied with a tractor-mounted sprayer at 280 l/hectare.

To determine lamb grazing preferences on paddocks of differing weed/alfalfa abundance, two weeks prior to the initiation of grazing we esophageally fistulated (Ellis et al., 1984; Adams et al., 1991) four wethers with a common grazing experience of the other experimental lambs. Each day of the 28-day grazing trial, the four fistulated lambs were placed in a block (one lamb per treatment) and were rotated to a new block daily. Fistulated lambs were sampled for 30 minutes each morning. Prior research at this location indicated that lambs select weeds first, then gradually increase the amount of alfalfa selected (Bell et al., 1996). Therefore day of grazing was not considered to be a factor of interest and was not included in the statistical model. Since all four fistulated lambs grazed a single land (block) per day, day of grazing and blocks were confounded and not used as a factor in the statistical model. To maximize the amount of extrusa at the 0800 collection periods, fistulated lambs were fasted overnight prior to grazing. After the morning collection period, the extrusa from each lamb was washed and filtered in cheese cloth and frozen for subsequent chemical analyses.

Since by design the forage DM per paddock varied in our experimental paddocks and to maintain a constant grazing pressure on all the paddocks, we used the put-and-take (Forage Grazing Terminology Committee, 1992) grazing method. We used four constant "tester" (Mott and Lucas, 1952) lambs per 0.04-hectare paddock. Based on ocular estimates of forage biomass, additional "grazer" lambs were placed or removed from experimental paddocks to keep a constant grazing pressure (Forage Grazing Terminology Committee, 1992). Each day the number of lambs (testers plus grazers) per 0.04-hectare paddock were noted to calculate grazing days per hectare. Prior to grazing, tester lambs were weighed after a 16-hour overnight fast. Grazing initiated on January 25, 1994, and on January 30, 1995. Lambs grazed for 14 days on experimental paddocks and then, remaining in the same block, grazed another 14 days on the same treatment. After 28 days of grazing, tester lambs were fasted overnight for 16 hours and weighed. Total kg lamb gain per hectare was calculated as tester ADG times grazing days per hectare.

On the day prior to the initiation of grazing, the forage in eight randomly allocated 0.25-m^2 quadrats in each experimental paddock were harvested to estimate forage standing crop. Forage and extrusa samples were separated into alfalfa and individual weed species and dried for 72 hours at 50 °C in a forced-air oven.

Forage and extrusa samples were subjected to the following chemical analyses: DM, crude protien (CP), ash

(AOAC, 1980), neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL; Goering and Van Soest, 1970). We used the fungal cellulase method (Bughara and Sleper, 1986; Dickerson et al., 1988) to estimate %IVDMD of the extrusa and the individual forage species.

ANOVA was conducted on the data using SAS procedures (SAS, 1988). The independent variables that affected the dependent production variables (ADG, grazing days per hectare, kg per hectare) were year, land within year, treatment and treatment-by-year. The independent variables that affected the lamb extrusa dependent variables (percent alfalfa, percent broadleaf, percent grasses, %IVDMD) were year, individual lamb within year, treatment and treatment within year. We considered the independent variables year, land and lamb to be random (Hicks, 1973; Gill, 1978) requiring a partitioning of the EMS with each factor requiring a specified F-test. We used LSD (Steel and Torrie, 1960) to separate treatment means where appropriate.

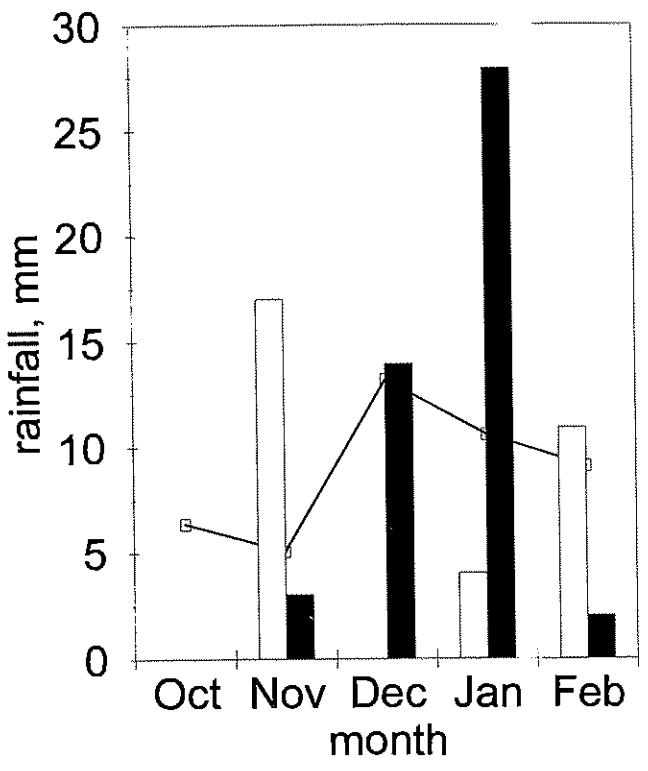
Results and Discussion

Weeds that germinated in the experimental paddocks were: prickly lettuce (*Lactuca serriola* L.), annual sowthistle (*Sonchus asper* L., Hill), littleseed canarygrass (*Phalaris minor* Retz.), nettleleaf goosefoot (*Chenopodium murale* L.), common lambsquarter (*Chenopodium album* L.), london rocket (*Sisymbrium irio* L.), wild beets (*Beta macrocarpa* L.), little mallow (*Malva parviflora* L.), silversheath knotweed (*Polygonum argyrocoleon* L.), wild oats (*Avena fatua* L.), volunteer wheat (*Triticum aestivum* L.), creeping wartcress (*Coronopus squamatus* L.) and volunteer barley (*Hordeum vulgare* L.).

In 1993/94 herbicides were not effective in controlling grasses (Table 1). At the initiation of grazing in 1994 total weed DM as a percentage of total paddock DM was 58, 63, 67 and 71% for the Weed-0, Weed-1/3, Weed-2/3 and Weed-100 treatments, respectively. In 1995, total weed DM as a percentage of total paddock DM was 11, 27, 39 and 49% for the Weed-0, Weed-1/3, Weed-2/3 and Weed-100 treatments, respectively. We attribute the lack of 1994 grass control from our herbicide treatment to the greater-than-normal precipitation in November 1993 (Figure 1). During the winter of 1994, imazethapyr stunted but did not kill the grasses, as we had expected. The grasses later regrew. Broadleaf weeds were effectively controlled with our herbicide treatment (Table 1). Although forage DM yields differed each year (Table 1), our original intention was to have four different levels of weed availability by strip applications of herbicide to the experimental paddocks. Snaydon (1981) affirmed that on the same grazed pasture, yearly pasture yields often vary by two- to four-fold. Uncontrollable and random weather factors often affect the outcome of grazing experiments (Guerrero and Marble, 1991; Rumbaugh et al., 1993; Bell et al., 1996).

Neither year ($P = 0.19$), land ($P = 0.33$) nor treatment ($P = 0.23$) affected lamb ADG. ADG from prior lamb grazing research (Guerrero and Marble, 1991) at this research facility was affected ($P = 0.05$) by year. Year did not affect ($P = 0.17$) grazing days per hectare; however, lands ($P = 0.01$) and treatment ($P < 0.01$) did affect grazing days per hectare. By experimental design we expected to place a greater number of lambs on the weedier plots. One of the lands (land A; Table 2) in the first year was severely grass infested. Similarly, with previous lamb grazing on alfalfa at this research facility, lands have affected ($P < 0.01$) alfalfa production (Mitchell et al., 1991). Year ($P = 0.02$) and treatment ($P < 0.01$) affected lamb yield as kg per hectare; however, lands did not ($P = 0.33$) affect lamb yield. The Weed-100 paddocks had greater ($P < 0.05$) kg lamb production per hectare than any of the herbicide-treated paddocks. Shaw and Dodd (1979) observed that grazing cattle

Figure 1. Winter precipitation at University of California Desert Research and Extension Center (81-year mean, 1993-1994, 1994-1995).



preferred non-herbicide treated forage.

Our overall lamb gains of about 0.20 kg per day on alfalfa (Table 2) compare with the ADG data of other researchers (0.17 kg/day, Guerrero and Marble, 1991; 0.14 kg/day, Karnezos et al., 1994). Crowder (1985) affirmed that ruminant liveweight gain increased with increasing percentage of legume in the pasture. Reid et al. (1987) fed different legume/grass hay ratios to lambs and noted that DM intake of the lambs increased as the amount of legume hay consumption increased. Our treatment variable, with varying amounts of alfalfa/weeds in the experimental weedy seedling alfalfa paddocks, did not affect lamb ADG (P = 0.23; Table 2).

None of the weeds in our study were toxic. Many weeds, while having chemical feed attributes indicative of high intake and digestibility, are nevertheless unpalatable and avoided by lambs (Marten and Andersen, 1975; Marten et al., 1987). While sheep might readily consume certain weeds, their gains, in some cases, might be reduced (Landgraf et al., 1984).

Year affected the percentage of alfalfa (P = 0.09), broadleaf weeds (P = 0.04) and grass (P < 0.01) in lamb esophageal extrusa. Averaged over all treatments, lamb diets included 53.6 and 26.9% grasses in 1994 and 1995, respectively (Table 3). Individual lambs within year consumed alfalfa (P = 0.02) at different rates, but not broadleaf weeds (P = 0.22) or grasses (P = 0.34). It is common for lambs within the same group grazing at the same time to have quite different diet selection patterns (Marten, 1978; Lynch et al., 1992).

Treatment did not affect the percentage of alfalfa (P = 0.49) or broadleafs (P = 0.49) in lamb esophageal extrusa, but did affect the percentage of grasses (P = 0.08). Grasses comprised 31.7, 33.6, 44.1 and 51.7% of lamb diets for Weed-0, Weed-1/3, Weed-2/3 and Weed-100, respectively (Table 3). Since ADG was similar among treatments (P = 0.23) and since the lambs consumed more grasses (Table 3) from Weed-100 than from the other treatments, the results of this study agree with Ely (1994) who affirmed that grazing lambs could be finished on cool-season grasses.

Year affected %IVDMD of lamb esophageal extrusa (P < 0.01); however, individual lambs within year (P = 0.56) or treatment (P = 0.31) had no effect. In 1994 and 1995 over all treatments, %IVDMD was 62.8 and 67.2%, respectively. Reid et al. (1987) similarly found that %IVDMD was similar in mixtures of legumes and grasses.

In weedy seedling alfalfa in the irrigated Sonoran Desert, lambs selected broadleaf weeds and grasses (Table 3) in greater proportion than their relative availabilities (Table 1). These data agree with Bell et al. (1996) that on weedy seedling alfalfa, lambs initially consume weeds and as the availability of weeds decrease, the lambs then start to consume alfalfa. Our data do not agree with those of Rumbaugh et al. (1993), who found that during spring grazing, range ewes prefer

Table 1. Mean botanical composition and dry matter yield of seedling alfalfa at University of California Desert Research and Extension Center.

1994				
	Forage, % DM			
Treatment[a]	Alfalfa	Broadleafs	Grasses	
Weed-0	41.6	0.1	58.3	
Weed-1/3	36.7	2.8	60.5	
Weed-2/3	32.7	5.0	62.3	
Weed-100	29.3	6.9	63.8	
	Forage, DM kg/hectare			
Treatment	Alfalfa	Broadleafs	Grasses	Total DM
Weed-0	1289	4	1809	3101
Weed-1/3	1254	96	2064	3414
Weed-2/3	1218	188	2320	3726
Weed-100	1183	280	2577	4039
1995				
	Forage, % DM			
Treatment	Alfalfa	Broadleafs	Grasses	
Weed-0	88.8	0	11.2	
Weed-1/3	72.9	3.7	23.4	
Weed-2/3	60.7	6.6	32.6	
Weed-100	51.0	8.8	40.1	
	Forage, DM kg/hectare			
Treatment	Alfalfa	Broadleafs	Grasses	Total DM
Weed-0	2100	0	264	2363
Weed-1/3	1985	101	636	2723
Weed-2/3	1871	203	1006	3082
Weed-100	1756	304	1381	3442

[a] Weed-0 = paddocks completely weed-free; Weed-1/3 = one-third of paddock weed-infested; Weed-2/3 = two-thirds of paddock weed-infested; and Weed-100 = paddocks completely weed-infested.

alfalfa over globemallow (*Sphaeralcea* spp.) and grasses.

Information on the chemical composition of individual plant species is shown in Table 4. These data support the higher %IVDMD found in the 1995 diets compared to 1994 (Table 3). Creeping wartcress, london rocket, little mallow, prickly lettuce and annual sowthistle are comparable or superior to alfalfa in feed quality. Nutrient density of annual grasses, while adequate to meet the requirements of growing lambs, was lower than the nutrient contents of broadleaf weeds. If lamb grazing in seedling alfalfa in the Sonoran Desert is timed relative to the physiological maturity of both the alfalfa and the weeds (Taylor, 1994; Olson and Lacey, 1994), many of the weed species have the potential of providing very high quality feed (Marten et al., 1987; Bell et al., 1996).

Conclusions

Since grazing lambs have proven to be a good weed control measure in seedling alfalfa and not detrimental to long-term alfalfa production in the irrigated Sonoran Desert (Bell et al., 1996), and since grazing lambs had the same ADG ($P = 0.23$) on weedy seedling alfalfa as on herbicide-treated alfalfa, we conclude that grazing lambs contribute to sustainable agricultural production practices by decreasing the amounts of herbicides required for alfalfa production. Both the grazier and the alfalfa grower would benefit by having lambs graze weedy seedling alfalfa for weed control in the irrigated Sonoran Desert. Since the Weed-100 and Weed-2/3 paddocks had increased ($P < 0.01$) grazing days per hectare, the grazier would benefit by reducing labor costs by using a specific field for a longer period before having to move the lambs. The grower would benefit from reduced herbicide costs and by being able to market weeds as if the weeds were alfalfa. Since neither lamb (Table 2) nor alfalfa performance (Bell et al., 1996) are decreased by grazing weedy seedling alfalfa, we are in agreement with Landgraf et al. (1984) who stated: "Sheep can be classified as a biological weed control agent."

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Table 2. Mean lamb performance on seedling alfalfa with specific alfalfa/weed biomass availabilities in the irrigated Sonoran Desert.

	ADG, kg/day	grazing days/hectare	kg/ha
Year			
1994	0.207	1895	397[c]
1995	0.185	1741	320[d]
SE	0.01	27.1	19.6
Land[a] (Year)			
1994			
A	0.187	2078[e]	401
B	0.207	1791[f]	377
C	0.228	1815[g]	415
1995			
A	0.183	1729[h]	313
B	0.210	1748[i]	375
C	0.163	1748[i]	274
SE	0.02	46.9	34.0
Treatment[b]			
Weed-0	0.200	1441[j]	283[n]
Weed-1/3	0.174	1614[k]	281[n]
Weed-2/3	0.189	1990[l]	380[o]
Weed-100	0.222	2227[m]	493[p]
SE	0.02	38.3	27.8
Treatment•Year			
1994			
Weed-0	0.180	1597	284
Weed-1/3	0.186	1634	304
Weed-2/3	0.219	2079	457
Weed-100	0.244	2268	546
1995			
Weed-0	0.219	1284	282
Weed-1/3	0.162	1593	258
Weed-2/3	0.159	1902	302
Weed-100	0.201	2186	440
SE	0.02	54.2	39.2

[a] Localism for area between raised irrigation borders; in this experiment, blocks.
[b] Weed-0 = paddocks completely weed-free; Weed-1/3 = one-third of paddock weed-infested; Weed-2/3 = two-thirds of paddock weed-infested; and Weed-100 = paddocks completely weed-infested.
[c-p] Means within independent variables with different superscripts differ, LSD ($P < 0.05$).

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Table 3. Least square means (±SE) of characteristics of lamb extrusa on seedling alfalfa with differing alfalfa/weed biomass availabilities at the University of California Desert Research and Extension Center.

	% alfalfa	% broadleaf	% grasss	%IVDMD
Year				
1994	35.3[a] ± 3.3	11.0[c] ±1.9	53.6[e] ± 3.4	62.8[g] ± 0.62
1995	55.5[b] ± 5.3	18.3[d] ±3.0	26.9[f] ± 5.4	67.2[h] ± 0.99
Treatment[k]				
WEED-0	62.5 ± 6.4	6.1 ± 3.7	31.7[i] ± 6.6	66.3 ± 1.21
WEED-1/3	49.7 ± 5.8	16.7 ± 3.3	33.6[i] ± 6.0	65.8 ± 1.10
WEED-2/3	35.6 ± 5.6	21.0 ± 3.2	44.1[ij] ± 5.8	64.3 ± 1.06
WEED-100	33.7 ± 6.1	14.8 ± 3.5	51.7[j] ± 6.3	63.6 ± 1.15

[a-j] Within independent variable and within column, means with different superscripts differ, LSD ($P < 0.10$).

[k] WEED-0 = paddocks completely weed-free; WEED-1/3 = one-third of paddock weed-infested; WEED-2/3 = two-thirds of paddock weed-infested; and WEED-100 = paddocks completely weed-infested.

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Table 4. Chemical composition of alfalfa and weeds in seedling alfalfa at the University of California Desert Research and Extension Center.

	% DM					
	CP	NDF	ADF	ADL[a]	ASH[a]	IVDMD[a]
			1994			
alfalfa (*Medicago sativa*)	26.3^{f}	29.0^{j}	21.6^{h}	7.1	8.7	70.3
littleseed canarygras (*Phalaris minor* Retz.)	18.5^{l}	46.9^{f}	22.1^{h}	2.8	12.2	58.7
creeping wartcress (*Coronupus squamatus*)	29.7^{c}	15.8^{r}	14.7^{m}	3.3	14.9	82.0
nettleleaf goosefoot (*Chenopodium murale*)	22.0^{j}	26.0^{k}	17.4^{kl}	6.2	17.1	61.5
common lambsquarter (*Chenopodium album*)	22.8^{i}	27.0^{j}	15.1^{m}	4.7	16.3	61.4
london rocket (*Sisymbrium irio*)	25.0^{g}	22.9^{l}	19.8^{i}	5.8	13.0	70.1
little mallow (*Malva parviflora*)	23.9^{h}	17.3^{q}	16.4^{l}	3.3	12.1	78.1
prickly lettuce (*Lactuca serriola*)	23.2^{hi}	19.2^{no}	18.1^{jk}	3.7	15.2	85.5
annual sowthistle (*Sonchus asper*)	22.5^{ij}	17.9^{pq}	17.3^{kl}	3.8	17.6	81.0
wild beets (*Beta macrocarpa*)	22.7^{i}	23.7^{l}	14.7^{m}	3.8	21.2	61.6
volunteer wheat (*Triticum aestivum*)	10.9^{o}	50.2^{d}	27.4^{e}	4.5	7.5	50.1
wild oats (*Avena fatua*)	12.4^{n}	48.9^{e}	27.4^{e}	4.3	7.7	54.9
			1995[b]			
alfalfa	28.7^{d}	37.4^{g}	33.4^{c}	4.3	10.8	77.8
littleseed canarygrass	19.9^{k}	48.0^{e}	29.2^{d}	2.6	13.8	64.6
nettleleaf goosefoot	22.4^{ij}	30.4^{h}	23.4^{g}	18.0	18.3	57.1
common lambsquarter	27.2^{e}	29.9^{hi}	18.1^{jk}	8.5	18.1	58.5
london rocket	26.0^{f}	21.8^{m}	17.3^{kl}	4.9	14.7	80.9
little mallow	29.0^{cd}	18.5^{op}	16.8^{l}	3.4	14.0	80.3
prickly lettuce	28.8^{d}	20.1^{n}	18.3^{j}	4.2	14.8	73.7
annual sowthistle	21.9^{j}	30.7^{h}	23.9^{g}	5.6	16.6	80.9
wild beets	18.2^{l}	26.2^{k}	25.9^{f}	7.5	19.9	60.1
wild oats	14.5^{m}	56.7^{c}	19.8^{i}	7.0	10.5	53.0
SE	0.17	0.34	0.30			

[a] Insufficient repetition, no SD calculated.
[b] Due to rainfall, samples taken at later date with many species at later maturity.
[c-r] Within column, means with different superscripts differ, LSD ($P < 0.05$).

Effects of Protein Source on Performance of Rambouillet Rams

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Summary

A study was conducted to examine the effects of protein source on performance of Rambouillet rams. Thirty-six February-born ram lambs approximately eight months old were randomly allocated to four feed treatments with three replications per treatment and three rams in each replication. The treatments consisted of a control ration that contained soybean (SBM) and cottonseed (CSM) meals as the protein sources (a ration identical to that used in the Texas Agricultural Experiment Station's ram performance test held in Sonora, TX) and three treatments containing the following protein sources: blood meal (BM), fish meal (FM) and a combination of BM and FM. Each of the rations used in the study were formulated to exceed the NRC nutrient requirements for replacement ram lambs (NRC, 1985). Rams were shorn and weighed initially then weighed at 28-day intervals during the 112-day study. Feed intakes were calculated by pen (one replication) for each 28-day period to obtain an estimate of feed efficiency. At the conclusion of the test, animals were weighed and a mid-side wool sample was taken prior to shearing (112 days). Feed efficiency (gain per unit weight of feed consumed) tended to be higher ($P < 0.09$) in rams consuming the FM diet. Further, animals consuming the FM diet were consistently higher in overall live weight gain, average daily gain (ADG) and feed efficiency throughout the trial. However, no significant differences ($P > 0.05$) among treatments were observed, by weigh period, for weight gain, ADG and feed efficiency. Animals in the BM treatment tended to produce the shortest ($P = 0.07$) wool. In summary, the FM-based diet tended to result in faster, more efficient weight gains than diets based on the other protein sources.

Key words: sheep, protein, wool.

Introduction

The need to identify cost-effective protein sources that are capable of increasing wool production and feed efficiency of sheep is vital to improving the profitability of the sheep industry. Studies have been conducted to assess various protein sources on the performance of sheep and cattle. Schafer (1992) suggested that FM and CSM produced higher ADG in growing rams compared to feather meal. However, he also stated that feather meal was used more efficiently by sheep. Fahmy et al. (1992) concluded that sheep fed FM as a protein source exhibited superior ADG compared to animals fed SBM. Hussein and Jordan (1991) stated that the addition of FM to a diet would invariably increase ADG, but would not improve feed efficiency in sheep. Different protein sources have been demonstrated to alter rumen pH and volatile fatty acid (VFA) production (Hussein et al., 1991). These authors also concluded that FM diets produce a higher molar concentration of acetate and propionate in the rumen compared to SBM-based diets.

This study was designed to investigate the effects of protein sources on performance and wool characteristics of Rambouillet rams. The protein sources that were used are a CSM/SBM combination, BM, FM and a BM/FM combination.

Materials and Methods

Thirty-six Rambouillet ram lambs, approximately eight months old and 78 kg live weight, were acquired from the Angelo State University Management, Instruction and Research Center (San Angelo, TX). After

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[4] Ivermectin - Ivomec. A product of Merck and Co., Rahway, NJ 07065 USA. Dosage: 3 ml/12 kg live weight, administered orally.

[5] *Clostridium perfringens* Type C and D toxoid. Anchor Laboratories, Inc., St. Joseph, MO 64506. Dosage: 2 ml per lamb, injected subcutaneously.

weaning (at an average of 120-days of age), rams were maintained on a common ration for 90 days until initiation of the test in October, 1994, at which time the rams were treated for internal parasites[4] and vaccinated against enterotoxemia[5].

Rams were shorn and weighed at the initiation of the study. Rams were randomly assigned to treatments and pens with three replications per treatment and three rams per replication (pen). The four rations were formulated to be isonitrogenous and isocaloric (Table 1); however, after proximate analysis of the rations (Table 2), it was observed that the control ration (SBM/CSM) was approximately 1% lower in crude protein (CP) than the other rations. The observed variation in CP was a result of ration preparation by a commercial feed mill. Since all diets exceeded the National Research Council's (NRC) nutrient requirements for CP for replacement ram lambs (NRC, 1985), any differences or lack thereof among treatments may be attributed to protein source rather that level of crude protein. In addition, the BM ration was lower in Ca and P levels than the other three rations. However, the levels of these minerals were also within the NRC (1985) recommended levels. Essentially the only difference among rations was the source of the protein. SBM/CSM (control), BM, FM and a combination of BM and FM were the protein sources used in the rations. Diet samples were taken weekly and combined by weigh period for proximate analysis by a commercial laboratory. Rams were fed at a rate of 4% of their body weight per day and feeding rates were adjusted every 28 days using the pen average body weight. Clean, fresh water was available at all times.

Upon completion of the 112-day trial, live weights were recorded. Mid-side wool samples were removed and the rams were shorn to obtain grease fleece weights. Ten staples of wool were removed from random locations throughout each fleece and were used for staple length determination (ASTM, 1995b). Each fleece was cored (32-by-1.25 cm cores) and the

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

Ingredient	SBM/CSM[b] (Control)	BM[c]	FM[d]	BM/FM[e]
Corn	26.8	33.3	30.8	32.3
Urea	0.35	0.35	0.35	0.35
Salt	1.2	1.2	1.2	1.2
Alfalfa, dehy	29.0	29.0	29.0	29.0
Molasses	5.0	5.0	5.0	5.0
Calcium carbonate	0.5	0.5	0.5	0.5
Cottonseed hulls	24.0	24.0	24.0	24.0
Vitamin E	0.01	0.01	0.01	0.01
Selenium, 0.06%	0.04	0.04	0.04	0.04
Ammonium chloride	0.5	0.5	0.5	0.5
Vitamin A-44	0.01	0.01	0.01	0.01
TM[f] premix	0.08	0.08	0.08	0.08
Cottonseed meal	6.25	—	—	—
Soybean meal	6.25	—	—	—
Blood meal	—	6.0	—	3.0
Fish meal, menhaden	—	—	8.5	4.0

[a] All ingredients in % as-fed basis.
[b] SBM/CSM = soybean meal and cottonseed meal combination.
[c] BM = blood meal.
[d] FM = fish meal.
[e] BM/FM = blood meal and fish meal combination.
[f] TM = trace mineral premix. The percent ingredients of the premix are as follows: sodium chloride, 64.7; potassium chloride, 19; sulfur, 10; zinc oxide, 0.387; vitamin D (30,000 IU/g), 0.093; chlortetracycline (50,000 IU/g), 3.0; and molasses, 1.5.

Table 2. Nutrient composition of experimental diets[a].

Ingredient	SBM/CSM[b] (Control)	BM[c]	FM[d]	BM/FM[e]
Dry matter, %	91.2	91.2	91.9	90.8
TDN[f], %	64.2	64.0	64.7	64.0
Crude protein, %	14.5	15.5	15.1	15.4
ADF[g], %	25.0	25.8	25.3	24.8
NDF[h], %	37.6	36.8	36.2	34.7
NEm, Mcal/kg	1.4	1.4	1.4	1.4
NEg, Mcal/kg	0.84	0.84	0.86	0.84
Calcium, %	0.81	0.59	1.09	0.78
Phosphorus, %	0.36	0.18	0.43	0.36
Magnesium, %	0.22	0.15	0.19	0.15
Potassium, %	1.02	0.80	1.47	0.77
Sodium, %	0.19	0.28	0.25	0.11
Sulphur, %	0.22	0.20	0.24	0.23
Iron, ppm	256.5	295.2	213.6	203.0
Copper, ppm	5.03	5.02	3.00	9.90
Manganese, ppm	50.3	46.2	46.1	40.6
Zinc, ppm	44.3	36.1	34.1	39.6

[a] All nutrients on as-fed basis.
[b] SBM/CSM = soybean meal and cottonseed meal combination.
[c] BM = blood meal.
[d] FM = fish meal.
[e] BM/FM = blood meal and fish meal combination.
[f] TDN = total digestible nutrients.
[g] ADF = acid detergent fiber.
[h] NDF = neutral detergent fiber.

core samples (2-by-25 g) were used to determine lab scoured yield (ASTM, 1995a) and average fiber diameter of the entire fleece. Average fiber diameters were also determined for the mid-side samples. Both sets of average fiber diameters were determined using an Optical Fibre Diameter Analyser (OFDA) and a test method outlined by the International Wool Textile Organization (IWTO, 1995). Fibers from each side sample were measured at the tip and the base of the staple. This was done to determine fiber diameter at the initiation and at the end of the test to better assess the effect of protein source on average fiber diameter. All wool analyses were performed at the Texas Agricultural Experiment Station's Wool and Mohair Research Laboratory (San Angelo, TX).

Data were analyzed using analysis of variance to determine differences among protein sources. Animals were nested within pens and pens served as replications. Simple T-test analyses were conducted to compare two different protein sources when an overall treatment effect was not significant ($P > 0.10$; Hicks, 1993; SAS, 1995). When there was an overall treatment effect ($P < 0.10$), Fisher's least significant difference was used to distinguish differences among treatment means.

Table 3. Effects of protein source on animal performance.

	Treatments				
Variables	Control[a]	BM[b]	FM[c]	BM/FM[d]	SE[e]
Initial weight, kg	79.2	78.8	77.9	78.0	2.71
Final weight, kg	111.4[f]	113.2	116.6[g]	114.3	1.73
Weight gain, kg	32.3[f]	34.4	38.7[g]	36.3	2.01
ADG[h]	0.29[f]	0.31	0.35[g]	0.33	0.02
Feed efficiency[i]	0.080[f]	0.090	0.102[g]	0.097	0.002

[a] Combination of soybean meal and cottonseed meal.
[b] BM = blood meal.
[c] FM = fish meal.
[d] BM/FM = blood meal and fish meal.
[e] SE = standard error.
[f,g] Control or fishmeal means without a common superscript are different ($P < 0.1$).
[h] ADG = average daily gain, kg gain/day.
[i] Feed efficiency = kg gain/kg feed.

Table 4. Effects of protein source on wool production and fiber characteristics.

	Treatments				
Variables	Control[a]	BM[b]	FM[c]	BM/FM[d]	SE[e]
GFW[f]	12.0	11.7	12.4	12.9	0.70
Y[g]	50.7	49.8	49.8	49.1	1.40
CFW[h]	6.1	5.8	6.2	6.3	0.31
ASL[i]	14.5[j]	12.6[k]	14.1[j]	14.0[j]	0.58
Initial side AFD[l]	23.44	22.97	24.01	23.01	0.44
Final side AFD	23.58	23.28	24.52	23.61	0.45
Core AFD	23.10	22.48	23.58	22.86	0.50

[a] Combination of soybean meal and cottonseed meal.
[b] BM = blood meal.
[c] FM = fish meal.
[d] BM/FM = blood meal and fish meal.
[e] SE = standard error.
[f] GFW = grease fleece weight, kg; adjusted to 365 days.
[g] Y = lab scoured yield, %.
[h] CFW = clean fleece weight, kg; adjusted to 365 days.
[i] ASL = average staple length, cm; adjusted to 365 days.
[j,k] Means in the same row without a common superscript are different ($P < 0.05$).
[l] AFD = average fiber diameter, µm.

Results and Discussion

Animal Performance

Ram body weight gains were 32.3, 34.4, 38.7 and 36.3 kg per head for the control, BM, FM and BM/FM rations, respectively. Live weight gain for rams fed FM tended to be greater ($P = 0.09$) than for rams fed the control ration. However, there were no differences ($P = 0.26$) among the other three treatments (Table 3). The same trend in mean values was also observed for ADG with the FM treatment being greater ($P = 0.09$) than the control. Fahmy et al. (1992) reported similar results showing that ADG of FM and corn gluten meal fed lambs was higher ($P < 0.01$) than lambs fed SBM. No differences in ADG were detected among the other three treatments ($P > 0.10$; Table 3). Rams fed the FM ration also tended to be more efficient ($P = 0.09$) at converting feed to animal mass than rams in both the control and BM treatments. No differences in feed efficiency ($P > 0.25$) were detected among other treatments. No 28-day period effects ($P > 0.15$) were found for weight gain, ADG and feed efficiency. These results are similar to those reported by Hussein and Jordan (1991) and Fahmy et al. (1992) in which SBM and FM were compared. Our data suggest that using FM as a protein source for growing rams will tend to improve their performance, especially in terms of feed efficiency, compared to the alternative protein sources SBM, CSM and BM.

Wool Production

Rams fed the BM ration produced shorter ($P < 0.05$) wool than rams fed the control, FM or BM/FM rations (Table 4). Grease fleece weights (GFW), yields (Y), clean fleece weights (CFW) and average fiber diameters (AFD) were not affected ($P > 0.1$) by treatments. Except for the

staple length results, these results are in agreement with those of Schloesser et al. (1993) and Schafer (1992), who also reported no effects of protein source on wool production or quality. Our results indicated that the BM ration produced shorter staple length wool compared to the other rations.

Conclusions

The use of FM as the protein source in a ration fed at 4% of body weight to growing Rambouillet rams tended to increase overall weight gain and feed efficiency compared to the control ration (soybean meal and cottonseed meal). In contrast, the BM ration produced comparable weight gains while maintaining a relatively low AFD, but the BM ration resulted in shorter staple length wool. The combination BM/FM diet tended to produce results intermediate between BM and FM (yield and clean fleece weight being the exceptions). This study did not identify any advantages of BM over the control ration. The FM-based diet tended to be used more efficiently than the control ration and tended to produce higher ADG than the control or BM rations. However, FM is generally more expensive than other sources of protein and may not be a cost-effective alternative protein source. Our data indicate that additional research is needed to identify more efficient and less expensive protein sources with which to feed sheep.

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Fiber Diameter Measurements of Fine-wool Rams on Performance Test[1,2]

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Summary

Average fiber diameter (AFD), standard deviation of fiber diameter (SD) and coefficient of variation of fiber diameter (CV) were determined for core-sampled pre-test fleeces, side and britch on-test samples and core-sampled post-test fleeces for 531 rams participating in the Texas Agricultural Experiment Station's Ram Performance Test during the years 1994, 1995 and 1996. Pre-test fleece measurements were shown not to provide a good indication of the AFD of wool grown during the test. Further, although side samples and post-test core samples were significantly correlated ($r^2 = 0.75$) in terms of AFD, side samples were coarser (1.33 µm; $P < 0.0001$) than whole fleece core samples. Britch and side AFD differences were not indicative of whole fleece variability of AFD ($r^2 < 0.04$). These last two observations have important implications for the fine-wool ram performance tests conducted by the Texas Agricultural Experiment Station (TAES; San Angelo, TX) and the University of Wyoming (UW; Laramie, WY).

Key words: average fiber diameter, performance test, ram.

Introduction

Average fiber diameter and standard deviation of fiber diameter are important price-determining characteristics of raw wool because (together with length characteristics) they govern the size and uniformity of yarn, the efficiency of yarn production and ultimately the type of product that can be manufactured from a particular lot of wool (Iman et al., 1990; Lupton, 1995). Consequently, AFD and fiber diameter variability, either SD or CV, are two of the variables used to assess overall merit of fine-wool rams on performance test (Riley et al., 1996). In the TAES Performance Test (Shelton and Lewis, 1986; Waldron and Lupton, 1996), the AFD of a side sample is used to estimate AFD of the fleece grown during the test. The difference between AFD of a britch sample and that of the corresponding side sample is used as an indicator of fiber diameter variability. In addition, the AFD of side and britch samples constitute two independent culling levels (24.94 and 26.39 µm, respectively) for certification of rams in the American Rambouillet Sheep Breeders' Association. Previous work (Lupton et al., 1990) on a limited number (100) of rams participating in the 1989 TAES test and rams (78) in the 1989 UW performance test (Iman et al., 1990) indicated that AFD of side sample was a good indicator ($r = 0.89$) of AFD of whole fleeces and that the difference in AFD between britch and side was significantly but only poorly correlated ($r = 0.15$) with whole-fleece CV of fiber diameter. In contrast, the CV of fiber diameter of the whole fleece core sample was moderately correlated ($r = 0.45$) to the CV of fiber diameter of the side sample. One implication for fine-wool ram testing and selection of stud rams was that the CV of fiber diameter of the whole fleece is not a sensitive indicator of coarse britch wool (and vice versa).

The current three-year study was designed to establish the relationships between AFD and variability of fiber diameter for fleeces collected at the beginning of performance tests, side and britch samples collected during the performance tests and whole fleeces shorn at the end of the tests. By measuring fibers on three different sets of rams participating in three separate performance tests, the effect of year on the various measures of fiber diameter was also determined. Results from this experiment permit informed recommendations to be

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made concerning the use of the most appropriate measures of fiber diameter distribution in fine-wool selection programs and/or index equations.

Materials and Methods

Rams participating in the 1994, 1995 and 1996 TAES Ram Performance Tests were routinely shorn at the beginning of the test. The "pre-test" fleeces were expected to be variable as a result of different pre-test management practices, environments, ages and genetic backgrounds of the rams. Thirty-two half-inch core samples were removed from each pre-test fleece (Johnson and Larsen, 1978). Pre-test core samples (PRC) were washed and dried (ASTM, 1995), conditioned, sub-sampled with a 2-mm mini-corer and the resulting subsamples were measured for AFD, SD and CV using an Optical Fibre Diameter Analyser (OFDA; IWTO, 1995). Ninety-eight days into the performance tests, mid-side (S) and britch (B) samples were removed from each ram. These wool samples were subsampled close to the base of the staple using a 2 mm "snippeter" device. This sampling site was chosen because it is known that AFD of a side sample of a ram on test tends to be constant after the first 28 days (Schafer, 1992; Bohnert, 1994). The resulting 2-mm snippets were cleaned with solvents (1, 1, 1-trichloroethane, ethanol and acetone), dried, conditioned and measured for AFD, SD and CV using the OFDA. At the end of the 143-day performance tests, each ram was shorn. These fleeces were post-test core sampled (POC) and measured in an identical manner to the pre-test fleeces.

Data were analyzed to provide simple statistics (mean, SD, CV) for each variable measured and simple linear regression analyses and analyses of variance were performed on the data using the MEANS, REG and GLM procedures of SAS (SAS, 1992). For these analyses it was assumed that all rams were genetically independent of each other. In fact, this was not the case. Several rams each year had common sires and a few had common dams. We considered that these few relationships would not significantly affect the results of our analyses.

Results and Discussion

Tables 1, 2 and 3 show least squares means and standard errors by year for AFD, SD and CV of the PRC, S, B and POC wool samples, respectively. Overall, the AFD of the PRC did not differ among years ($P > 0.05$). In

Table 1. Least squares means (and standard errors) of average fiber diameters by year.[a]

Year	N	PRC, µm	S, µm	B, µm	POC, µm
1994	201	19.95 (0.10)	23.71[b] (0.13)	26.97[b] (0.17)	22.06[c] (0.11)
1995	169	20.20 (0.11)	23.27[c] (0.15)	26.23[c] (0.18)	22.43[b] (0.12)
1996	161	20.22 (0.11)	23.94[b] (0.15)	26.56[b,c] (0.18)	22.48[b] (0.12)

[a] N = number of rams in performance test; PRC = pre-test core sample; S = side sample; B = britch sample; POC = post-test core sample.
[b,c] Column means having different superscripts differ ($P < 0.05$).

Table 2. Least squares means (and standard errors) of standard deviation of fiber diameter by year.[a]

Year	N	PRC, µm	S, µm	B, µm	POC, µm
1994	201	4.63[b] (0.04)	4.34[b] (0.04)	5.66[b] (0.06)	4.42 (0.04)
1995	169	4.04[c] (0.05)	3.76[d] (0.04)	4.54[c] (0.07)	4.48 (0.04)
1996	161	4.05[c] (0.05)	3.97[c] (0.04)	4.72[c] (0.07)	4.43 (0.04)

[a] N = number of rams in performance test; PRC = pre-test core sample; S = side sample; B = britch sample; POC = post-test core sample.
[b,c,d] Column means having different superscripts differ ($P < 0.05$).

Table 3. Least squares means (and standard errors) of coefficient of variation of fiber diameter by year.1

Year	N	PRC, µm	S, µm	B, µm	POC, µm
1994	201	23.21[b] (0.19)	18.31[b] (0.12)	20.95[b] (0.19)	20.04 (0.14)
1995	169	20.00[c] (0.21)	16.17[d] (0.13)	17.31[c] (0.21)	20.00 (0.15)
1996	161	20.03[c] (0.21)	16.57[c] (0.13)	17.33[c] (0.21)	19.72 (0.16)

[a] N = number of rams in performance test; PRC = pre-test core sample; S = side sample; B = britch sample; POC = post-test core sample.
[b,c,d] Column means having different superscripts differ ($P < 0.05$).

contrast, mean side sample AFD in 1995 was less than 1994 or 1996 ($P < 0.05$). Britch AFD exhibited a similar pattern but core samples from the whole fleece indicated that 1994 fleeces were finer ($P < 0.05$) than the other two years. Interestingly, the amount of fleece coarsening that occurred in each test period was not affected by year (POC – PRC = 2.1, 2.2 and 2.3 µm in 1994, 1995 and 1996, respectively; $P = 0.39$). To a very close approximation, the overall average fineness of the rams at the start of the test was not different among years. Every effort was made to manage and feed the rams on test in an identical manner in each year of the experiment. Nevertheless, year effects on all measures of fiber diameter (except the above-mentioned measures of coarsening) were significant, indicating that other environmental factors may affect the performance of the rams. Thus, care is required when comparing among-year performance of rams. Such comparisons are best made using percentage deviations from an annual mean for the particular trait being considered.

Table 4. Least squares means of average fiber diameter, standard deviation and coefficient of variation of various wool samples taken from 531 ram fleeces.

Item	PRC[a]	S[b]	B[c]	POC[d]
AFD, µm	20.11[h]	23.64[f]	26.61[e]	22.30[g]
SD, µm	4.27[g]	4.04[h]	5.02[e]	4.44[f]
CV, %	21.23[e]	17.10[h]	18.81[g]	19.95[f]

[a] PRC = pre-test core sample.
[b] S = side sample.
[c] B = britch sample.
[d] POC = post-test core sample.
[e-h] Row means having different superscripts differ ($P < 0.05$).

Table 5. Simple linear regression equations and coefficients of determination (r^2) for various measures of average fiber diameter, standard deviation and coefficient of variation.[a]

Dependent variable	Regression equation	r^2
Average fiber diameter		
S	AFD = 6.03 + 0.88 PRC	0.43
S	AFD = 5.15 + 0.67 B	0.74
S	AFD = –0.61 + 1.09 POC	0.75
Standard deviation		
S	SD = 2.19 + 0.43 PRC	0.27
S	SD = 2.01 + 0.40 B	0.55
S	SD = 1.90 + 0.48 POC	0.21
Coefficient of variation		
S	CV = 11.10 + 0.28 PRC	0.21
S	CV = 9.15 + 0.42 B	0.47
S	CV = 11.24 + 0.29 POC	0.09
POC SD[b]	CV = 4.17 + 0.09 (B AFD[c] – S AFD[c])	0.04
POC CV[d]	CV = 19.48 + 0.15 (B AFD[c] – S AFD[c])	0.01

[a] S = Side sample; PRC = pre-test core sample; B = britch sample; POC = post-test core sample.
[b] SD = standard deviation of fiber diameter.
[c] AFD = average fiber diameter.
[d] CV = coefficient of variation of fiber diameter.

For the three-year period (Table 4), wool produced during the test (POC) was 2.20 µm coarser than that shorn from the animals at the start of the test. Britch samples were 2.97 µm coarser than side samples and side samples were 1.33 µm coarser than post-test core samples of the whole fleece (POC). The observed consistent coarseness of the side sample compared to the fleece as a whole is contrary to earlier observations on rams participating in performance tests. However, a similar observation has been reported previously for crossbred ewes under range conditions (Iman et al., 1990).

Typically the AFD of fibers produced on the side of the animals during the first 28 days of the performance test is 3.6 µm finer than those produced during the remaining time (Bohnert, 1994; Salisbury, 1996; Schafer, 1992). Assuming a similar differential in other body areas, it should not be surprising that the POC samples are invariably finer than the S samples. Yearly trends in SD of fiber diameter shown in Table 2 tend to follow closely the trends in AFD. The CV data (SD/AFD × 100) summarized in Table 3 confirms that the variability in side and britch samples is generally less than that observed for either of the core samples.

Although AFD of pre-test core, side, britch and post-test core samples differ, regression analyses confirmed that the measurements are significantly correlated. A selection of pertinent regression equations and their corresponding coefficients of determination (r^2) are given in Table 5. Only 43% of the variation in S AFD can be accounted for by the variability of PRC AFD (Table 5 and Figure 1). In contrast, 75% of the variation in S AFD is accounted for by variation in POC AFD (Table 5 and Figure 2). The two measures of variability of fiber diameter (SD and CV) invariably exhibit lower r^2 values than the corresponding AFD correlation.

The differences between side and britch AFD values were thought to be a reasonable indicator of variability of fiber diameter in the fleeces as a whole. The two regression equations at the bottom of Table 5 and Figure 3

show that such is not the case. This observation is in agreement with that made by Iman et al. in 1990. Measures of whole-fleece variability of fiber diameter are best determined by measuring representative core samples.

Conclusions

Pre-test fleece measurements did not provide a good indication of the average fiber diameter of wool grown during the performance test.

The average fiber diamber of side samples and post-test whole fleece core samples were significantly correlated. However, side samples were coarser than core samples.

Differences in average fiber diamber between side and britch samples were not indicative of whole fleece variability in fiber diameter.

Whole-fleece variability of fiber diameter is best determined by measuring representative core samples.

Implications

In terms of average fiber diameter and its associated variability, rams participating in the TAES and UW performance tests are being assessed using different criteria. Because these criteria are used to certify the rams in a common association (The American Rambouillet Sheep Breeders' Association), some corrective measures need to be taken. Preferably, this would be done without lowering current standards that have been in effect for many years. One suggested solution for future ram tests would be as follows. First, both testing agencies would measure AFD and CV of side, britch and whole fleeces. The current certification standards based on side and britch AFD measurements would be retained. However, the TAES index equation would be modified to match the UW equation in which AFD and CV of whole fleeces are used instead of AFD of side samples and AFD differences (britch minus side). In general, measures of fiber diameter variability are expected to become more important to breeders and processors since measurement methods have become more efficient.

Figure 1. Side sample fiber diameter (SAFD) versus pre-test core average fiber diameter (PTCAFD).

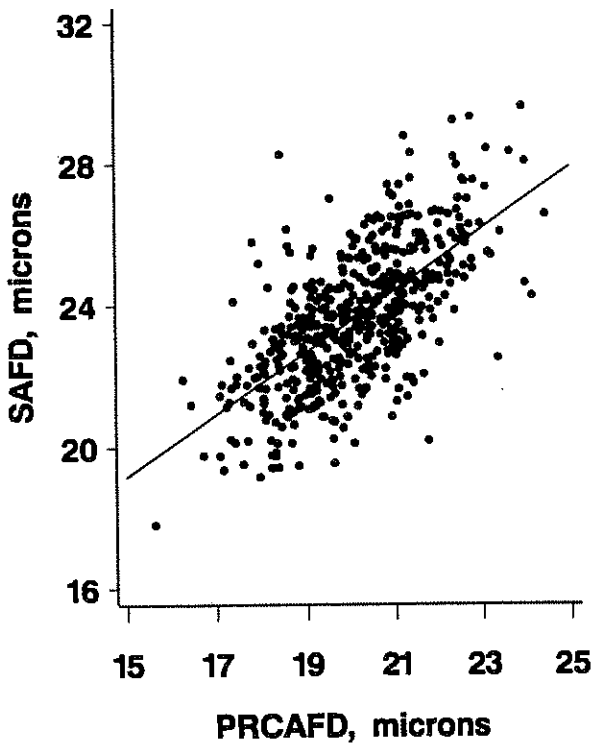

Figure 2. Side sample fiber diameter (SAFD) versus post-test core average fiber diameter (POCAFD).

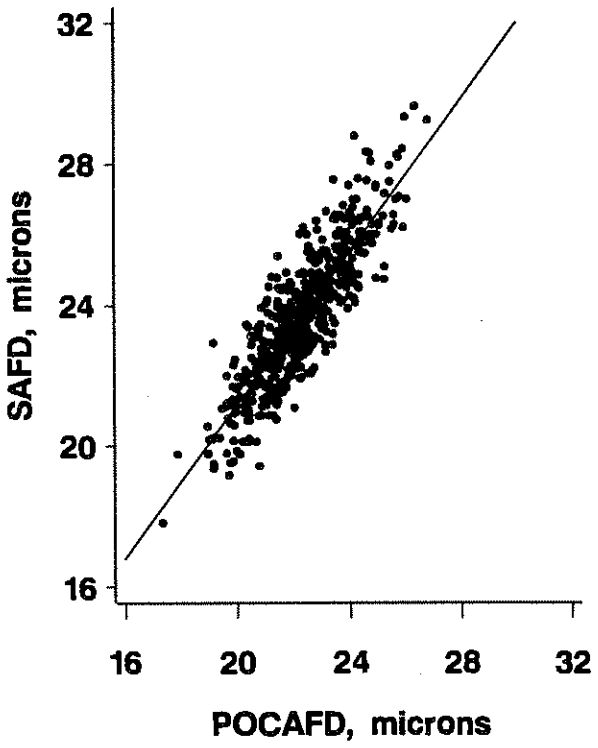

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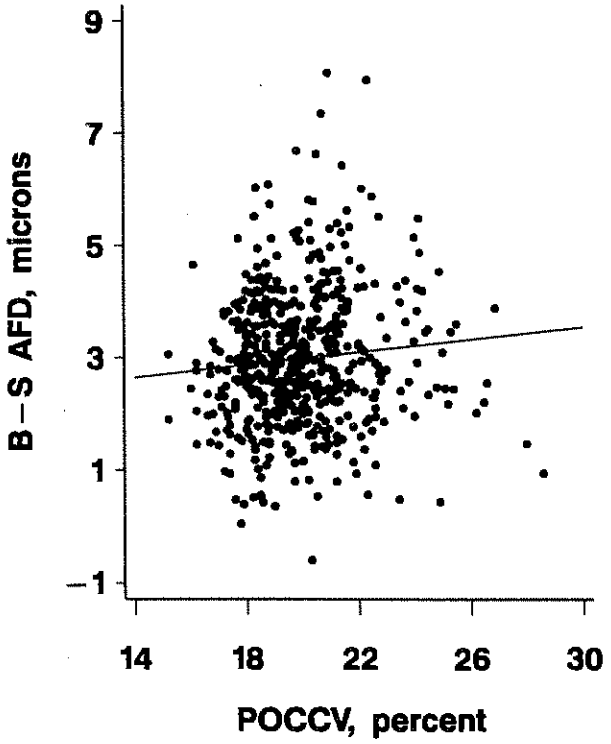
Figure 3. Britch minus side average fiber (B – S AFD) versus coefficient of variation of fiber diameter for whole fleece (POCCV).



The Influence of Lamb Chronological Age, Slaughter Weight and Gender on Carcass Measurements[1]

L.E. Jeremiah, S.D.M. Jones, A.K.W. Tong and L.L. Gibson

Summary

A total of 1,660 lambs representative of the Canadian market lamb population were slaughtered and evaluated using various carcass measurements. Differences attributable to gender in loin-eye area were not detected ($P > 0.05$). Loin-eye area decreased ($P < 0.05$) with slaughter weight in carcasses from ram lambs over 12 months of age at slaughter but increased ($P < 0.05$) with increasing slaughter weight in carcasses from young ram lambs (three to six months of age at slaughter) and carcasses from ewe and wether lambs, irrespective of age. Loin-eye area also increased ($P < 0.05$) with advancing age in carcasses from heavyweight wether carcasses (68.2 to 76.8 kg live) but decreased ($P < 0.05$) with advancing age in carcasses from ram lambs weighing 58.9 to 67.7 kg live. Ewe lamb carcasses had the greatest and ram lamb carcasses had the least body wall thickness ($P < 0.05$). Body wall thickness generally increased ($P < 0.05$) with increasing slaughter weight but was not generally related to chronological age ($P > 0.05$). Ewe lamb carcasses also had the most and ram lamb carcasses had the least subcutaneous fat thickness ($P < 0.05$). Subcutaneous fat thickness increased ($P < 0.05$) with increasing slaughter weight in young lambs (less than nine months of age), but generally was not related to chronological age ($P > 0.05$). Ewe lamb carcasses also received the highest and ram lamb carcasses received the lowest ($P < 0.05$) conformation scores. Conformation scores generally increased ($P < 0.05$) with increasing slaughter weight but generally was not related to chronological age ($P > 0.05$). The composite results confirm previous findings that ewe lamb carcasses are the fattest and ram lamb carcasses are the leanest and demonstrate subcutaneous fat thickness increases with increasing slaughter weight in young lambs. They also indicate that chronological age has little influence on most carcass measurements, and that increasing slaughter weight increases loin-eye area in young ram lambs while decreasing loin-eye area in older ram lambs.

Key words: lamb, carcass measurements, chronological age, slaughter weight, gender.

Introduction

Results of cutting trials have established significantly greater monetary returns could be obtained by all segments of the industry by production and utilization of leaner, higher-yielding lambs (Carpenter, 1966). In addition, a recent consumer survey demonstrated the population of lambs currently being produced and marketed in Canada are too fat for the vast majority of Canadian consumers (Jeremiah et al., 1992).

The ultimate desirability of a lamb carcass is determined by the yield of edible portion and the quality of the muscles which comprise this portion. In this regard, numerous reports have suggested various quantitative and compositional measures of ultimate carcass desirability, including: trimmed primal retail cuts (Spurlock and Bradford, 1965; Spurlock et al., 1966; Zinn, 1961; Cunningham et al., 1967; Carpenter et al., 1964; Hoke, 1961), total retail cuts (Oliver et al., 1967; Ringkob et al., 1964), carcass value (Carpenter et al., 1964), edible portion (Judge and Martin, 1963; Johnston et al., 1967), separable physical components (Moody et al., 1965; Judge et al., 1966; Field et al., 1963; Hankins, 1947; Palsson, 1939; Barton and Kirton, 1958; Ringkob et al., 1964; Timon and Bichard, 1965; Walker and McMeeken, 1944), chemical composition (Hankins, 1947; Khandekar et al., 1965; Pradham et al., 1966; Munson et al., 1966; Adams et al., 1970) and weight of edible meat per

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day of age (Carpenter, 1966). Since these measures of ultimate carcass desirability require the carcass to be broken down into individual cuts, or physical or chemical components, various studies have utilized certain carcass measurements to estimate these measures (Carpenter et al., 1964, 1969; Oliver et al., 1967, 1968; Hoke, 1961; Field et al., 1963; Spurlock and Bradford, 1965; Ringkob et al., 1964; Cunningham et al., 1967; Judge et al., 1966; Spurlock et al., 1966; Wise, 1978).

Although numerous studies have examined the effects of various inherent factors, including chronological age, slaughter weight and gender on carcass measurements, there have been no comprehensive studies conducted which have evaluated the combined effects of these inherent traits on the carcass measurements of a sample representative of the Canadian market lamb population.

The present study was designed to provide an evaluation of the influence of chronological age, slaughter weight and gender on various carcass measurements. The relationship of carcass measurements to lean content and saleable meat yield has previously been reported (Jones et al., 1992, 1996).

Materials and Methods

A total of 1,660 lambs were selected on the basis of age, slaughter weight, gender and fatness to fill specific subclasses in an experimental design grid (Jeremiah et al., 1997). The lambs evaluated were a representative sample of the entire range of lambs currently being marketed in Canada, rather than a set of animals of controlled breeding and dietary management, slaughtered at different weights and/or ages. The lambs in the present study were purchased from commercial sheep producers with breeding records and certified birthdates for the lambs purchased, so that both the breeding and chronological ages could be ascertained. The lambs were predominantly crossbreds, involving some combination fot he following breeds: Cheviot, Columbia, Dorset, Finnish Landrace, Hampshire, Leicester, Montadale, Ranbouillet, Romanoff, Romney, Shropshire, Southdown, Suffolk, Targhee and Texel. Breeds and breed crosses were allocated as evenly as possible among age/weight/gender subclasses and care was taken to prevent a given breed or breed-cross from constituting a majority in any given age/weight/gender subclass.

Fatness and gender were ascertained the day prior to slaughter. Fatness was ascertained both subjectively by a trained and experienced evaluator and ultrasonically, and the same fatness criteria were applied to all age/slaughter weight/gender subclasses. Breed composition necessarily varied among age/slaughter weight subclasses but was relatively constant within subclasses. Since the lambs were purchased from different producers, it is possible they were fed differently and it is possible this may have influenced compositional properties. The actual frequency distribution of lambs evaluated has been presented (Jeremiah et. al, 1997) by age, weight, gender and fatness subclass.

All lambs were slaughtered at the Lacombe Meat Research Centre (Lacmbe, AB) under simulated commercial conditions.

Immediately after slaughter, the left side of each carcass was probed at the following anatomical sites using a Hennessy lamb grading probe: between the 10th and 11th thoracic vertebra, 4 and 11 cm off the midline; between the 12th and 13th thoracic vertebra, 4 and 11 cm off the midline; and 4 cm off the midline at the 2nd and 5th lumbar vertebra. Measurements of fat, lean and total tissue depth were taken at each of these locations and these measurements were repeated 24 hours later on the left side of the cold carcass. All warm carcasses were subjectively scored for muscling (1 = very thin; 5 = very thick). At 24 hours postmortem, all carcasses were subjectively and objectively evaluated for fat thickness and muscling. Subcutaneous fat thickness at the 12th thoracic vertebra (4 cm from the midline) was subjectively estimated and measured using a ruler. Carcass conformation was estimated by an experienced evaluator using a five-point descriptive scale (1 = very thin; 5 = very thick).

The left side of each carcass was then separated between the 12th and 13th thoracic vertebra and subcutaneous fat thickness, body wall thickness, and the width, depth and area of the Longissimus dorsi muscle was measured.

Data were analyzed using the general linear model (GLM) procedures of SAS (1985). Sources of variation were: age, slaughter weight, gender and the two-way and three-way interactions of these variables. Mean separation of significant main effects was by single degree of freedom linear contrast. Within subclass linear regression was used to detect significant trends with advancing age and increasing slaughter weight (Puri and Mullen, 1980).

Results and Discussion

Loin-eye area is an important trait to consumers, particularly for lamb since it relates directly to lean-to-bone ratio in the most valuable cuts (Jeremiah, 1982) and has been traditionally utilized as an estimate of muscling in the carcass and particularly in the most valuable cuts (Carpenter et al., 1969; Cunningham et al., 1967). In the present study, loin-eye area did not differ among genders ($P > 0.05$), within any age/slaughter weight subclass (Table 1).

Loin-eye area increased ($P < 0.05$) with increasing slaughter weight in carcasses from young ram lambs (age group 1, 3 to 6 months of age, $r^2 = 0.70$, $P < 0.05$) and ewe and wether lamb carcasses, irrespective of chronological age (ewes: age group 1, 3 to 6 months of age, $r^2 = 0.98$, $P < 0.001$; age group 2, 6 to 9 months of age, $r^2 = 0.67$, $P < 0.05$; age group 3, 9 to 12 months of age, $r^2 = 0.92$, $P < 0.01$; age group 4, 12 to 15 months of age, $r^2 = 0.83$, $P < 0.05$; wethers: age group 1, 3 to 6 months of age, $r^2 = 0.77$, $P < 0.05$; age group 2, 6 to 9 months of age, $r^2 = 0.85$, $P < 0.05$; age group 3, 9 to 12 months of age, $r^2 = 0.94$, $P < 0.01$; age group 4, 12 to 15 months of age, $r^2 = 0.85$, $P < 0.05$), but decreased ($P < 0.05$) with increasing slaughter weight in carcasses from older ram lambs (age

group 4, 12 to 15 months of age, r^2 = 0.96, $P < 0.01$; data not shown in tabular form). This finding is probably attributable to the longissimus muscle in ram lambs maturing at one year of age (Butterfield et al., 1984). Loin-eye area also increased ($P < 0.05$) with advancing age in carcasses from heavy-weight wether lambs (weight group 5, 68.2 to 76.8 kg live, r^2 = 0.96, $P < 0.01$), but decreased ($P < 0.05$) with advancing age in carcasses from ram lambs weighing 58.9 to 67.7 kg live (age group 4, r^2 = 0.87, $P < 0.05$; data not shown in tabular form).

Present results are in general agreement with the reports of Ray and Mandigo (1963, 1966) but are contrary to reports that ram lambs had the largest and ewe lambs had the smallest loin-eyes (Carpenter et al., 1969; Spurlack and Bradford, 1965; Field et al., 1967; Judge et al., 1966) and that wether lambs had larger loin-eyes than ewe lambs (Wise, 1978). Present results also generally support the previous conclusion that increasing slaughter weight was associated with larger rib-eye areas (Wise, 1978). It is possible that the inconsistencies in the relationships of loin-eye area with advancing age and slaughter weight arose as a result of differences in breeding or feeding regime.

Loin-eye area by definition should be a function of loin-eye width and length and therefore should be closely correlated to these linear measurements. As expected, in the present study these measurements were highly related to loin-eye area (loin-eye width: r^2 = 0.45; loin-eye length: r^2 = 0.62). Loin-eye width was observed to increase progressively (in data not presented in tabular form) with increasing slaughter weight in carcasses from older wether lambs (more than 9 months; r^2 = 0.94, age group 3; r^2 = 0.98, age group 4, $P < 0.01$) but to decrease progressively with increasing slaughter weight in carcasses from older ram lambs (more than 12 months, r^2 = 0.91, age group 4, $P < 0.05$). In addition, loin-eye width was observed to decrease progressively with advancing age in carcasses from wether lambs 50.0 to 58.6 kg at slaughter (weight group 3, r^2 = 0.88, $P < 0.05$) and ram lambs 58.9 to 67.7 kg at slaughter (weight group 4, r^2 = 0.90; $P < 0.05$). Ram

Table 1. Least square means and standard errors for loin-eye area, body wall thickness, actual fat thickness and conformation scores of carcasses from lambs in various age/weight/gender subclasses.

		Slaughter Weight (kg)									
		31.8-40.4		40.5-49.5		50.0-58.6		58.9-67.7		68.2-76.8	
Age Group	Gender	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
						Loin-Eye Area[d] (sq. cm)					
1 (3-6 months)	Ram	12.1	0.57	14.9	0.51	16.2	0.47	18.3	0.46	16.2	1.92
	Ewe	12.3	0.54	14.6	0.53	16.3	0.45	15.4	0.55	—	—
	Wether	12.5	0.52	13.4	0.53	15.9	0.55	15.7	0.55	—	—
2 (6-9 months)	Ram	14.0	1.92	15.0	0.43	15.3	0.40	15.4	0.42	16.7	0.45
	Ewe	12.8	2.71	14.0	0.40	16.2	0.42	16.5	0.42	15.2	0.45
	Wether	—	—	14.0	0.39	15.6	0.39	16.8	0.42	16.1	0.45
3 (9-12 months)	Ram	16.2	1.92	13.9	0.45	14.0	0.41	14.9	0.41	17.2	0.45
	Ewe	—	—	15.0	0.44	15.2	0.41	15.9	0.45	16.5	0.46
	Wether	10.8	2.71	14.8	0.44	15.1	0.41	15.0	0.43	16.9	0.44
4 (12-15 months)	Ram	—	—	16.9	2.71	15.1	0.49	14.5	0.45	14.7	0.45
	Ewe	14.4	2.71	15.3	1.57	15.4	0.46	15.3	0.45	16.3	0.43
	Wether	—	—	14.1	1.92	15.4	0.45	16.3	0.44	17.6	0.40
						Body Wall Thickness[e] (mm)					
1 (3-6 months)	Ram	12.0	1.46	14.0[b]	1.35	18.8[b]	1.24	22.2	1.21	27.5	5.04
	Ewe	11.6	1.43	19.8[a]	1.40	25.2[a]	1.19	23.1	1.46	—	—
	Wether	12.4	1.37	16.6[b]	1.40	24.9[a]	1.46	21.2	1.46	—	—
2 (6-9 months)	Ram	10.5	5.04	18.9	1.14	19.3	1.08	20.0[b]	1.11	22.9	1.19
	Ewe	19.0	7.13	18.9	1.06	20.8	1.11	23.2[a]	1.11	24.3	1.19
	Wether	—	—	17.8	1.03	20.0	1.01	22.9[a]	1.10	22.8	1.19
3 (9-12 months)	Ram	21.0	5.04	17.6[b]	1.17	15.1[c]	1.09	18.8[b]	1.09	24.3	1.19
	Ewe	—	—	21.9[a]	1.16	25.7[a]	1.08	25.9[a]	1.19	24.2	1.21
	Wether	17.0	7.13	18.8[b]	1.16	19.7[b]	1.08	21.0[b]	1.14	23.9	1.16
4 (12-15 months)	Ram	—	—	23.0	7.13	19.3[b]	1.28	15.9[b]	1.19	19.3[b]	1.19
	Ewe	32.0	7.13	23.0	4.12	22.0[a]	1.21	25.1[a]	1.19	26.2[a]	1.14
	Wether	—	—	25.0	5.04	24.1[a]	1.19	24.2[a]	1.16	26.5[a]	1.05

(Table continued on next page.)

lamb carcasses generally had the longest and ewe lamb carcasses generally had the shortest loin-eyes. Loin-eye length tended to increase progressively with increasing slaughter weight (in data not presented in tabular form), particularly in young lambs (less than 9 months; rams: age group 1, $r^2 = 0.90$, $P < 0.05$; age group 2, $r^2 = 0.93$, $P < 0.01$; ewes: age group 1, 3 to 6 months of age, $r^2 = 0.95$, $P < 0.01$; age group 2, 6 to 9 months of age, $r^2 = 0.89$, $P < 0.05$; wethers: age group 1, 3 to 6 months of age, $r^2 = 0.88$, $P < 0.05$; age group 2, 6 to 9 months of age, $r^2 = 0.93$, $P < 0.01$; age group 3, 9 to 12 months of age, $r^2 = 0.92$, $P < 0.01$). In addition, loin-eyes were observed to become progressively longer in carcasses from wether lambs with advancing age (weight group 2, 40.5 to 49.5 kg live, $r^2 = 0.87$, $P < 0.05$; weight group 4, 58.9 to 67.7 kg live, $r^2 = 0.97$, $P < 0.01$; weight group 5, 68.2 to 76.8 kg live, $r^2 = 0.99$, $P < 0.001$).

Since lamb carcasses traditionally have not been broken in commerce, various carcass measurements have been utilized to estimate loin-eye area. In the present study, measures of lean depth between the twelfth and thirteenth vertebra, 4 cm off the midline on both warm and cold carcasses, were highly related to loin-eye area (warm, $r^2 = 0.26$; cold, $r^2 = 0.32$; $P < 0.01$). Wether carcasses generally had the greatest and ram carcasses generally had the least lean depth between the 12th and 13th thoracic vertebra, 4 cm of the midline, when measured on the warm carcass with the Hennessey grading probe. Ram lamb carcasses generally had the least lean depth when measured identically on the cold carcass. Such findings appear contrary to several reports indicating carcasses from ram lambs had the largest loin-eyes (Field, 1971). However, in the present study carcasses from ram

Table 1. (Continued.)

		Slaughter Weight (kg)									
		31.8-40.4		40.5-49.5		50.0-58.6		58.9-67.7		68.2-76.8	
Age Group	Gender	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
		Actural Fat Thickness[f] (AFT), mm									
1 (3-6 months)	Ram	2.2	0.55	2.2[b]	0.51	3.5[b]	0.47	4.7	0.45	13.3	1.90
	Ewe	2.7	0.54	4.0[a]	0.53	5.4[a]	0.45	5.1	0.55	—	—
	Wether	2.0	0.52	3.5[a]	0.53	5.5[a]	0.55	4.8	0.55	—	—
2 (6-9 months)	Ram	1.0b	1.90	4.2	0.43	4.1	0.40	4.4[b]	0.42	5.3	0.45
	Ewe	8.0a	2.69	4.6	0.40	4.5	0.42	4.8[ab]	0.42	5.6	0.45
	Wether	—	—	3.8	0.39	4.1	0.38	5.3[a]	0.41	5.5	0.45
3 (9-12 months)	Ram	4.0	1.90	4.6	0.45	2.4[c]	0.41	3.7[c]	0.41	4.6	0.45
	Ewe	—	—	5.0	0.44	5.8[a]	0.41	6.4[a]	0.44	5.1	0.45
	Wether	6.0	2.69	4.2	0.44	4.7[b]	0.41	4.6[b]	0.43	5.1	0.44
4 (12-15 months)	Ram	—	—	4.5	2.69	4.1[b]	0.48	3.0[b]	0.45	4.3[b]	0.45
	Ewe	9.0	2.69	7.5	1.55	5.2[a]	0.45	6.1[a]	0.45	6.6[a]	0.43
	Wether	—	—	7.8	1.90	6.0[a]	0.45	6.0[a]	0.44	6.2[a]	0.40
		Conformation Score[g]									
1 (3-6 months)	Ram	2.12[b]	0.14	2.82[b]	0.13	3.55[b]	0.12	4.26[a]	0.12	5.00	0.50
	Ewe	2.64[a]	0.14	3.23[a]	0.14	4.13[a]	0.12	3.88[b]	0.14	—	—
	Wether	2.59[a]	0.14	2.96[b]	0.14	3.96[a]	0.14	4.25[a]	0.14	—	—
2 (6-9 months)	Ram	2.00	0.50	2.72[b]	0.11	3.42[b]	0.11	3.63[b]	0.11	4.42[ab]	0.12
	Ewe	3.00	0.71	3.11[a]	0.11	3.88[a]	0.11	4.14[a]	0.11	4.53[a]	0.12
	Wether	—	—	3.06[a]	0.10	3.54[b]	0.10	3.93[a]	0.11	4.19[b]	0.12
3 (9-12 months)	Ram	1.00[b]	0.71	1.70[c]	0.12	2.27[c]	0.11	2.98[c]	0.11	4.11[b]	0.12
	Ewe	—	—	3.13[a]	0.12	3.77[a]	0.11	3.95[a]	0.11	4.53[a]	0.12
	Wether	3.00[a]	0.71	2.63[b]	0.11	2.95[b]	0.11	3.55[b]	0.11	4.24[ab]	0.11
4 (12-15 months)	Ram	—	—	3.00	0.71	2.62[b]	0.12	2.94[b]	0.12	3.61[b]	0.12
	Ewe	3.00	0.71	3.67	0.41	3.57[a]	0.12	4.22[a]	0.12	4.62[a]	0.11
	Wether	—	—	3.00	0.50	3.75[a]	0.12	4.00[a]	0.11	4.65[a]	0.10

[a,b,c] Means in the same column and trait and age group without a superscript or bearing a common superscript do not differ significantly ($P > 0.05$).

[d] Measured on the cut loin surface between the twelfth and thirteenth thoracic vertebra.

[e] Measured on the cut loin surface between the twelfth and thirteenth thoracic vertebra, 11 cm off the midline.

[f] Measured on the cut loin surface between the twelfth and thirteenth thoracic vertebra, 4 cm off the midline and perpendicular to the longitudinal axis of the longissimus muscle.

[g] Scaled by a trained and experienced evaluator, using a five-point descriptive scale (1 = very thin; 5 = very thick).

lambs generally had longer loin-eyes, possibly explaining why differences in loin-eye area attributable to gender were not observed in the present study.

Warm lean depth generally increased with slaughter weight (rams: age group 1, 3 to 6 months of age, r^2 = 0.97, $P < 0.001$; age group 2, 6 to 9 months of age, $r^2 = 0.98$, $P < 0.001$; ewes: age group 1, 3 to 6 months of age $r^2 = 0.92$, $P < 0.01$; wethers: age group 3, 9 to 12 months of age, r^2 = 0.93, $P < 0.01$; data not presented in tabular form), but cold lean depth generally was not related to slaughter weight ($P > 0.05$). Warm lean depth generally increased in heavyweight ewe and wether lamb carcasses (in data not presented in tabular form) with advancing age (ewes: weight group 4, 58.9 to 67.7 kg live, r^2 = 0.95, $P < 0.01$; weight group 5, 68.2 to 76.8 kg live, $r^2 = 0.99$, $P < 0.001$; wethers: weight group 5, 68.2 to 76.8 kg live, $r^2 = 0.95$, $P < 0.01$) but increased progressively with advancing age in carcasses from ram lambs 58.9 to 67.7 kg at slaughter (weight group 4, $r^2 = 0.99$, $P < 0.001$), possibly as a result of differences in breeding or dietary regime.

Body wall thickness between the 12th and 13th thoracic vertebra, 11 cm off the midline, has been proposed as an estimator of carcass composition (Kirton et al., 1984) and used commercially in New Zealand to identify overfat carcasses since 1973.

Ewe lamb carcasses had greater body wall thickness measured with a ruler on the cut surface of the loin between the 12th and 13th thoracic vertebra, 11 cm off the midline, than ram lamb carcasses ($P < 0.05$) when they were in age group 1 (3 to 6 months of age) and weight groups 2 and 3 (40.5 to 58.6 kg live), age group 2 (6 to 9 months of age) and weight group 4 (58.9 to 67.7 kg live), age group 3 (9 to 12 months of age) and weight groups 2, 3 and 4 (40.5 to 67.7 kg live) and age group 4 (12 to 15 months of age) and weight groups 3, 4 and 5 (50.0 to 76.8 kg live; Table 1). Ewe lamb carcasses also had greater body wall thickness than wether lamb carcasses ($P < 0.05$) when they were in age group 1 (3 to 6 months of age) and weight group 2 (40.5 to 49.5 kg live) and age group 3 (9 to 12 months of age) and weight groups 2, 3 and 4 (40.5 to 67.7 kg live). Wether lamb carcasses also had greater body wall thickness than ram lamb carcasses ($P < 0.05$) when they were in age group 1 (3 to 6 months of age) and weight group 3 (50.0 to 58.6 kg live), age group 2 (6 to 9 months of age) and weight group 4 (58.9 to 67.7 kg live), age group 3 (9 to 12 months of age) and weight group 3 (50.0 to 58.6 kg live) and age group 4 (12 to 15 months of age) and weight groups 3, 4 and 5 (50.0 to 76.8 kg live). Consequently ewe lamb carcasses had the greatest and ram lamb carcasses had the least body wall thickness. Body wall thickness generally increased with slaughter weight (rams: age group 1, 3 to 6 months of age, $r^2 = 0.79$, $P < 0.05$; age group 2, 6 to 9 months of age, $r^2 = 0.97$, $P < 0.01$; ewes: age group 2, 6 to 9 months of age, $r^2 = 0.67$, $P < 0.05$; wethers: age group 2, 6 to 9 months of age, $r^2 = 0.87$, $P < 0.05$; age group 3, 9 to 12 months of age, $r^2 = 0.82$, $P < 0.05$; data not presented in tabular form). Body wall thickness was positively related to chronological age (in data not presented in tabular form) only in ram lamb carcasses in weight group 2 (40.5 to 49.5 kg live, r^2 = 0.82, $P < 0.05$) and negatively related to chronological age only in ram lamb carcasses in weight group 4 (58.9 to 67.7 kg live, $r^2 = 0.96$, $P < 0.01$). Such inconsistency in trends indicate that body wall thickness was not related to chronological age.

Body wall thickness or total tissue depth can also be estimated with the Hennessey grading probe by probing the warm or cold carcass between the 12th and 13th ribs, 11 cm off the midline (GRI measurement). GRI measurements were highly related to body wall thickness when taken both on the warm and cold carcasses (r^2 = 0.59 and 0.69, respectively). Ram lamb carcasses had the least total tissue depth (GRI measurement) when measured on both the warm and cold carcasses. Warm total tissue depth increased progressively with slaughter weight in young wether lambs (less than 9 months; age group 1, 3 to 6 months of age, $r^2 = 0.78$, $P < 0.05$; age group 2, 6 to 9 months of age, $r^2 = 0.86$, $P < 0.05$; data not presented in tabular form). Warm total tissue depth increased progressively with advancing age in wether lamb carcasses in weight group 2 (40.5 to 49.5 kg live, r^2 = 0.92, $P < 0.05$) but decreased progressively with advancing age in ram lamb carcasses in weight group 4 (58.9 to 67.7 kg live, $r^2 = 0.93$, $P < 0.01$). Such inconsistency in trends indicates warm GRI measurements were not related to chronological age. Cold GRI measurements of total tissue depth increased progressively with slaughter weight only in wether lamb carcasses in age group 2 (6 to 9 months of age, $r^2 = 0.85$, $P < 0.05$; data not presented in tabular form), indicating cold total tissue depth was not related to slaughter weight. Cold GRI total tissue depth measurements increased progressively with advancing age (in data not presented in tabular form) in wether lamb carcasses in weight group 2 (40.5 to 49.5 kg live, $r^2 = 0.99$, $P < 0.001$) but decreased progressively with advancing age in ram lamb carcasses in weight group 4 (58.9 to 67.7 kg live, $r^2 = 0.99$, $P < 0.001$). Such inconsistency in trends indicates cold GRI total tissue depth measurements were not related to chronological age.

Subcutaneous fat thickness has been a carcass measurement traditionally used to estimate carcass composition and yield of salable product (Carpenter et al., 1969; Cunningham et al., 1967). Subcutaneous fat thickness, measured on the cut surface of the loin 4 cm off the midline, perpendicular to the longitudinal axis of the longissimus muscle, between the 12th and 13th thoracic vertebra (actual fat thickness; AFT) was greater on ewe lamb carcasses ($P < 0.05$) than on ram lamb carcasses when they were in age group 1 (3 to 6 months of age) and weight groups 2 and 3 (40.5 to 58.4 kg live), age group 2 (6 to 9 months of age) and weight group 1 (31.8 to 40.4 kg live), age group 3 (9 to 12 months of age) and weight groups 3 and 4 (50.0 to 67.7 kg live) and age group 4 (12 to 15 months of age) and weight groups 3, 4 and 5 (50.0 to 76.8 kg live; Table 1). Ewe lamb carcasses also had greater AFT than wether lamb

carcasses ($P < 0.05$) when they were in age group 3 (9 to 12 months of age) and weight groups 3 and 4 (50.0 to 67.7 kg live). Wether lamb carcasses had greater AFT than ram lamb carcasses ($P < 0.05$) when they were in age group 1 (3 to 6 months of age) and weight groups 2 and 3 (40.5 to 58.6 kg live), age group 2 (6 to 9 months of age) and weight group 4 (58.9 to 67.7 kg live), age group 3 (9 to 12 months of age) and weight groups 3 and 4 (50.0 to 67.7 kg live) and age group 4 (12 to 15 months of age) and weight groups 3, 4 and 5 (50.0 to 76.8 kg live). Consequently, ewe lamb carcasses had the most and ram lamb carcasses had the least AFT. AFT increased progressively with slaughter weight (rams: age group 2, 6 to 9 months of age, $r^2 = 0.95$, $P < 0.01$; ewes: age group 1, 3 to 6 months of age, $r^2 = 0.82$, $P < 0.05$), indicating AFT increased progressively with increasing slaughter weight in young lambs (less than 9 months). AFT increased progressively ($P < 0.05$) with advancing age (in data not presented in tabular form) in ewe lamb carcasses in weight group 2 (40.5 to 49.5 kg live, $r^2 = 0.81$, $P < 0.05$) but decreased progressively with advancing age in ram lamb carcasses in weight group 4 (58.9 to 67.7 kg live, $r^2 = 0.93$, $P < 0.01$). Such inconsistency in trends indicates AFT was not generally related to chronological age.

Present results are in general agreement with and support previous reports that ram lamb carcasses had less subcutaneous fat than ewe and wether lamb carcasses (Carpenter et al., 1969) and that ewe lamb carcasses were generally fatter than ram and wether carcasses and had greater subcutaneous fat thickness (Carpenter et al., 1969; Kemp et al., 1962; Walker, 1950; Wise, 1978). Present findings also support the observation that increasing slaughter weight was associated with greater fatness (Wise, 1978).

Since lamb carcasses traditionally have not been broken in commerce, it is not possible to measure actual subcutaneous fat thickness. Consequently, it is often estimated subjectively, measured with a ruler on the cold carcass, or estimated with an electronic probe on either the warm or cold carcass. Some British studies (Chadwick et al., 1986; Kempster et al., 1986) have indicated visual assessment of lamb carcass fatness predicted the proportion of carcass lean with equal or better precision than probe or ruler measurements of total tissue depth. In the present study, subcutaneous fat thickness between the 12th and 13th thoracic vertebra, 4 cm off the midline, estimated by a trained and experienced evaluator, were highly related ($r^2 = 0.09$, $P < 0.001$) with AFT. Ewe lamb carcasses were estimated to have the most and ram lamb carcasses were estimated to have the least subcutaneous fat ($P < 0.05$) between the 12th and 13th thoracic vertebra, 4 cm off the midline (EFT; data not shown in tabular form). EFT increased progressively with increasing slaughter weight (rams: age group 1, 3 to 6 months of age, $r^2 = 0.89$, $P < 0.01$; age group 2, 6 to 9 months of age, $r^2 = 0.69$, $P < 0.05$; age group 3, 9 to 12 months of age, $r^2 = 0.80$, $P < 0.05$; ewes: age group 1, 3 to 6 months of age, $r^2 = 0.86$, $P < 0.05$; age group 3, 9 to 12 months of age, $r^2 = 0.95$, $P < 0.01$; wethers: age group 2, 6 to 9 months of age, $r^2 = 0.90$, $P < 0.05$; age group 3, 9 to 12 months of age, $r^2 = 0.98$, $P < 0.01$; age group 4, 12 to 15 months of age, $r^2 = 0.94$, $P < 0.01$). EFT increased progressively with chronological age in wether lamb carcasses in weight group 4 (58.9 to 67.7 kg live, $r^2 = 0.88$, $P < 0.05$) but decreased progressively with advancing age in ram lamb carcasses in weight group 2 (40.5 to 49.5 kg live, $r^2 = 0.79$, $P < 0.05$). Such inconsistency in trends indicates EFT was not related to chronological age.

Subcutaneous fat thickness measured with a ruler on the cold carcass between the 12th and 13th ribs, 4 cm off the midline (measured fat thickness, MFT), was highly related to AFT ($r^2 = 0.08$, $P < 0.001$) but accounted for only a small amount of the variation in AFT. Ewe lamb carcasses also had the most and ram lamb carcasses had the least MFT ($P < 0.05$). MFT increased progressively with increasing slaughter weight (rams: age group 1, 3 to 6 months of age, $r^2 = 0.71$, $P < 0.05$; age group 2, 6 to 9 months of age, $r^2 = 0.90$, $P < 0.01$; age group 3, 9 to 12 months of age, $r^2 = 0.82$, $P < 0.05$; age group 4, 12 to 15 months of age, $r^2 = 0.83$, $P < 0.05$; ewes: age group 1, 3 to 6 months of age, $r^2 = 0.95$, $P < 0.01$; age group 2, 6 to 9 months of age, $r^2 = 0.81$, $P < 0.05$; age group 3, 9 to 12 months of age, $r^2 = 0.95$, $P < 0.01$; wethers: age group 1, 3 to 6 months of age, $r^2 = 0.80$, $P < 0.05$; age group 2, 6 to 9 months of age, $r^2 = 0.90$, $P < 0.05$; age group 3, 9 to 12 months of age, $r^2 = 0.95$, $P < 0.01$; age group 4, 12 to 15 months of age, $r^2 = 0.98$, $P < 0.001$). MFT increased with chronological age only in heavyweight (68.2 to 76.8 kg live) wether lamb carcasses ($r^2 = 0.99$, $P < 0.001$).

Jones et al. (1992) reported probe measurements of subcutaneous fat thickness between the 12th and 13th thoracic vertebra, 4 cm off the midline, provided a more accurate estimation of lamb carcass lean content than visual assessment. In the present study these probe measurements taken on the warm (W12/13FT) and cold (C12/13FT) carcasses were highly related to AFT ($r^2 = 0.56$ and 0.67, respectively). Ewe lamb carcasses had the most and ram lamb carcasses had the least W12/13FT and C12/13FT ($P < 0.05$; data not shown in tabular form). W12/13FT increased progressively with increasing slaughter weight in young lambs (less than 9 months; rams: age group 1, 3 to 6 months of age, $r^2 = 0.79$, $P < 0.05$; ewes: age group 1, 3 to 6 months of age, $r^2 = 0.86$, $P < 0.05$; age group 2, 6 to 9 months of age, $r^2 = 0.77$, $P < 0.01$; wethers: age group 2, 6 to 9 months of age, $r^2 = 0.80$, $P < 0.05$) and C12/13FT increased progressively with increasing slaughter weight, particularly in wether lamb carcasses (ewes: age group 1, 3 to 6 months of age, $r^2 = 0.84$, $P < 0.05$; wethers: age group 1, 3 to 6 months of age, $r^2 = 0.79$, $P < 0.05$; age group 3, 9 to 12 months of age, $r^2 = 0.83$, $P < 0.05$). W12/13FT also decreased progressively with advancing age in heavyweight rams (more than 58.9 kg live; weight group 4, 58.9 to 67.7 kg live, $r^2 = 0.90$, $P < 0.05$; weight group 5,

68.2 to 76.8 kg live, $r^2 = 0.95$, $P < 0.01$). C12/13FT increased progressively with advancing age in ram lamb carcasses in weight group 2 (40.5 to 49.5 kg live, $r^2 = 0.79$, $P < 0.05$), but decreased progressively with advancing age in ram lamb carcasses in weight groups 4 and 5 (58.9 to 76.8 kg live) ($r^2 = 0.94$, $P < 0.01$ and 0.85, $P < 0.05$, respectively). Such inconsistency in trends indicates electronic probe measurements of subcutaneous fat thickness were not related to chronological age, irrespective of whether the measurements were made on warm or cold carcasses.

The meat industry has traditionally paid more for carcasses with superior conformation, and breeders and meat traders still attach importance to conformation as an indicator of commercial value, based upon the belief conformation reflects lean to bone ratio and muscle thickness (Kempster et al., 1982). In the present study, ewe lamb carcasses generally received the highest and ram lamb carcasses generally received the lowest conformation scores. Ewe lamb carcasses were given higher conformation scores than ram lamb carcasses ($P < 0.05$) when they were in age group 1 (3 to 6 months of age) and weight groups 1, 2 and 3 (31.8 to 58.6 kg live); age group 2 (6 to 9 months of age) and weight groups 2, 3 and 4 (40.5 to 67.7 kg live); age group 3 (9 to 12 months of age) and weight groups 2, 3, 4 and 5 (40.5 to 76.8 kg live); and age group 4 (12 to 15 months of age) and weight groups 3, 4 and 5 (50.0 to 76.8 kg live; Table 1). Ewe lamb carcasses also received higher ($P < 0.05$) conformation scores than wether lamb carcasses when they were in age group 1 (3 to 6 months of age) and weight group 2 (40.5 to 49.5 kg live); age group 2 (6 to 9 months of age) and weight groups 3 and 5 (50.0 to 58.6 and 68.2 to 76.8 kg live, respectively); and age group 3 (9 to 12 months of age) and weight groups 2, 3 and 4 (40.5 to 67.7 kg live). However, ewe lamb carcasses received lower conformation scores than both ram and wether carcasses ($P < 0.05$) when they were in age group 1 (3 to 6 months of age) and weight group 4 (58.9 to 67.7 kg live). Wether lamb carcasses received higher conformation scores ($P < 0.05$) than ram lamb carcasses when they were in age group 1 (3 to 6 months of age) and weight groups 1 and 3 (31.8 to 40.4 and 50.0 to 58.6 kg live, respectively); age group 2 (6 to 9 months of age) and weight groups 2 and 4 (40.5 to 49.5 and 58.9 to 67.7 kg live, respectively); age group 3 (9 to 12 months of age) and weight groups 1, 2, 3 and 4 (31.8 to 67.7 kg live); and age group 4 (12 to 15 months of age) and weight groups 3, 4 and 5 (50.0 to 76.8 kg live). Conformation scores generally improved with increasing slaughter weight (rams: age group 1, 3 to 6 months of age, $r^2 = 0.87$, $P < 0.01$; age group 2, 6 to 9 months of age, $r^2 = 0.91$, $P < 0.01$; age group 3, 9 to 12 months of age, $r^2 = 0.82$, $P < 0.05$; ewes: age group 1, 3 to 6 months of age, $r^2 = 0.82$, $P < 0.05$; age group 2, 6 to 9 months of age, $r^2 = 0.78$, $P < 0.05$; age group 3, 9 to 12 months of age, $r^2 = 0.88$, $P < 0.05$; age group 4, 12 to 15 months of age, $r^2 = 0.86$, $P < 0.05$; wethers: age group 1, 3 to 6 months of age, $r^2 = 0.79$, $P < 0.05$; age group 2, 6 to 9 months of age, $r^2 = 0.91$, $P < 0.01$; age group 4, 12 to 15 months of age, $r^2 = 0.89$, $P < 0.05$). Conformation scores decreased (in data not presented in tabular form) with advancing age only in ewe lamb carcasses in weight group 3 (50.0 to 58.6 kg live, $r^2 = 0.99$, $P < 0.001$) and ram lamb carcasses in weight group 4 (58.9 to 67.7 kg live, $r^2 = 0.94$, $P < 0.01$).

Since conformation score by definition reflects muscle thickness, a high relationship would be expected between these traits. In the present study, conformation and muscling scores were highly related ($r^2 = 0.62$, $P < 0.001$). Therefore ewe lamb carcasses also generally received the highest and ram lamb carcasses generally received the lowest muscling scores. Muscling scores also generally increased with increasing slaughter weight (rams: age group 1, 3 to 6 months of age, $r^2 = 0.92$, $P < 0.05$; age group 2, 6 to 9 months of age, $r^2 = 0.66$, $P < 0.05$; age group 3, 9 to 12 months of age, $r^2 = 0.79$, $P < 0.05$; ewes: age group 1, 3 to 6 months of age, $r^2 = 0.99$, $P < 0.001$; age group 2, 6 to 9 months of age, $r^2 = 0.88$, $P < 0.05$; age group 4, 12 to 15 months of age, $r^2 = 0.92$, $P < 0.01$). Ram lamb carcasses were perceived to become less well muscled with advancing age after they reached 50.0 kg in slaughter weight (weight group 3, 50.0 to 58.6 kg live, $r^2 = 0.84$, $P < 0.05$; weight group 4, 58.9 to 67.7 kg live, $r^2 = 0.81$, $P < 0.05$; weight group 5, 68.2 to 76.8 kg live, $r^2 = 0.98$, $P < 0.001$).

By definition, conformation reflects lean-to-bone ratio and muscle thickness, but when subjective visual conformation scores are based upon a limited range of fatness, conformation scores identify fat rather than lean carcasses (Kempster et al., 1982). Moreover, conformation has little value as a predictor of the lean content of the most valuable cuts or of carcass composition within breed (Kempster et al., 1982). In addition, conformation's relationship to lean content is dependent upon the control of variation in fatness since fatter carcasses tend to receive higher conformation scores. However, fat-corrected conformation has been reported not to be a valuable predictor of carcass composition (Kempster et al., 1982; Garrett et al., 1992; Jones et al., 1992). Despite this, Jones et al. (1996) concluded that conformation provided a small but useful increase in the precision of prediction of salable meat yield.

Present results indicate conformation and muscling scores were closely related ($r^2 = 0.62$, $P < 0.001$) and were both highly related to muscling (loin eye area: $r^2 = 0.10$ and 0.08, $P < 0.001$, respectively) and fatness (AFT: $r^2 = 0.07$ and 0.06, respectively, $P < 0.001$) but did not account for very much of the variation in either. Therefore, present results are in agreement with a previous report that conformation was an inaccurate indicator of muscling in carcasses from ewes and wethers due to greater subcutaneous fat cover (Kempster et al., 1982). Moreover, since both conformation and muscling scores closely paralleled subcutaneous fat cover, present results fail to support the conclusion that ram lamb carcasses were more muscular than ewe lamb carcasses (Carpenter et al., 1969).

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The Influence of Lamb Chronological Age, Slaughter Weight and Gender on Physiological Maturity Indicators[1]

L.E. Jeremiah, A.K.W. Tong and L.L. Gibson

Summary

The influences of chronological age, slaughter weight and gender were examined on the physiological maturity indicators of 1,660 commercial lambs representative of the Canadian market lamb population. The relationships of these physiological maturity indicators to cooking, palatability and consumer acceptance traits were also evaluated. Sacral ossification and rib color scores were most highly related to chronological age but accounted for only 22 and 16% of the variation, respectively. Breakjoint score was the only physiological maturity indicator not related to chronological age. Ewe lamb carcasses generally had the flattest ribs, least amount of color on their ribs and the highest incidence of spooljoints at older ages (more than 9 months) and heavy weights (more than 68.2 kg live). The ribs of heavyweight ram carcasses (more than 50.0 kg live) became whiter with advancing age but the incidence of spooljoints increased with advancing age only in heavyweight ewe lamb carcasses (more than 68.2 kg live). Relationships with cooking, palatability and consumer acceptability traits indicated as lambs matured physiologically, their meat required longer cooking times, sustained greater drip and evaporative cooking losses and became more juicy but less tender. In addition, connective tissue became more perceptible and lamb flavor intensified. However, these changes resulted in only a slight reduction in consumer acceptance, probably of little practical importance.

Key words: lamb, chronological age, slaughter weight, gender, physiological maturity.

Introduction

Lowe (1948) reported that the animal's chronological age at the time of slaughter constituted one of the major determinants of meat tenderness. Barwick (1980) concluded that the consumers' best guide to eating quality was animal age and Ramsey (1984) reported that maturity had a substantial influence on palatability, particularly tenderness. Smith et al. (1969) reported chronological age was a meaningful indicator of lamb tenderness and overall palatability but also indicated that chronological age was more highly related to quality attributes of leg roasts and loin chops than maturity score. However, they indicated that, of the carcass parameters evaluated, maturity score and flank streaking were the traits most highly related to palatability. However, factors other than physiological maturity influence lean color and bone structure, limiting the accuracy of these parameters as maturity indicators, but Ho et al. (1989) indicated these parameters were still the best indicators of physiological maturity. Pinkas et al. (1979) observed that decreases in tenderness with advancing age and Jeremiah et al. (1971) reported age to be related to both tenderness and cooking losses. Many other reports have demonstrated significant inverse relationships between the animal's age or physiological maturity and meat tenderness (Jeremiah, 1978). However, some reports have indicated these relationships to be inconsistent or nonexistent (Jeremiah, 1978). In addition, Hunsley et al. (1967) reported that the relationship between chronological age and tenderness was not linear and Berry et al. (1971, 1972, 1974) reported that tenderness measurements among physiological maturities were often inconsistent. Reagan et al. (1976) reported that increases in chronological age were related to decreases in initial and muscle fiber tenderness in older animals and to shear force values in all maturity groups, despite the fact they failed to observe differences in tenderness among physiological maturity groups. Such inconsistency in findings may be partially explained by the observations of Schmidt et al. (1968) that the

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effects of physiological maturity on meat tenderness were largely dependent upon the internal temperature to which the meat was cooked, since internal temperatures above 60 °C tended to mask tenderness differences between animals of different ages. In this regard, the report of Walter et al. (1965) that the effects of chronological age and physiological maturity were manifested through cooking, possibly as a response of stromal (connective tissue) proteins to heat, is relevant.

Jeremiah et al. (1971) observed that increases in lamb chronological age increased cooking losses ($P < 0.01$) and decreased tenderness ($P < 0.01$) and reported cooking losses were inversely related to juiciness ($P < 0.01$). Consequently, the detrimental effects of advancing chronological age or physiological maturity on tenderness may be manifested through a drying effect during cooking.

Composite previous findings imply carcasses from young or youthful animals are generally likely to be more tender than carcasses from older or more mature animals, but neither chronological age nor physiological maturity can be used as accurate predictors of meat tenderness despite the fact that Reagan et al. (1976) reported chronological age to be one of the most important determinants of tenderness variability.

Although it has been reported that older and more mature animals contained a lower proportion of moisture in their carcasses (Jeremiah et al., 1997; Reagan et al., 1976), differences in juiciness attributable to chronological age or physiological maturity were not observed (Reagan et al., 1976).

Field et al. (1978) reported that the flavor of older 68-kg ram lambs was less desirable than the flavor of younger 41-kg ram lambs. Other workers have observed flavor intensity to increase (Weller et al., 1962; Paul et al., 1964) and flavor desirability to decrease (Misock et al., 1976) with advancing age in lambs at very heavy weights (80 kg). However, the reported correlations between age and flavor desirability (Misock et al., 1976) was very low and there was no linear trend. In addition, Crouse et al. (1982) indicated that maturity was not related to lamb flavor and Paul et al. (1964) failed to detect age differences in flavor between wethers 5.5 and 11.5 months of age. Jacobson et al. (1962) concluded that the variation among individual animals was greater than the variation due to age.

Berry et al. (1974) reported that all physiological maturity indicators were significantly related to palatability and indicated youthful carcasses generally received higher palatability ratings. However, Jennings et al. (1976) reported physiological maturity determined from lean or bone indicators affected palatability only to a slight extent.

The present study was designed to evaluate the effects of lamb chronological age, slaughter weight and gender on indicators of physiological maturity and to examine the relationships of these indicators with cooking, palatability and consumer acceptance traits.

Materials and Methods

A total of 1,660 commercial lambs were selected on the basis of age, slaughter weight, gender and fatness to fill specific subclasses in an experimental design grid (Jeremiah et al., 1997). The lambs evaluated were a representative sample of the entire range of lambs currently being marketed in Canada, rather than a set of animals of controlled breeding and dietary management slaughtered at different weights and/or ages. The lambs in the present study were purchased from commercial sheep producers with breeding records and certified birthdates for the lambs purchased so that both the breeding and chronological ages could be ascertained. The lambs were predominantly crossbreds involving some combination of the following breeds: Cheviot, Columbia, Dorset, Finnish Landrace, Hampshire, Leicester, Montadale, Ranbouillet, Romanoff, Romney, Shropshire, Southdown, Suffolk, Targhee and Texel. Breeds and breed crosses were allocated as evenly as possible among age/weight/gender subclasses and care was taken to prevent a given breed or breed-cross from constituting a majority in any given age/weight/gender subclass.

Dentition, fatness and gender were ascertained the day prior to slaughter. Dentition score was determined by a trained and experienced evaluator using a five-point descriptive scale (1 = zero to four teeth cut; 5 = two temporary incisors replaced). Fatness was ascertained both subjectively by a trained and experienced evaluator using a three-point descriptive scale (1 = lean; 3 = fat) and ultrasonically, and the same fatness criteria were applied to all age/slaughter weight/gender subclasses. Breed composition necessarily varied among age/slaughter weight subclasses but was relatively constant within subclasses. Since the lambs were purchased from different producers, it is possible they were fed differently and it is possible this may have influenced compositional properties. The actual frequency distribution of lambs evaluated is presented in Table 1 by

Table 1. Simple correlation coefficients and probabilities for relationships between indicators of physiological maturity and chronological age in days.

Trait	r	P
Dentition score	0.19	0.0001
Breakjoint score	-0.02	0.5585
Breakjoint color score	0.15	0.0006
Rib flatness socre	-0.18	0.0001
Rib color score	0.40	0.0001
Flank color score	-0.31	0.0001
Sacral ossificaiton score	-0.47	0.0001

age, weight, gender and fatness subclass.

All lambs were slaughtered at the Lacombe Meat Research Centre (Lacombe, AB) under simulated commercial conditions. Warm carcasses were weighed and chilled for 24 hours at 1 °C (±1 °C). At 24 hours postmortem, the number of break and spooljoints on the front legs of each carcass was recorded and the breakjoints were subjectively evaluated on a four-point scale for color and moistness combined (1 = very red and moist; 4 = white and dry). In addition, the shape (1 = round; 2 = oval; 3 = flat) and color (1 = red; 4 = white) of the ribs, and the color of the flanks (1 = light red; 4 = dark red) were subjectively evaluated. After splitting the carcass, the amount of sacral ossification (1 = no ossification; 5 = complete ossification) was also subjectively determined.

Loin roasts between the 12th thoracic and the last lumbar vertebra were removed from the right side of each lamb carcass within the sample of the 1,660 lambs previously described (Jeremiah et al., 1997). Each wholesale loin was weighed, vacuum packaged and frozen at -30 °C in still air. They were then held at this temperature until evaluated (90 to 180 days). Upon removal from the freezer all loins were thawed at 4 °C for 48 hours and then reweighed to determine thaw-drip losses. A saber thermocouple was then inserted into the center of each loin and they were roasted in an electric convection oven, preheated to 177 °C, to an internal temperature of 75 °C. Upon removal from the oven each loin and its associated drip were weighed to determine drip, evaporative and total cooking losses, and each loin was subjectively evaluated for degree of doneness (1 = rare; 5 = well done) and cooking times were recorded. Six cubes (1.9 cm sides) were then removed from each loin, taking care to avoid large pieces of fat and connective tissue, and randomly assigned to an experienced, six-member laboratory panel screened and trained according to American Meat Science Association guidelines (AMSA, 1978). Subsamples were held in covered glass containers in a 70-°C water bath until evaluated (10 to 15 minutes).

Panel sessions were conducted in well-ventilated temperature-controlled partitioned booths under 1076 lux of incandescent and fluorescent white light. Room-temperature distilled water and unsalted soda crackers were provided to remove flavor residues between sample evaluations (Larmond, 1977). Panelists evaluated subsamples using eight-point descriptive scales for initial and overall tenderness (8 = extremely tender; 1 = extremely tough), amount of perceptible connective tissue (8 = no perceptible connective tissue; 1 = abundant perceptible connective tissue), juiciness (8 = extremely juicy; 1 = extremely dry) and flavor intensity (8 = extremely intense lamb flavor, 1 = extremely bland lamb flavor). The presence of any off-flavor was also noted.

Three cores (13 mm) were also removed parallel to the muscle fibers from each loin using a mechanical cork borer after the loins had been refrigerated overnight at 4 °C. Each core was then sheared three times using the Ottawa Texture Measuring System fitted with a Warner-Bratzler blade, and mean shear force values were calculated and recorded.

A total of 3,320 lamb leg roasts (1,660 shank and 1,660 butt halves) were distributed to lamb consuming households in 21 central Alberta regions for evaluation of acceptability of flavor, juiciness, tenderness and overall palatability. A total of 1,528 and 1,529 responses were obtained for shank and butt leg roasts, respectively.

Consuming households were instructed to prepare the roasts which they received using the method they normally employed for preparation of lamb leg roasts, but to record the cooking methods and times employed and the degree of doneness at the point of consumption. Following preparation, each household was asked to reach a consensus rating for the acceptability of the flavor, juiciness, tenderness and overall palatability of the roasts which they received using a five-piont hedonic scale (1 = disliked extremely; 5 = liked extremely).

Data for physiological maturity indicators were analyzed using the general linear model (GLM) procedures of SAS (1985). Sources of variation were: age, slaughter weight, gender and their two-way and three-way interactions. Mean separation of significant main effects was by single degree of freedom linear contrast. Linear regression was used to detect significant relationships with advancing age and increasing slaughter weight and to evaluate relationships with cooking, palatability and consumer acceptance traits (Puri and Mullen, 1980).

Results and Discussion

Simple correlation coefficients for relationships of physiological maturity indicators with chronological age for the entire sample population (Table 1) indicated the only indicator not significantly related to chronological age was breakjoint score. Ironically, this indicator has been traditionally used in grading systems to estimate age and maturity and to segregate lamb from mutton. Although all of the other indicators were significantly correlated with chronological age, the magnitude of the correlation coefficients were relatively low. The two most precise indicators, sacral ossification scores and rib color scores, accounted for only 22 and 16% of the variation in chronological age, respectively.

Although Ho et al. (1989) reported dentition was not gender dependent, the data presented in Table 2 indicate ewe lamb carcasses were more physiologically mature based upon dentition, when they were at heavy weights (more than 68.2 kg live) and over nine months of age. Relationships in dentition scores were not observed ($P > 0.05$) with either increasing slaughter weight or advancing age, primarily because ram and wether lambs do not start to lose their temporary incisors until after 12 months of age and ewe lambs do not start to lose their temporary incisors until after 9 months of age.

The data presented in Table 2 indicate a general lack of consistency of gender differences among age and slaughter weight subclasses. No relationships in sacral ossification scores were observed with increasing slaughter weight ($P > 0.05$), indicating sacreal ossification was not related to slaughter weight. Negative relationships in sacral ossification scores with advancing age were observed only in ram carcasses in weight group 3 (50.0 to 58.6 kg live, $r^2 = 0.93$, $P < 0.05$), and ewe lamb carcasses in weight group 5 (68.2 to 76.8 kg live, $r^2 = 0.99$, $P < 0.01$), indicating sacral ossification was not generally related to chronological age.

In general, ewe carcasses had the flattest ribs and ram carcasses had the

Table 2. Least square means and standard errors for carcass traits indicative of physiological maturity.

		Slaughter Weight Group									
		1 31.8-40.4 kg		2 40.5-49.5 kg		3 50.0-58.6 kg		4 58.9-67.7 kg		5 68.2-76.8 kg	
Age group	Gender	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Dentition Score											
1	Ram	2.00	0.09	2.00	0.08	2.00	0.08	2.00	0.07	2.00	0.31
3-6 months	Ewe	2.00	0.09	2.00	0.08	2.00	0.07	2.00	0.09	—	—
	Wether	2.00	0.08	2.00	0.08	2.00	0.09	2.00	0.09	—	—
2	Ram	2.00	0.31	2.00	0.07	2.00	0.06	2.00	0.07	2.00	0.07
6-9 months	Ewe	2.00	0.43	2.00	0.06	2.00	0.07	2.00	0.07	2.00	0.07
	Wether	—	—	2.00	0.06	2.00	0.06	2.00	0.07	2.00	0.07
3	Ram	2.00	0.31	2.00	0.07	2.00	0.07	2.00	0.07	2.00[b]	0.07
9-12 months	Ewe	—	—	2.00	0.07	2.00	0.07	2.08	0.07	2.25[a]	0.07
	Wether	2.00	0.43	2.00	0.07	2.00	0.07	2.00	0.07	2.00[b]	0.07
4	Ram	—	—	2.00	0.43	2.17[ab]	0.07	2.08[b]	0.07	2.25[b]	0.07
12-15 months	Ewe	2.00	0.43	2.00	0.25	2.29[a]	0.07	2.78[a]	0.07	2.62[a]	0.07
	Wether	—	—	2.00	0.31	2.06[b]	0.07	2.68[a]	0.07	2.39[b]	0.06
Sacral Ossification Score											
1	Ram	3.04	0.12	3.00	0.11	3.00	0.10	3.00[a]	0.10	3.00	0.41
3-6 months	Ewe	3.00	0.12	3.00	0.11	2.85	0.10	2.75[b]	0.13	—	—
	Wether	3.00	0.11	3.00	0.11	3.00	0.12	2.95[a]	0.13	—	—
2	Ram	3.00	0.41	2.79[b]	0.09	2.93[ab]	0.09	2.89	0.09	2.94[a]	0.10
6-9 months	Ewe	3.00	0.58	3.02[a]	0.09	3.02[a]	0.09	2.94	0.10	2.03[c]	0.12
	Wether	—	—	2.94[ab]	0.08	2.70[b]	0.09	2.94	0.10	2.39[b]	0.11
3	Ram	1.00	0.41	1.42	0.10	1.71[a]	0.10	1.43[a]	0.09	1.50[ab]	0.12
9-12 months	Ewe	—	—	1.48	0.10	1.26[b]	0.10	1.59[a]	0.10	1.63[a]	0.11
	Wether	—	—	1.31	0.11	1.42[b]	0.10	1.10[b]	0.10	1.36[b]	0.10
4	Ram	—	—	3.00	0.58	1.69[b]	0.11	2.45[b]	0.10	2.10[a]	0.10
12-15 months	Ewe	1.00	0.58	2.33	0.33	1.94[a]	0.10	2.66[a]	0.10	1.54[c]	0.10
	Wether	—	—	3.00	0.41	1.71[b]	0.10	2.12[c]	0.10	1.81[b]	0.10
Rib Flatness Score											
1	Ram	2.17	0.08	2.14	0.08	2.09	0.07	2.00	0.07	2.00	0.29
3-6 months	Ewe	2.08	0.08	2.00	0.08	2.09	0.07	2.00	0.08	—	—
	Wether	2.15	0.08	2.04	0.08	2.08	0.08	2.00	0.08	—	—
2	Ram	3.00a	0.29	2.21	0.07	2.24	0.06	2.07[b]	0.06	2.11[b]	0.07
6-9 months	Ewe	1.00b	0.41	2.20	0.06	2.15	0.06	2.27[a]	0.06	2.39[a]	0.07
	Wether	—	—	2.19	0.06	2.12	0.06	2.05[b]	0.06	2.00[b]	0.07
3	Ram	1.50	0.29	1.35[b]	0.07	1.77[b]	0.06	1.65[b]	0.06	1.81[b]	0.07
9-12 months	Ewe	—	—	1.63[a]	0.07	1.91[a]	0.06	2.08[a]	0.07	2.28[a]	0.07
	Wether	2.00	0.41	1.50[a]	0.07	1.86[ab]	0.06	2.11[a]	0.07	1.89[b]	0.07
4	Ram	—	—	2.00	0.41	1.65[b]	0.07	2.08[c]	0.07	2.00[b]	0.07
12-15 months	Ewe	2.00	0.41	2.33	0.24	2.11[a]	0.07	2.39[a]	0.07	2.15[a]	0.07
	Wether	—	—	2.50	0.29	2.08[a]	0.07	2.24[b]	0.07	2.17[a]	0.06

(Table continued on next page.)

roundest ribs (Table 2). Negative relationships were detected in rib flatness scores with increasing liveweight in ram carcasses in age group 1 (3 to 6 months, $r^2 = 0.79$, $P < 0.05$) and wether carcasses in age group 2 (6 to 9 months, $r^2 = 0.87$, $P < 0.05$), indicating ribs became progressively more round as slaughter weight increased in these subgroups. However, a positive relationship in rib flatness scores with increasing slaughter weight was detected in ewe carcasses in age group 2 (6 to 9 months, $r^2 = 0.91$, $P < 0.05$). Such lack of consistency in relationships indicates rib shape generally is not related to slaughter weight. A negative relationship in rib flatness scores of ewe carcasses in weight group 5 (68.2 to 76.8 kg live, $r^2 = 0.92$, $P < 0.05$) was the only signifi-

Table 2. (Continued.)

		Slaughter Weight Group									
		1 31.8-40.4 kg		2 40.5-49.5 kg		3 50.0-58.6 kg		4 58.9-67.7 kg		5 68.2-76.8 kg	
Age group	Gender	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
						Rib Color Score					
1	Ram	2.50	0.14	2.39^{ab}	0.13	2.12^{b}	0.12	2.14^{b}	0.11	2.00	0.47
3-6 months	Ewe	2.26	0.13	2.31^{b}	0.13	2.31^{a}	0.11	2.63^{a}	0.14	—	—
	Wether	2.44	0.13	2.58^{a}	0.13	2.38^{a}	0.14	2.42^{ab}	0.14	—	—
2	Ram	2.50	0.47	2.51	0.11	2.33^{b}	0.10	2.22^{b}	0.10	2.33^{b}	0.11
6-9 months	Ewe	2.00	0.67	2.36	0.10	2.51^{b}	0.10	2.59^{a}	0.10	2.92^{a}	0.11
	Wether	—	—	2.54	0.10	2.76^{a}	0.09	2.36^{ab}	0.10	2.53^{b}	0.11
3	Ram	4.00	0.47	3.41^{a}	0.11	3.34^{a}	0.10	2.93^{b}	0.10	2.78^{b}	0.11
9-12 months	Ewe	—	—	3.00^{b}	0.11	3.07^{b}	0.10	3.34^{a}	0.11	3.44^{a}	0.11
	Wether	3.00	0.67	2.97^{b}	0.11	3.05^{b}	0.10	3.13^{ab}	0.11	2.92^{b}	0.11
4	Ram	—	—	2.00	0.67	3.32^{a}	0.11	3.00^{a}	0.11	2.86^{a}	0.11
12-15 months	Ewe	3.00	0.67	2.33	0.39	2.86^{b}	0.11	2.50^{b}	0.11	2.54^{b}	0.11
	Wether	—	—	3.00	0.47	2.67^{b}	0.11	2.54^{b}	0.11	2.65^{ab}	0.10
						Breakjoint Score					
1	Ram	1.04	0.04	1.07	0.04	1.00	0.03	1.00	0.03	1.00	0.14
3-6 months	Ewe	1.00	0.04	1.00	0.04	1.00	0.03	1.00	0.04	—	—
	Wether	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	—	—
2	Ram	1.00	0.14	1.00	0.04	1.00	0.03	1.00	0.03	1.00	0.03
6-9 months	Ewe	1.00	0.20	1.00	0.03	1.00	0.03	1.00	0.03	1.06	0.03
	Wether	—	—	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03
3	Ram	1.00	0.20	1.00	0.03	1.05	0.03	1.00	0.03	1.00^{b}	0.03
9-12 months	Ewe	—	—	1.00	0.03	1.00	0.03	1.05	0.03	1.17^{a}	0.03
	Wether	1.00	0.20	1.00	0.03	1.00	0.03	1.00	0.03	1.00^{b}	0.03
4	Ram	—	—	1.00	0.20	1.00^{c}	0.03	1.03^{b}	0.03	1.00^{b}	0.03
12-15 months	Ewe	1.00	0.20	1.00	0.11	1.06^{b}	0.03	1.11^{a}	0.03	1.21^{a}	0.03
	Wether	—	—	1.00	0.14	1.11^{a}	0.03	1.00^{b}	0.03	1.07^{b}	0.03
						Breakjoint Color					
1	Ram	2.04	0.13	2.07	0.12	2.06	0.11	2.03	0.11	2.00	0.44
3-6 months	Ewe	2.00	0.12	2.04	0.12	2.06	0.11	2.17	0.13	—	—
	Wether	2.00	0.12	2.00	0.12	2.00	0.13	2.00	0.13	—	—
2	Ram	2.00	0.44	2.26^{a}	0.10	2.00^{b}	0.09	1.98	0.10	2.00	0.10
6-9 months	Ewe	2.00	0.62	2.04^{b}	0.09	2.00^{ab}	0.10	2.02	0.10	1.94	0.10
	Wether	—	—	2.10^{ab}	0.09	2.20^{a}	0.09	1.95	0.10	2.06	0.10
3	Ram	3.50^{a}	0.44	2.14^{b}	0.10	2.59^{a}	0.09	2.30^{a}	0.10	2.11^{a}	0.10
9-12 months	Ewe	—	—	2.53^{a}	0.10	2.41^{a}	0.09	2.11^{ab}	0.10	1.72^{b}	0.10
	Wether	2.00b	0.62	2.18^{b}	0.10	2.20^{b}	0.09	2.05^{b}	0.10	2.08^{a}	0.10
4	Ram	—	—	2.00	0.62	2.35^{ab}	0.11	2.31^{a}	0.10	2.17^{b}	0.10
12-15 months	Ewe	4.00	0.62	2.33	0.36	2.43^{a}	0.11	2.28^{ab}	0.10	2.38^{a}	0.10
	Wether	—	—	2.00	0.44	2.19^{b}	0.10	2.08^{b}	0.10	2.26^{ab}	0.09

(Table continued on next page.)

cant relationship observed with advancing age, indicating rib shape was generally not related to chronological age in lambs 3 to 15 months of age.

Ewe carcasses generally had the least amount of red color on their ribs (Table 2). Negative relationships in rib color scores were detected with increasing slaughter weight in ram carcasses in age groups 1 (3 to 6 months, $r^2 = 0.85$, $P < 0.01$) and 3 (9 to 12 months, $r^2 = 0.96$, $P < 0.01$), indicating the ribs of these carcasses became progressively redder as slaughter weight increased. However, a positive relationship was observed with increasing slaughter weight in ewe carcasses in age group 2 (6 to 9 months, $r^2 = 0.93$, $P < 0.01$). This lack of consistency in relationships indicates rib color was generally not related to slaughter weight. Positive relationships in rib color scores with advancing age were observed in ram carcasses in weight groups 3 (50.0 to 58.6 kg live, $r^2 = 0.83$, $P < 0.05$), 4 (58.9 to 67.7 kg live, $r^2 = 0.83$, $P < 0.05$) and 5 (68.2 to 76.8 kg live, $r^2 = 0.95$, $P < 0.01$), indicating the ribs of ram lambs with slaughter weights in excess of 50.0 kg became progressively whiter as the animals became older.

Ho et al. (1989) observed gender differences in the occurrence of spooljoints and indicated spooljoints were observed first on ewe carcasses and last on wether carcasses. Ewe carcasses had the highest incidence of spooljoints when they were over 9 months of age and at heavy weights (more than 68.2 kg live) in the present study (Table 2). No relationships in breakjoint scores were detected with increasing slaughter weight ($P > 0.05$), indicating breakjoint score was not related to slaughter weight. A positive relationship ($P < 0.05$) in breakjoint scores with advancing age was observed in ewe carcasses in weight group 5 (68.2 to 76.8 kg live, $r^2 = 1.00$, $P < 0.001$) indicating the incidence of spooljoints increased progressively with chronological age only in heavy weight ewe carcasses (more than 68.2 kg live).

There was no consistency in gender differences in breakjoint color scores observed among age/liveweight subgroups (Table 2). No significant relationships in breakjoint color scores were observed either with increasing slaughter weight or advancing age ($P > 0.05$), indicating breakjoint color was not related to either slaughter weight or chronological age.

Ram and wether carcasses had higher flank color scores or darker red flanks than ewe carcasses at heavier slaughter weights (more than 58.9 kg; Table 2). Positive relationships in flank color scores were detected with increasing slaughter weight in ram carcasses in age groups 1 (3 to 6 months, $r^2 = 0.87$, $P < 0.05$) and 2 (6 to 9 months, $r^2 = 0.92$; $P < 0.01$). However, a negative relationship was observed with increasing slaughter weight in wether carcasses in age group 4 (12 to 15 months, $r^2 = 0.91$, $P < 0.01$). These results indicate the flanks of young ram carcasses (less than 9 months) became progressively darker red in color with increasing slaughter weight, while the flanks of older wether carcasses (more than 12 months) became progressively lighter red in color with increasing slaughter weight. Negative relationships in flank color scores were observed in ewe carcasses in weight groups 1 (31.8 to 40.4 kg live, $r^2 = 0.93$, $P < 0.05$) and 5 (68.2 to 76.8 kg live, $r^2 = 1.00$, $P < 0.01$) and ram carcasses in weight group 3 (50.0 to 58.6 kg live, $r^2 = 0.82$, $P < 0.05$), indicating the flanks of light (less than 40.5 kg live) and heavy (more than 67.7 kg live) ewe carcasses and intermediate weight (50.0 to 58.6 kg live) ram carcasses

Table 2. (Continued.)

		Slaughter Weight Group									
		1 31.8-40.4 kg		2 40.5-49.5 kg		3 50.0-58.6 kg		4 58.9-67.7 kg		5 68.2-76.8 kg	
Age group	Gender	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
		Flank Color Score									
1	Ram	2.29[b]	0.18	2.71	0.16	3.06	0.15	2.94[a]	0.15	3.00	0.61
3-6 months	Ewe	2.56[ab]	0.17	2.96	0.17	2.86	0.15	1.83[b]	0.18	—	—
	Wether	2.89[a]	0.17	2.92	0.17	3.00	0.18	2.96[a]	0.18	—	—
2	Ram	2.00	0.61	2.79	0.14	3.04	0.13	2.85[b]	0.13	3.25[a]	0.14
6-9 months	Ewe	2.00	0.86	3.00	0.13	3.17	0.13	3.27[a]	0.13	2.00[c]	0.14
	Wether	—	—	2.88	0.12	2.92	0.12	3.02[ab]	0.13	2.58[b]	0.14
3	Ram	3.50	0.61	2.38[b]	0.14	2.14[b]	0.13	2.00[a]	0.13	2.86[a]	0.14
9-12 months	Ewe	—	—	2.87[a]	0.14	2.66[a]	0.13	1.39[b]	0.14	1.42[c]	0.14
	Wether	3.00	0.86	2.34[b]	0.14	1.84[c]	0.13	1.84[a]	0.14	2.39[b]	0.14
4	Ram	—	—	3.00	0.86	1.94	0.15	2.64[a]	0.14	1.67[a]	0.14
12-15 months	Ewe	1.00	0.86	2.33	0.50	1.83	0.15	2.50[ab]	0.14	1.12[b]	0.14
	Wether	—	—	3.50	0.61	2.00	0.14	2.30[b]	0.14	1.80[a]	0.13

[a,b,c] Means in the same column and age group without a superscript or bearing a common superscript do not differ significantly ($P > 0.05$).

became progressively darker red in color with advancing age.

Dentition score was positively related ($P < 0.001$) to cooking times and drip, evaporative and total cooking losses (Table 3), indicating as the animals cut, lost and had their temporary incisors replaced, the meat from those animals required longer cooking times and sustained greater drip and evaporative cooking losses. Dentition scores were also positively related ($P < 0.05$) to meat flavor intensity and negatively related to initial and overall taste panel tenderness ($P < 0.05$), indicating as the animals cut, lost and had their temporary incisors replaced the intensity of lamb flavor increased and the tenderness of the meat decreased (Table 3).

Rib flatness score was also positively related to cooking times ($P < 0.01$), and drip ($P < 0.001$), evaporative ($P < 0.01$) and total ($P < 0.001$) cooking losses, indicating that as the animal's ribs became flatter the meat took longer to cook and sustained greater drip and evaporative cooking losses (Table 3). Rib flatness score was also positively related to degree of doneness ($P < 0.05$) and shear force value ($P < 0.001$) and negatively related ($P < 0.001$) to initial and overall panel tenderness ratings, indicating that as the animal's ribs became flatter, the meat appeared more well done even though cooked to the same internal temperature, and it also decreased in tenderness.

Rib color score was positively related to panel juiciness score ($P < 0.001$), and negatively related to cooking time ($P < 0.001$), initial and overall panel tenderness scores ($P < 0.001$), shear force value and consumer ratings of butt roast tenderness ($P < 0.001$), overall palatability ($P < 0.05$) and shank roast tenderness ($P < 0.01$; Table 3). These findings indicate that as the animal's ribs became whiter the meat required less time to cook and became less tender but more juicy.

Breakjoint score was positively related to drip and total cooking losses and panel flavor intensity ratings ($P < 0.01$), indicating that as the incidence of spooljoints increased, the drip and total cooking losses increased and the lamb flavor in the meat became more intense (Table 3).

Breakjoint color scores were positively related to panel juiciness ratings ($P < 0.05$) and negatively related to cooking time ($P < 0.001$), drip ($P < 0.001$), evaporative ($P < 0.01$) and total ($P < 0.001$) cooking losses, amount of perceptible connective tissue ($P < 0.05$) and panel ratings of initial and overall tenderness ($P < 0.05$; Table 3). These relationships indicate that as the breakjoints became whiter and drier, the meat required longer cooking times, sustained greater evaporative and drip cooking losses, became less tender and contained more perceptible connective tissue, but was juicier.

Table 3. Pearson correlation coefficients for relationships of physiological maturity indicators with cooking, palatability and consumer acceptance traits.

	Dentition score	Rib flatness score	Rib color score	Breakjoint score	Breakjoint color score	Sacral ossification score	Flank color score
Cooking time	0.13[c]	0.19[c]	-0.11[c]	0.04	-0.15[c]	0.04	0.02
Degree of doneness	-0.04	0.05[a]	-0.02	0.05	0.00	0.04	0.01
Cooking drip loss	0.21[c]	0.17[c]	0.02	0.08[b]	-0.10[c]	-0.20[c]	-0.18[c]
Evaporative cooking loss	0.09[c]	0.08[b]	0.01	0.03	-0.08[b]	-0.12[c]	-0.05
Total cooking loss	0.17[c]	0.15[c]	0.02	0.07[b]	-0.10[c]	-0.18[c]	-0.10[c]
Initial tenderness	-0.06[a]	0.01	-0.10[c]	-0.04	-0.05[a]	0.01	-0.05
Overall tenderness	-0.05[a]	0.02	-0.10[c]	-0.03	-0.06[a]	0.01	-0.03
Amount of perceptible connective tissue	0.02	-0.14[c]	0.04	-0.02	-0.05[a]	-0.31[c]	-0.21[c]
Juiciness	-0.04	-0.12[c]	0.11[c]	0.04	0.06[a]	0.15[c]	-0.14[c]
Flavor intensity	0.05[a]	-0.03	0.01	0.07[b]	0.00	0.19[c]	-0.11[c]
Shear force	-0.02	0.12[c]	-0.06[a]	0.00	-0.02	0.24[c]	0.23[c]
Butt:							
Flavor	0.01	-0.02	-0.02	0.00	-0.04	0.01	-0.01
Juiciness	-0.00	-0.01	-0.04	0.01	0.02	0.00	-0.02
Tenderness	-0.04	-0.03	-0.09[c]	-0.01	-0.00	0.03	0.01
Overall palatability	-0.02	0.00	-0.05[a]	-0.01	-0.01	0.04	0.03
Shank:							
Flavor	0.00	-0.01	-0.01	0.03	-0.05	-0.02	-0.03
Juiciness	0.01	-0.04	-0.03	0.00	-0.03	0.07[b]	-0.05
Tenderness	-0.01	-0.05	-0.07[b]	-0.03	-0.02	-0.06[a]	-0.02
Overall palatability	0.00	-0.03	-0.04	0.01	-0.05	-0.03	-0.03

[a] $P < 0.05$
[b] $P < 0.01$
[c] $P < 0.001$

Sacral ossification scores were positively related to panel juiciness scores ($P < 0.001$), flavor intensity scores ($P < 0.001$), shear force ($P < 0.001$) and consumer ratings of shank roast juiciness ($P < 0.01$) and negatively related to drip, evaporative and total cooking losses ($P < 0.001$) amount of perceptible connective tissue and consumer ratings of shank roast tenderness ($P < 0.05$). These relationships also indicate that, as the animal's sacrum became more ossified, the meat sustained greater drip and evaporative cooking losses and became more juicy and less tender, the connective tissue became more perceptible and the lamb flavor intensified.

Flank color scores were positively related to shear force value and negatively related to initial and overall panel tenderness, amount of perceptible connective tissue, juiciness, flavor intensity and drip and total cooking losses ($P < 0.001$; Table 3). Therefore, as the flanks became darker red in color, the meat became less tender and juicy and had more perceptible connective tissue and more bland flavor; also, both drip and total cooking losses were reduced.

Consequently the composite of these relationships indicates that, as lambs mature physiologically, their meat requires longer cooking times, sustains greater drip and evaporative cooking losses and becomes more juicy and less tender. In addition, the connective tissue becomes more perceptible and the lamb flavor intensifies. However, such changes resulted in only a slight reduction in consumer acceptance. Therefore present findings support previous reports that cooking losses increased (Jeremiah et al., 1971), tenderness decreased (Pinkas et al., 1979; Jeremiah et al., 1971) and flavor intensity increased (Weller et al., 1962; Paul et al., 1964) with advancing age or physiological maturity. Present findings also support a previous conclusion that physiological maturity influenced palatability only to a slight extent (Jennings et al., 1976) and partially support another previous conclusion that all maturity indicators were significantly related to palatability (Berry et al., 1974). However, present findings disagree with previous reports that chronological age or physiological maturity did not influence juiciness (Reagan et al., 1976) or flavor (Paul et al., 1964; Crouse et al., 1982).

Conclusions

Sacral ossification and rib color scores were most highly related to chronological age but accounted for only 22 and 16% of the variation, respectively. Breakjoint score was the only physiological maturity indicator not related to chronological age. Ewe lamb carcasses generally had the flatest ribs, the least amount of color on their ribs and the highest incidence of spooljoints at older ages (more than 9 months) and heavy weights (more than 68.2 kg live). Therefore ewe lamb carcasses were the most physiologically mature. The ribs of heavyweight ram carcasses (more than 50.0 kg live) became whiter with advancing age but the incidence of spooljoints increased with advancing age only in heavyweight ewe lamb carcasses (more than 68.2 kg live). Relationships with cooking, palatability and consumer acceptance traits indicated as lambs matured physiologically, their meat required longer cooking times, sustained greater drip and evaporative cooking losses and became more juicy but less tender. In addition, connective tissue became more perceptible and lamb flavor intensified. However, these changes resulted in only a slight reduction in consumer acceptance, probably of little practical importance.

Acknowledgments

The authors are grateful to Alberta Agriculture (Farming for the Future), the Ontario Ministry of Agriculture and Food and the Alberta Sheep and Wool Commission for their financial support; to Ian Clark, Carol Pierson and Wendy Jehn for their technical assistance; to Ray Wilson, Gene Chambers, Don Brereton, Chuck Pimm, Dick Harris, Mike Vanson, Richard Johnson and Dave Henry for their assistance with slaughter and dissection; and to Anna Alexander and Loree Verquin for typing this manuscript.

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Research Briefs

Nutritional consequences among ingredients of free-choice feeding Awassi lambs

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Thirty 3-month-old male Awassi lambs were weaned at 70 to 80 days of age. The were fed a complete and mixed ration (24 Mcal ME per kg and 17% CP) or the same ingredients (ground barley, wheat bran, cottonseed meal, alfalfa hay) free-choice in separate feeders. Ration additives (minerals, vitamins, Ionophore) were mixed with individual ingredients at the same ratio to the complete ration. The lambs allowed free choice ingredients gained faster (16%) and had better feed efficiency (11%) than those fed the mixed ration. They also chose a higher energy and lower protein ration. This suggests that 17% protein may have been high for the mixed ration and that the metabolic cost of deamination of the excess protein may have been a partial explanation for the improved feed efficiency with the free-choice feeds. The major point of interest about this study is the indication that lambs can be fed free-choice ingredients thus possibly eliminating the necessity for expensive mixing equipment under farm conditions.

Prepared by Maurice Shelton.

Potential for Woody Plant Control by Spanish Goats in the Sagebrush-Steppe

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For a number of reasons western juniper (*Juniperus occidentalis* Hook.) is expanding its range and sagebrush (*Artemisia* sp.) is increasing in density and cover on Northern Great Basin rangelands. This woody plant encroachment often displaces the more desirable grass/forb component of the vegetation. Presently we have no chemicals that economically control western juniper and chemical control of sagebrush, on public lands especially, is becoming politically unpopular. Because biological control agents are more acceptable on public lands, we explored the utility of Spanish goats (*Capra hircus*) for controlling these woody increasers.

Our objectives were first to assess the potential of Spanish goats for woody plant control during the growing season and late-summer after forages had cured and to determine the nutritive value of the goats' dietary choices. Direct observations and bite-counts of eight dry, non-pregnant female goats were used to quantify plant species selected over four consecutive days during each of the two forage phases. Samples of the forages selected by the goats were also harvested and evaluated for crude protein (CP), neutral (NDF) and acid detergent fiber (ADF) and in-vitro dry matter digestibility (IVDMD). Available herbage was sampled from twenty-five 1-m^2 plots prior to each grazing trial.

When forages were actively growing approximately 534 kg/hectare of herbage were available to the goats with 92% derived from grasses and 8% furnished by forbs. After forages had cured, 572 kg/hectare of herbage were available with 74% supplied by grasses and 26% furnished by forbs. Sagebrush density was 3,000 shrubs/hectare and juniper density was 169/hectare. The most prominent grasses were *Festuca idahoenis*, *Agropyron spicalum* and *Poa sandbergii*. Prominent forbs included *Cordylanthus ramosus*, *Eriogonum sperocephalum*, *Erigeron linearis*, *Erigeron flifolius*, *Phlox hoodii* and *Astragalus filipes*.

Dietary preference of the goats shifted with changes in plant phenology. When forages were actively growing, goats harvested roughly 71% of their total bites from forbs and 28% were selected from grasses. *Astragalus filipes* (22%), *Achillea millefolium* (17%), *Lepidium perfoliatum* (9%) and *Lithospermum ruderale* (8%) were the most prominently eaten forbs.

Agropyron spicatum (9%), *Festuca idahoenis* (5%) and *Agropyron desertorum* (8%) were the most frequently selected grasses. When forages had cured, forbs still dominated the diet at 56% of total bites, grasses ranked second at roughly 35 and 9% of bites were harvested from *Juniperus occi-*

dentalis. The most prominent forbs included *Astragalus filipes* (25%), *Achillea millefolium* (12%) and *Lithospermum ruderale* (12%). Major grasses were *Agropyron spicatum* (12%), *Agropyron desertorum* (8%) and *Koeleria cristata* (8%). Weighted means suggested the goats' diets were roughly 11% CP when the forages were growing and 7% CP when forages were cured. We suspect, however, that actual diets were of higher quality than our hand-compounded efforts.

As we ideally wished to affect target plants without undue impact on the more desirable vegetation, we suggest that Spanish goats have little potential for control of established *Artemisia* and *Juniperus* on good-condition rangeland supporting an array of nutritious forages. Further study is needed, however, to examine their potential where selective grazing opportunities are more restricted and where sagebrush and juniper are in their initial stages of establishment.

Compiled by David Ganskopp.

News and Notes

It has been announced that the headquarters for the Sheep Improvement Center will be in the Federal Center in Lakewood, CO, a suburb of Denver.

A paper entitled, "BSE: The Regulation of Animal Derived Protein – An Animal Producer's View of Science and Risk," presented by Paul Rodgers to the American Society of Animal Science at their annual meeting in Nashville, TN, on July 31, 1997, contained the following statement, "A question facing the animal industry group is: How do we make policy decisions when the science behind an issue is unclear? It has been said that 'in the absence of information, perception becomes reality, and perceptions are usually far worse than reality.'"

A copy of this paper may be obtained by contacting Rodgers at:

American Sheep Industry Assoc.
6911 South Yosemite Street
Englewood, CO 80112-1414

A revised and updated version of the *Sheep Producers Handbook* is available and may be purchased from ASI at the above address.

Sheep & Goat Research Journal
Guidelines for Authors

Objective

The aim of the Sheep & Goat Research Journal is to provide a publication of sheep and goat research findings which can be used by scientists, educators, Extension agents and sheep and goat producers alike. The specific goal of the Journal is to gather and distribute current research information on all phases of sheep and goat production and to encourage producer use of research which has practical application. The Journal is published three times each year.

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We are most interested in publishing articles of research relating to all aspects of sheep and goat production and marketing. Articles should relate and contribute to the advancement of the American sheep and goat industries and/or their products. All research manuscripts must represent unpublished original research. The submission of review articles is encouraged but will require review as well as those reporting original research. Articles which promote commercial products or services will not be approved for publication. Conclusions reached must be supported by research results. An orientation to practical applied research which may be useful to the sheep and goat industries is encouraged. At least one author of each manuscript must subscribe to the Journal.

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Manuscripts will be subject to critical review by an editorial board or others designated by the editor. Authors will be notified of acceptance or rejection of papers by mail. Manuscripts needing revision will be returned to authors and should be revised and returned by the deadline indicated. When papers are accepted for publication, the authors must send a floppy disk with the manuscript in the ASCII file format along with two hard copies. Papers not suitable for publication will be returned to the authors with a statement of reasons for rejection. Consult the Sheep & Goat Research Journal Editorial Policy and Procedures for details of the technical requirements for manuscripts submitted to the Journal.

Guidelines

Several sources were consulted, including the Journal of Animal Science and the Council of Biology Editors, Inc., when preparing these guidelines. Though the nature of the Journal is such that relatively few regulations are needed on style and form, we have attempted to standardize the manner in which the material is published as a service to Journal subscribers. Following are general guidelines for style and form.

Format

Manuscripts must be typed and double-spaced; five copies must be submitted. The lines on all pages including those pages for Literature Cited and Figure Legends must be numbered in the left margin beginning with the numeral one (1) at the top of the page. Tables should be as few and as simple as is feasible for presentation of the essential data; tables should be typed and double-spaced. Each table should be on a separate sheet. All figures used in the text must be camera-ready. The author will be billed at full cost if figure preparation is required.

Research manuscripts should follow the format of:

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Primary authors will receive galley proofs of articles. Corrected proofs should be returned by the deadline indicated. Failure to do so will result in delay of article publication.

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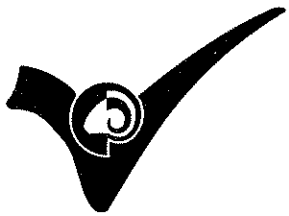

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American Sheep Industry Association

Contents of Volume 13, Number 1: 1997

Contents of Volume 13, Number 2: 1997

Comparison of U.S. Fine-Wool Breeds and Australian Merino F1 Crosses: I. Wool Characteristics and Body Weight[1]

G.D. Snowder[2,3], C.J. Lupton[4], J.M. Shelton[4], R.W. Kott[5], G.E. Bradford[6], M.R. Dally[7], A. D. Knight[2], H.A. Glimp[7], J.N. Stellflug[2], P.J. Burfening[5] and P.V. Thompson[4]

Summary

This study investigated the effects of infusing genes from two dissimilar Australian Merino types [fine-wool (FWM) and strong-wool (SWM)] into different U.S. fine-wool flocks on wool characteristics of resulting first cross (F1) ewes. The F1 ewes were the offspring from U.S. fine-wool ewes in different flocks located in four states (CA, ID, MT, TX) mated naturally or artificially to one of three ram types: FWM, SWM or Texas Rambouillet (RAMB). Identical six rams per sire breed were used to produce the F1 ewes (FWM, SWM and RAMB, respectively) for evaluation of body weight (BW) and wool characteristics at one and two years of age. Body weights were heaviest for ewes sired by RAMB compared with SWM and FWM ewes ($P < 0.05$). Fleece weight, staple length and yield (Y) were significantly increased ($P < 0.05$) by crossbreeding Australian Merino types on U.S. fine-wool ewes. Fleece weights at one and two years of age were greatest for SWM cross ewes ($P < 0.05$). Fiber diameters were 0.5 μm finer in FWM ewes compared to RAMB ewes. Variability of fiber diameters was lower for RAMB ewes than FWM and SWM ewes ($P < 0.05$). Subjective scores for wool face covering and belly wool covering were not very different among the three groups of ewes. However, subjective scores for quantity of skin folds were higher for FWM and SWM ewes compared with RAMB ewes ($P < 0.05$). In conclusion, wool production in U.S. fine-wool breeds can be improved by crossbreeding to selected Australian Merino rams. However, a decision to use this approach should also consider other production parameters.

Key words: crossbreeding, merino, sheep, wool, fiber.

Introduction

The Australian Merino has been subjected to selection pressure for improving wool characteristics (particularly clean fleece weight, staple length, fiber diameter) since the early 1800s. Consequently, the fleece weight in some Australian Merino strains was increased from 3.6 to more than 10 kg (Austin, 1944). Some of the early genetic improvements in staple length and fleece weight of Australian Merinos were attributed to the importation of U.S. Rambouillet and Vermont Merinos starting as early as 1866. In fact, the Australian Peppin Merino strain came to fame shortly after breeding Australian ewes to such well-known U.S. rams as *Emperor* and *Grimes* that sheared fleeces of more than 11.5 kg in 1866 (Austin, 1944). Over time, U.S. and Australian fine-wool sheep diverged in appearance and fleece traits due to selection for different parameters. U.S. breeders have tended to favor a dual-purpose animal while Australian breeders continued to focus mainly on wool traits.

A relaxation in the ban against exporting Australian Merino sheep

[1] This research was conducted as a multi-institution cooperative project by the CSREES Western Region Coordinating Committee Number 39. Appreciation is expressed to the National Program Staff of the USDA/ARS for funding the semen purchases. Project leaders acknowledge the significant contributions of the large number of technicians involved in this multi-institution project that made this study successful.

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during the 1980s resulted in the availability of Australian Merino genetics to U.S. producers. Previous research (in the 1930s) for improving U.S. wool production by importing and breeding Australian Merinos showed favorable responses in fiber diameter, follicle density and clean fleece weights (Bell et al., 1936). The present study was undertaken to evaluate potential advantages of crossbreeding modern Australian Merinos with U.S. fine-wool sheep.

Materials and Methods

This study was conducted as a multi-institution research project involving four locations: U.S. Sheep Experiment Station (Dubois, ID); Montana State University (Bozeman, MT); Texas Agricultural Experiment Station, Texas A&M University System (San Angelo, TX); and Hopland Research and Extension Center, University of California (Hopland, CA). The research project was designed to characterize wool production, lamb production (Snowder et al., 1998a) and carcass traits (Snowder et al., 1998b) of the offspring from two strains of Australian Merino sheep crossed with U.S. fine-wool sheep. The overall study was conducted between 1988 and 1993. Wool performance was measured on animals born in 1989 and sheared in 1990 and 1991.

Two specific types of Australian Merinos were utilized. The fine-wool Merino is recognized for finer fiber diameters and dense fleeces. The strong-wool Merino is characterized by relatively heavy and high-yielding fleeces and long staple length. Six rams from each strain were selected from many with available frozen semen. The Australian rams were classified into one of the two types based on their own fleece data and the strains of origin. Rams were primarily selected for fleece characteristics representative of their strain (i.e., fiber fineness or clean fleece weight) based upon reported data. Rams with excessive body folds and/or small body size were not desirable and were selected against in the strong-wool Merino types but low numbers of available fine-wool Merino rams did not make this independent culling practical. The six fine-wool Merino rams used in this study ranged in average fiber diameter (AFD) from 17.3 to 23.6 µm and each grew approximately 13 kg of clean wool per year. AFD among the selected strong-wool Merino rams ranged from 24.1 to 28.1µm with annual clean wool production averaging more than 14 kg. In both cases, the data provided in sales catalogues were used to make the selection decision. Frozen semen from each ram was purchased from a international commercial dealer.

Six Rambouillet rams were selected from Rambouillet flocks in Texas. All rams selected had performed well on a central ram performance test (Shelton, 1979) or were derived from flocks that had successfully participated in the test program for a number of years. The crossbred offspring from fine-wool Merino and strong-wool Merino rams were compared with offspring from the selected Rambouillet sires.

Reported data were used to compare sire types for fleece characteristics. Yearling fleece weights and yields of the selected Australian Merino rams were generally superior to those of the selected Rambouillet rams (Table 1). Average clean fleece weight of the fine-wool Merino and strong-wool Merino rams exceeded that of the Rambouillet rams by 84 and 143%, respectively. Percentage yield in the strong-wool Merino rams averaged 78.4%, 50% higher than the Rambouillet rams. AFD of the Rambouillet sires was greater than fine-wool Merino and less than strong-wool Merino sires. However, it should be pointed out that these sire data were not collected under comparable conditions.

Generation of Lambs

F1 ewes were produced by mating the two strains of Australian Merino rams to ewes from two typical U.S. western range breeds, Rambouillet (at three locations) and Targhee (at one location). Crossbred offspring of the Merino rams were identified according to the sire Merino strain [i.e., fine-wool Merino (FWM) or strong-wool Merino (SWM)]. Control ewe populations (RAMB) were established at each location by breeding ewes (Targhee or Rambouillet) to the selected Rambouillet rams.

Six rams of each Australian Merino strain and six Texas Rambouillet rams were bred by artificial insemination or natural matings to Targhee ewes at Hopland (CA) and Rambouillet ewes at Dubois (ID), Bozeman (MT) and San Angelo (TX). Ewe populations at each location were randomly assigned to three groups of approximately equal numbers before breeding. Each ewe was artificially inseminated or naturally bred to a single sire. Age of ewes at breeding ranged from two to six years. The California ewes were bred during June while ewes at other locations were bred in autumn.

Management of Ewes

The management system of each location varied according to routine production procedures. In Idaho, ewes were managed under herded conditions on public lands typical of

Table 1. Mean fleece characteristics of highly selected Australian Merino and Rambouillet rams based on individual reported data.[a]

Sire breed[b]	Grease fleece weight, kg	Clean yield, %	Clean fleece weight, kg	AFD, µm
FWM	14.4	74.3	10.7	20.7
SWM	18.0	78.4	14.4	25.0
RAMB	11.1	52.4	5.8	21.4

[a] These data were not collected under comparable conditions. The data on Australian rams came from advertising material, while the data on Rambouillet rams came from central performance test records.

[b] FWM = Australian Merino fine-wool strain; SWM = Australian Merino strong-wool strain; RAMB = purebred Rambouillet.

western range sheep production. Spring grazing occurred on sagebrush mixed-grass ranges while summer grazing was on high-elevation mountain meadows and forest. In autumn, sheep grazed sagebrush pastures until breeding when they were confined in large open pens with rams and fed approximately 2.3 kg/(head•day) of chopped alfalfa hay and 0.5 kg/(head•day) whole barley grain. After breeding, the ewes were transported to western slope desert mountain ranges for winter grazing. Before lambing, ewes were returned to large open pens and fed a chopped alfalfa hay and whole barley grain diet similar to that at breeding. Ewes remained in the feedlot until shearing which occurred approximately 30 days before lambing. After shearing, pregnant ewes were placed in small feedlots and shed-lambed. At approximately 40 days post-lambing, ewes and lambs were turned out onto spring sagebrush pastures.

Ewes in California were generally managed under pasture-grazing conditions year round. At approximately 10 days before lambing, ewes were moved into the lambing shed and fed 1.8 kg/(head•day) of alfalfa hay. Ewes and lambs were shed-confined after lambing for three to five days and fed approximately 2.7 kg/(head•day) of alfalfa pellets. Post-lambing, ewes and lambs were maintained on subterranean clover and annual grass pastures.

Management of ewes in Montana was similar to that of California. Ewes grazed upland range grasses and forbs year round under fenced pasture conditions at altitudes ranging from 1,402 to 1,889 m. Prior to lambing, ewes were brought into feedlots with ad libitum access to alfalfa hay and supplemented with 0.6 kg/(head•day) of whole barley grain. At approximately 40 days post-lambing, ewes and lambs were returned to upland range grass pastures.

In Texas, ewes were managed on fenced pasture at Brady, TX. Late-autumn grazing was supplemented with access to a salt-limited protein and energy supplement until lambing. At lambing, ewes and lambs were confined in small pens for one or two days before being returned to pasture.

Ewe Body Weight

F1 ewes were weighed before breeding. Because of age differences at weighing, both within and across locations, BW were adjusted to weight on days 365 and 730 for statistical comparisons among sire breeds across locations.

Wool Characteristics

At approximately one year of age, lambs were visually evaluated for face covering, degree of skin folds and belly wool covering. Subjective scores for these variables ranged from 1 to 4 with lower values representing less expression of the trait. Face covering was scored according to Terrill (1949) as follows: "1" = open, wool not extending beyond the poll; "2" = wool covering to the eyes; "3" = wool covering slightly below the eyes but opened face; and "4" = wool covering below the eyes but the eye channel not completely blocked and subject to wool blindness. In Texas, the face cover scores were assigned according to the scale used in the Texas Ram Test (Shelton, 1979). In this case, the "1" score represents sheep with no wool below the eyes. This difference in scoring method resulted in obviously different values (as reported in Table 5), but did not influence the conclusions to be drawn from the breed comparisons.

Wool covering the belly typically contains a different (bolder) type of staple crimp compared to wool at other body locations. It also tends to be finer, shorter and less dense than the rest of the fleece. Belly wool scores relate to the area of belly wool with a score of "1" indicating a small confined area on the ventral side and a "4" representing belly wool extending from ventral to mid-side. Belly wool data were not collected on sheep from Montana. The sheep were not re-scored the following year as two-year-olds.

Prior to shearing, a sample of wool of approximately 150 g was shorn from the mid-side of each animal. These wool samples were analyzed for yield (Y), AFD and variation in fiber diameter (CV). The proportion of wool weight represented by clean fibers (Y) was determined at the Montana State University Wool Lab in Bozeman, MT, using a standard method (ASTM, 1993). Subsequently, subsamples from the clean wool samples were sent to the Wool and Mohair Research Lab in San Angelo, TX, for measurement of AFD and CV. The AFD were determined using the Peyer Texlab FDA 200 System (Lynch and Michie, 1976). Clean fleece weight was calculated as the product of an individual ewe's grease fleece weight and estimated clean wool yield. Relaxed staple length was measured by ruler on the live animal at three locations: point of the shoulder, mid-side and hip. The three values were averaged for each animal to derive a mean staple length. Recorded grease fleece weight was the sum of the sheared fleece weight and the weight of fleece sample. Because not all sheep were shorn at the same age, especially as yearlings, fleece weight and staple lengths were adjusted to a 365-day basis (average age at shearing varied from 336 to 404 days among locations).

Statistical Analyses

The statistical analyses were performed using Harvey's Mixed Model Least-Squares and Maximum Likelihood computer program (1990). The experimental design of this project was a nested split-plot. Therefore, Harvey's statistical model 7 was used because it allows analyses of experimental designs with nested effects that interact with a set of cross-classified fixed effects. BW and fleece characteristics were analyzed with fixed effects for sire breeds (FWM, SWM, RAMB) and location (ID, CA, TX, MT). The sire-of-the-ewe effect (n = 18) was considered random, nested within sire breeds and was used as the error term for sire breed effect. The interaction of location by sire within sire breed was used as the error term for the effect of location and the location-by-sire breed interaction. Preliminary analyses suggested that all other first level interactions were not important ($P > 0.10$).

Because most ewes were pregnant at the second shearing (79 to 100%

within a sire breed and location) it was necessary to determine if only pregnant ewes should be included in the statistical analyses. The low number of unbred ewes did not permit statistical testing of differences between bred and unbred ewes within sire breeds. Therefore, preliminary statistical analyses of wool characteristics from ewes that subsequently lambed were conducted to decide whether pregnancy changed the rank or significant differences due to sources of variation using all ewes (bred and unbred). Because most ewes were pregnant there was a large imbalance in the data set with some empty statistical cells. Therefore, it was not practical to use pregnancy status as an effect in the overall model. Least-squares means (LSM) from statistical models using only pregnant ewes and the models including all ewes were compared within sire breeds by Student's t-test. No differences ($P > 0.10$) were found between LSM derived from only pregnant ewes and from all ewes. Therefore, the reported statistical analyses included data from all ewes. Pregnancy has been shown to decrease wool production in the last trimester of pregnancy (Black and Reis, 1979) but its effect in this study could not be adequately determined.

Statistical comparisons of sire breeds were accomplished by contrasting LSM of independent variables using a priori pairwise Student's t-tests. When the interaction of sire breed-by-location was not significant, only the overall means for sire breeds were contrasted.

Because the rams were highly selected within each sire breed, it was of interest to determine differences among sires within their sire breed for wool characteristics. The identity of important differences among rams within a sire breed infers that selection within a sire breed may be as or more important than random selection within a sire breed. This was accomplished by separate statistical analyses for each sire breed. The statistical model for yearling wool characteristics included sire and location as fixed effects. Preliminary analyses suggested the sire-by-location interaction was not significant for wool characteristics. Sire LSM were contrasted within sire breed.

The effect of heterosis on wool production of the crossbred ewes could not be determined because purebred Merino and reciprocal cross populations were not produced. Jones and Napier (1984) found that levels of heterosis between Merino strains for fleece traits were small (0% for fiber diameter, 4% for clean fleece weight). Changes in wool traits resulting from infusion of Merino genes are more likely due to additive genetic effects.

Results and Discussion

The number of ewes varied across years as affected by natural attrition and predation. There were 650 yearling ewes and 563 ewes at two years of age (Table 2). The smaller sample size of the initial RAMB population ($n = 175$) compared with that of FWM ($n = 231$) and SWM ($n = 245$) was attributed to the relatively poor quality of the frozen RAMB semen.

No interactions of fixed effects were significant for BW or wool characteristics; all sire breeds responded similarly across locations ($P > 0.10$). Large differences among locations ($P < 0.01$) were observed for most response variables but are not discussed in detail. Differences among locations were due to many factors that could not be separated for proper explanation. Causes of variation among locations include genetic differences among sheep flocks and differences in management.

Sire breed influenced ewe body weights at both ages ($P < 0.05$; Table 3) with RAMB ewes being the heaviest ($P < 0.01$) and FWM ewes the lightest ($P < 0.05$). Overall, RAMB ewes were approximately 12% heavier than FWM ewes at each age. The average weight of SWM ewes was intermediate to FWM and RAMB ewes ($P < 0.05$). It was determined that the lighter weights of the FWM were not the result of slower growth rates but reflect a smaller mature size. This was inferred from a comparison of lamb carcass characteristics on wethers, half-sibs to the ewes in this study, that showed FWM carcasses were fatter and more physiologically mature than SWM or RAMB carcasses at comparable live weights and ages (Snowder et al., 1998b). In an earlier study, U.S. Merino ewes were 26% heavier than an imported strain of fine-wool Tasmanian Merinos at 2 years of age (Bell et al., 1936).

Wool traits differed among the progeny of the different ram strains (Table 3). Grease fleece weights of FWM and SWM ewes were heavier than those of RAMB ewes ($P < 0.05$). The heaviest fleeces were from SWM ewes and exceeded RAMB fleeces by 15 and 22% and FWM fleeces by 7 and 9% at one and two years of age, respectively. Fleeces from FWM ewes were 8 and 12% heavier compared to RAMB fleeces at one and two years of age, respectively.

Table 2. Number of F1 daughters of Australian Merino and Rambouillet rams by age and location.[a]

	1 year				2 years			
State	FWM	SWM	RAMB	Total	FWM	SWM	RAMB	Total
ID	53	61	39	153	52	61	37	150
TX	55	67	49	171	47	64	43	154
MT	53	45	25	123	44	35	23	102
CA	70	71	62	203	51	62	44	157
Total	231	244	175	650	194	222	147	563

[a] FWM = one-half Australian Merino fine-wool strain; SWM = one-half Australian Merino strong-wool strain; RAMB = purebred Rambouillet (ID, MT, TX) or one-half Rambouillet and one-half Targhee (CA).

The heavier fleeces from SWM crossbred ewes were associated with longer staple lengths (Table 3). It was also visually apparent that ewes from both Merino strains grew fleeces that were more dense than the RAMB ewes. This observation was not quantified. The longest staple lengths were observed in SWM ewes ($P < 0.05$). For yearling ewes, staple length of FWM and RAMB did not differ significantly ($P > 0.10$). However, the average staple length of two-year-old FWM ewes was slightly longer than for RAMB ($P < 0.05$). Staple lengths produced by all sire breeds were considered adequate for marketing as "staple" wool. Bell et al. (1936) also reported longer staple lengths for Australian Merinos compared with U.S. Merinos.

For Y of clean wool fibers, SWM was greater than FWM which was greater than RAMB ($P < 0.05$). Fleeces from FWM and SWM yearling crossbred ewes were higher yielding compared to RAMB fleeces (9 and 15%, respectively). Differences among sire breeds for Y did not change with age (one year old vs. two years old). However, fleeces from two-year-old ewes yielded higher than from yearlings ($P < 0.05$). The efficiencies of cleaning (scouring) and effluent treatment are both increased as clean Y increases. Thus, even though most wool is currently purchased on an clean weight basis, higher yielding wools are increasingly favored by the processing industry. It is also apparent that Y of fleeces from Idaho yearling ewes were considerably lower than those at other locations; this was caused by heavy dirt contamination that occurred between weaning and subsequent shearing when the ewe lambs were in a feedlot adjacent to plowed sandy potato fields subject to frequent strong winds.

Table 3. Least-squares means (LSM) for body weight (BW), fleece weights, yield (Y) and staple length of F1 Australian Merino and Rambouillet-type ewes.[a]

	Yearling ewes			2-year-old ewes		
Trait by location	FWM	SWM	RAMB	FWM	SWM	RAMB
BW, kg						
ID	37.1	38.2	41.5	48.1	50.5	54.8
TX	37.3	37.8	40.2	45.1	46.0	49.3
MT	50.6	54.4	57.6	54.4	54.6	59.9
CA	39.8	41.8	44.7	51.6	54.3	59.0
Overall ± SE	41.2 ± 0.74[b]	43.0 ± 0.74[c]	46.0 ± 0.75[d]	49.8 ± 0.90[b]	51.3 ± 1.00[c]	55.7 ± 1.00[d]
Grease fleece weight, kg						
ID	4.1	4.3	3.7	4.7	5.1	4.4
TX	3.5	4.1	3.6	4.8	4.9	4.1
MT	4.7	5.4	4.5	5	5.5	4.4
CA	4.0	4.2	3.7	4.1	4.3	3.5
Overall ± SE	4.2 ± 0.07[c]	4.5 ± 0.07[d]	3.9 ± 0.08[b]	4.6 ± 0.08[c]	5.0 ± 0.08[d]	4.1 ± 0.08[b]
Y, %						
ID	38.9	45.3	36.1	55.8	58.7	51.6
TX	59.6	58.8	54.1	66.1	68.9	62.1
MT	57.0	59.7	52.1	66.3	69.6	63.9
CA	64.0	67.4	58.8	69	71.9	63.4
Overall ± SE	54.9 ± 0.52[c]	57.8 ± 0.52[d]	50.3 ± 0.58[b]	64.3 ± 0.19[c]	67.3 ± 0.19[d]	60.2 ± 0.20[b]
Clean fleece weight, kg						
ID	1.6	2.0	1.3	2.6	3.0	2.3
TX	2.3	2.4	1.9	3.2	3.4	2.5
MT	2.6	3.0	2.3	3.3	3.8	2.8
CA	2.6	2.8	2.1	2.9	3.1	2.2
Overall ± SE	2.3 ± 0.10[c]	2.6 ± 0.10[d]	1.9 ± 0.10[b]	3.0 ± 0.08[c]	3.3 ± 0.08[d]	2.5 ± 0.08[b]
Staple length, cm						
ID	8.0	8.8	8.1	8.7	9.3	8.6
TX	8.9	9.1	8.7	11.1	11.7	11.0
MT	8.8	9.2	8.8	10.8	11.5	10.8
CA	9.4	10.2	9.2	9.2	9.8	8.5
Overall ± SE	8.8 ± 0.15[c]	9.3 ± 0.15[d]	8.7 ± 0.15[c]	10.0 ± 0.16[c]	10.6 ± 0.16[d]	9.8 ± 0.16[b]

[a] FWM = one-half Australian Merino fine-wool strain; SWM = one-half Australian Merino strong-wool strain; RAMB = purebred Rambouillet (ID, MT, TX) or one-half Rambouillet and one-half Targhee(CA).

[b,c,d] Values with different superscripts in the same row and age group column are different ($P < 0.05$).

Estimated clean fleece weight varied significantly among sire breeds ($P < 0.01$). Clean fleece weights of RAMB ewes were lighter by more than 20 and 30% compared with the clean fleece weights of FWM and SWM ewes, respectively, at both ages. The SWM ewes had clean fleece weights that were 10 to 13% heavier than FWM clean fleece weights. As previously mentioned, the heavier and higher yielding fleeces of the Australian Merino crossbred ewes were associated with longer staple lengths and greater density of wool follicles. Australian fine-wool and strong-wool Merinos have been reported to have 71.7 and 57.1 fibers/mm^2 (Botkin et al., 1988) compared to 32 to 40 fibers/mm^2 for Rambouillet sheep (Rogers, 1994).

The use of FWM rams resulted in an improvement (a decrease) in fiber diameter of 0.5 µm compared to U.S. fine-wool breeds (Table 4). An improvement in fiber diameter of only 0.5 µm suggests that the difference between the Australian fine-wool Merino and the Texas Rambouillet is now smaller than previously reported (Bell et al., 1936). A plausible explanation for the genetic improvement in fiber diameter of the Texas Rambouillet is that a central ram performance test has been conducted at Sonora, TX, for more than 45 years allowing breeders and producers to identify and select rams superior for *(inter alia)* wool traits (Shelton, 1979). AFD was not reduced by breeding SWM rams to U.S. fine-wool breeds. Measures of AFD for SWM and RAMB yearling ewes were not different ($P > 0.05$). For fleeces from two-year-olds, SWM AFD were slightly coarser (0.4 µm) than for RAMB ewes ($P < 0.05$).

The CV of fiber diameter for RAMB ewes were superior (lower) to FWM and SWM ewes ($P < 0.05$) at both ages. It has been noted previously that U.S. wools are more uniform than Australian wools in terms of fiber diameter (Lupton, 1995). A slight decrease in uniformity of fiber diameter was observed with increasing age in the FWM and RAMB ewes but not in the SWM ewes.

Subjective scores for wool face covering were similar among sire breeds but varied widely among locations (Table 5). The latter may be due to differences among ewe flocks or, more likely, differences in scoring methods. In general, none of the groups had much wool on the face. The important observation remains that infusion of SWM or FWM germplasm into U.S. fine-wool populations did not affect face cover score in any of the flocks studied.

Skin folds varied among sire breeds. The FWM ewes had more skin folds than SWM ewes ($P < 0.05$), and RAMB ewes had the lowest skin fold score ($P < 0.05$). A greater number of skin folds in Australian sheep compared with U.S. breeds has been previously observed (Bell et al., 1936; Austin, 1944). This extra skin is also associated with higher wool production in Australian Merino sheep. Skin folds have been shown to have a positive phenotypic and genetic relationship with greasy wool weight; its association with clean wool weight is positive phenotypically but slightly negligible genetically (Turner and Young, 1969). Wool produced on a skin fold (wrinkle) can have a higher fiber diameter and greater variability in fiber diameter than wool produced on a tight skin area (Sutton et al., 1995).

Subjective scores for belly wool covering did not differ among SWM and FWM ewes ($P > 0.05$). Belly wool score was higher (less desirable) for RAMB ewes compared with SWM and FWM ewes (1.6 vs. 1.4; $P < 0.05$). Visual inspection of the FWM and SWM cross ewes (TX) clearly revealed that Merino crossbreeding dramatically increased the quantity

Table 4. Least-squares means (LSM) of average fiber diameter (AFD) and coefficient of variation (CV) of fiber diameter for F1 Australian Merino and Rambouillet-type ewes by age and location.[a]

	Yearling ewes			2-year-old ewes		
Trait by location	FWM	SWM	RAMB	FWM	SWM	RAMB
AFD, µm						
ID	18.7	19	19.2	18.6	19.6	19.3
TX	19.2	19.7	19.7	18.6	19.2	19.3
MT	19.4	20.2	20.2	19.8	20.8	20.5
CA	21.7	22.8	22.3	23.2	24.2	22.9
Overall ± SE	19.8 ± 0.2[b]	20.5±.2[c]	20.3 ± 0.2[c]	20.0 ± 0.2[d]	20.9 ± 0.2[c]	20.5 ± 0.2[b]
CV						
ID	20.4	19.8	18.7	21	20.3	20
TX	18.5	18.7	18.2	19.6	19	18.1
MT	20	19.9	17.8	20.3	19.3	18.7
CA	19.8	20.2	19.3	20.3	19.7	20.3
Overall ± SE	19.7 ± 0.5[c]	19.6 ± 0.5[c]	18.5 ± 0.5[b]	20.3 ± 0.4[c]	19.6 ± 0.4[b]	19.1 ± 0.4[d]

[a] FWM = one-half Australian Merino fine-wool strain; SWM = one-half Australian Merino strong-wool strain; RAMB = purebred Rambouillet (ID, MT, TX) or one-half Rambouillet and one-half Targhee (CA).
[b,c,d] Values with different superscripts in the same row and age group column are different ($P < 0.05$).

and changed the appearance of the crimp in the belly wool. In fact, belly wool produced by the Merino cross ewes was hardly distinguishable from fleece wool in many instances. Unfortunately, this observation was not quantified.

Because sires of dams were highly selected on reported data within their sire breeds, it was meaningful to evaluate progeny phenotypic differences in wool traits among sires within their sire breed. Differences among sires within their sire breed for a wool trait suggest the trait may be improved by selection within the sire breed. The effect of sire within sire breed was significant ($P < 0.05$) for all sire breeds in most wool traits (Table 6), CV of fiber diameter in FWM and SWM fleece weights and staple lengths being the exceptions ($P > 0.10$). Sire differences were observed in all sire breeds for AFD and CV of fiber diameter; superior sires were identified in each sire breed (FWM 2, SWM 6, RAMB 4). CV can also be improved within each sire breed by selection because there were significant differences among sires with sires FWM 3, SWM 1 and RAMB 1 having the lowest CV of fiber diameter. Although overall fleece weights were greater for SWM ewes, there was no difference among sires ($P > 0.10$). However, there was potential to increase fleece weight by selecting within FWM and RAMB sire breeds for superior sires such as FWM 1 and RAMB 4. Staple length can also be improved by selection within sire breed; sires FWM 6, SWM 5 and RAMB 6 had longer staple lengths compared to other sires within their sire breeds ($P < 0.05$).

The comparison of sires evaluated in this study within their sire breed may not be indicative of the true range in variation of fleece characteristics that exist among all potential sires. However, significant variation among sires within sire breed suggests that further genetic improvement in wool characteristics can be made within sire breeds. The large variability in the progeny averages for wool traits among these highly-selected rams indicates that the rams were not as uniform as their reported individual performance suggests and also that progeny test data is a more reliable source of accurate data.

Table 5. Least-squares means (LSM) of subjective scores for face covering, skin folds and belly wool covering of F1 Australian Merino and Rambouillet-type yearling ewes.[a,b]

Trait by location	FWM	SWM	RAMB
Face covering			
ID	2.7	2.6	2.4
TX	1.0	1.0	1.0
MT	2.9	2.9	3.1
CA	2.2	2.0	2.0
Overall ± SE	2.2 ± 0.05	2.1 ± 0.05	2.1 ± 0.05
Skin folds			
ID	2.1	2.0	1.4
TX	2.1	1.8	1.4
MT	2.6	2.6	2.1
CA	2.2	1.9	1.2
Overall ± SE	2.3 ± 0.06[c]	2.1 ± 0.06[d]	1.5 ± 0.07[e]
Belly wool covering			
ID	1.3	1.3	1.5
TX	1.7	1.8	2.0
CA	1.0	1.1	1.3
Overall ± SE	1.4 ± 0.04[d]	1.4 ± 0.03[d]	1.6 ± 0.04[e]

[a] Scores were on a scale of 1 to 4, with "1" representing less expression of the trait.
[b] FWM = one-half Australian Merino fine-wool strain; SWM = one-half Australian Merino strong-wool strain; RAMB = purebred Rambouillet (ID, MT, TX) or one-half Rambouillet and one-half Targhee (CA).
[c,d,e] Values with different superscripts in the same row differ ($P < 0.05$).

Conclusions

From the selected rams used in this study it was concluded that FWM and SWM rams increased fiber production in crossbred populations. In the case of the SWM, this was accompanied by a small increase in AFD while FWM rams generally produced a decrease in AFD compared to RAMB sires. Comparison of sire breed means for wool characteristics suggests that U.S. wool fleece weight and fiber diameter can be improved by crossbreeding Australian Merinos to U.S. fine-wool breeds. However, fleece uniformity (inversely proportional to CV of fiber diameter) may be slightly decreased and mature body size will tend to be lower in animals with Australian Merino breeding.

In the U.S. wool marketing system, the observed differences in AFD, CV, Y and staple length would probably not affect unit prices paid for the wool produced by the three sire breeds. However, estimated gross returns from wool in 1989 would have been approximately $26.45, $29.10 and $22.05/ewe for FWM, SWM and RAMB two-year-olds, respectively. The lower wool prices in 1996 would have resulted in corresponding returns of $14.22, $15.64 and $11.85, respectively.

Producers seeking Australian Merino rams or their semen for breeding are advised to consider all available information including any estimated breeding values (EBV) for important wool characteristics to take advantage of the Australian Merino's wool characteristics and to minimize the negative effects on mature size and variation in fleece fiber diameter.

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Table 6. Least-squares means (LSM) of yearling ewe wool traits within sire breed.

Sire breed	Sire	Number of progeny	Grease fleece weight, kg	Staple length, cm	AFD, µm	CV of fiber diameter, %
FWM[a]	1	38	4.49[b]	8.86[c]	20.3[b]	21.7[b]
	2	29	4.06[c]	8.60[d]	19.0[e]	18.8[d]
	3	43	3.61[d]	7.96[e]	19.5[d]	18.1[d]
	4	47	3.54[d]	8.31[d]	19.9[c]	19.8[c]
	5	40	4.31[b,c]	9.04[c]	19.9[c]	19.4[c]
	6	34	4.27[b,c]	9.51[b]	19.9[c]	19.8[c]
SWM[a]	1	35	4.49	9.42[b]	21.1[b]	17.7[d]
	2	42	4.7	9.44[b]	20.3[c]	19.3[c]
	3	49	4.5	9.41[b]	20.4[c]	20.0[b]
	4	34	4.56	9.11[c]	20.8[c]	19.9[c]
	5	44	4.31	9.45[b]	20.5[c]	18.4[c]
	6	40	4.42	9.00[c]	19.3[d]	22.0[b]
RAMB[a]	1	27	4.47[b]	8.92[c,d]	20.1[c]	16.6[d]
	2	34	3.60[c]	8.19[d]	20.0[c]	18.9[b]
	3	31	3.80[d,e]	8.75[c]	20.1[c]	17.8[c]
	4	21	4.21[b,c]	9.09[b,c]	19.7[d]	19.6[b]
	5	28	3.89[c,d]	8.93[c]	21.0[b]	19.5[b]
	6	23	4.06[c,d]	9.14[b]	20.9[b]	18.5[c]

[a] FWM = one-half Australian Merino fine-wool strain; SWM = one-half Australian Merino strong-wool strain; RAMB = purebred Rambouillet (ID, MT, TX) or one-half Rambouillet and one-half Targhee (CA).

[b,c,d,e] Values with different superscripts within sire breed in the same column differ ($P < 0.05$).

Comparison of U.S. Fine-Wool and Australian Merino F1 Crosses: II. Growth and Carcass Characteristics[1]

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Summary

This study investigated the effects of incorporating genes of two dissimilar Australian Merino types, fine-wool (FWM) and strong-wool (SWM), into different U.S. fine-wool flocks on growth and carcass characteristics of first cross (F1) wether lambs. The F1 wethers were offspring of U.S. fine-wool ewes in four different flocks crossed to one of three ram types: 1) FWM; 2) SWM; or 3) Rambouillet (RAMB). Six rams per sire type were used to produce the F1 lambs. Growth rate of ewe and wether lambs (n = 1391) was measured from birth to weaning. Wethers (n = 355) were slaughtered at approximately 52 kg live weight. Carcass characteristics measured included: hot carcass weight, dressing percentage, leg conformation score, USDA Quality and Yield Grades, back fat depth, longissimus muscle area and percent kidney and pelvic (KP) fat. Statistical analyses were performed for a nested split-plot design. Lambs sired by RAMB rams grew faster than FWM- and SWM-sired lambs ($P < 0.05$). Carcasses from RAMB-sired lambs were the most desirable for leg conformation score, longissimus muscle area, back fat depth and yield grade. Carcasses from lambs sired by FWM rams had higher percentage KP fat and thicker measures of back fat depth than those sired by SWM and RAMB rams ($P < 0.05$). Sire breed did not influence dressing percent or quality grade ($P > 0.10$). It is suggested that Australian fine-wool Merino-cross lambs should be slaughtered at live weights lighter than RAMB-sired lambs to be comparable in fat characteristics to the more desirable RAMB carcasses. Generally, the characteristics of the RAMB-sired lamb carcasses were superior to Merino-sired carcasses.

Key words: crossbreeding, Merino, lamb, carcass, growth.

Introduction

Sheep provide U.S. consumers with two main products: lamb meat and wool. Improving the quality or quantity of one or both of these products can potentially increase consumer demand, raise the value of the raw product, increase producer income and help U.S. sheep producers to better compete with imported products.

The significant increase in wool prices worldwide during the late 1980s was accompanied by importation of Merino rams from Australia, especially by U.S. sheep producers wanting to improve fiber characteristics and production of their sheep. The use of Australian Merino rams in a cross breeding program improved wool production of U.S. fine-wool breeds (Snowder et al., 1998).

In contrast, the effects of modern Australian Merino breeding on U.S. lamb carcass characteristics is generally

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unknown. The smaller mature size of some Australian Merinos compared to U.S. fine-wool breeds suggests that lamb carcass characteristics may be negatively influenced by a Merino infusion. An earlier study of Merino lamb carcasses suggests that Merino/Targhee wether lambs grow more slowly and mature physiologically at lighter weights compared to Targhee lambs (Sakul et al., 1993).

Increases in wool production and income are desirable only if they are not exceeded by losses in income from lamb production. Therefore, a multi-institution research project was organized to investigate the effect of Australian Merino breeding on growth and carcass characteristics of U.S. lambs.

Materials and Methods

The study was conducted at four research locations: U.S. Sheep Experiment Station (Dubois, ID); Montana State University (Bozeman, MT); Texas Agricultural Experiment Station (San Angelo, TX); and Hopland Research and Extension Center, University of California (Hopland, CA). The objectives and breeding protocol of this project were previously described by Snowder et al. (1997).

Generation of Lambs

Growth rate to weaning was measured on 1,001 first cross (F1) lambs of Australian Merino heritage and 390 Rambouillet or Rambouillet/Targhee lambs. The F1 lambs were produced by mating rams of two strains of Australian Merino, fine-wool (FWM) and strong-wool (SWM), to ewes of two U.S. western range breeds, Rambouillet or Targhee, at four different locations. The FWM strain is recognized for relatively high wool production with superior fiber diameters. The six FWM rams used in this study ranged in fiber diameter from 17.3 to 23.6 μm and grew approximately 13 kg of clean wool per year. The SWM strain produces even heavier fleeces which are generally coarser in fiber diameter; the six SWM rams in this study ranged in fiber diameter from 24.1 to 28.1 μm and averaged over 14 kg of clean wool production in a year. Six Rambouillet rams were selected from flocks in Texas to produce control populations at each location.

The 18 rams were bred by artificial insemination or natural mating to Targhee ewes at Hopland (CA) and Rambouillet ewes at Dubois (ID), Bozeman (MT) and San Angelo (TX). Ewes were randomly assigned and exposed to only one ram either artificially or naturally. Age of the ewes at breeding ranged from two to six years. Breeding in Idaho and Texas stations occurred in the fall for spring-born lambs. In California, lambs were born in December.

Matings of Australian Merino rams produced F1 lambs of one-half FWM or SWM and one-half Targhee or Rambouillet. The offspring from the Texas Rambouillet rams were either pure Rambouillet or one-half Rambouillet and one-half Targhee. Lambs with Texas Rambouillet sires were grouped as Rambouillet-type (RAMB).

Lamb Management

Approximately 30 days prior to lambing, ewes at Idaho were divided into small flocks of approximately 300 head and placed in a feedlot pen. The feed ration consisted of chopped alfalfa hay (approximately 2 kg/(head•day) and whole corn grain [0.6 kg/(head•day)]. As the ewes lambed, ewes and lambs were gathered and moved into small single-ewe pens (2.4 m^2) in a lambing barn. All lambs were docked and ram lambs were castrated shortly after birth. At 2 days of age, ewes and lambs were moved outside to larger mixing pens with up to 12 ewe and lamb(s) pairs. At approximately 30 days of age, ewes and lambs were given access to fenced sagebrush grassland pasture. Ewes and lambs were trailed at roughly 60 days of age to high elevation mountain meadow and tall forb grazing communities where they remained under herded conditions until weaning (average age of 115 days). After weaning, wether lambs were adjusted over a 21-day period to a 65% whole corn and 35% pelleted alfalfa ration. Lambs were targeted for slaughter when they reached approximately 57 kg live weight.

At 30 days prior to lambing, ewes at California grazed mature annual pastures and were supplemented approximately 1.0 kg/(head•day) of alfalfa hay. At 10 days prior to lambing, ewes were moved into the lambing shed and fed 1.8 kg/(head•day) of alfalfa hay. Ewes and lambs were shed confined after lambing for 3 to 5 days. While in the lambing shed, ewes were fed approximately 2.7 kg/(head•day) of alfalfa hay for 3 to 5 days. Lambs were docked and males castrated shortly after birth. Post lambing, ewes and lambs were maintained on subclover pastures until weaning at approximately 100 days of age. After weaning, wether lambs were adjusted over a 6-week period to a 60:40 whole corn and pelleted alfalfa diet to which they were provided ad libitum access until slaughter.

Management of ewes and lambs in Montana was similar to that of Idaho. Pregnant ewes were brought into feedlots 30 days prior to lambing with ad libitum access to alfalfa hay and supplemented with 0.6 kg/(head•day) of whole barley grain. Lambing occurred in December and January. At lambing, ewe and lamb(s) were moved into small pens in a lambing barn for 1 to 3 days. Afterwards, ewes and lambs were moved outside to larger mixing pens with other ewes and lambs for approximately 40 days. All lambs were docked and ram lambs were castrated shortly after birth. Ewes and lambs were transported to the Red Bluff Research Ranch (Red Bluff, MT) where they grazed upland range grasses (bluebunch bunchgrass, Idaho fescue) and forbs (rubber rabbitbrush, lupine, western yarrow) until weaning in early September at a mean age of 123 days.

In Texas, pregnant ewes were managed on fenced pasture with access to a salt-limited protein and energy supplement until lambing. At lambing, ewes and lambs were placed in small pens for 1 to 2 days and then returned to smaller pastures. All lambs were docked and males were castrated shortly after birth. During the summer, all ewes and lambs were

managed as one flock and rotated through available grazing pastures. At approximately 100 days of age, the wether lambs were weaned. Wether lambs were adjusted to an ad libitum diet of 13.7% crude protein (CP) and 3.21 Mcal DE/kg based on sorghum grain and peanut hulls. Lambs were fed by sire groups in large open pens until they reached slaughter weight.

Growth rate from birth to weaning was measured on all ewe and wether lambs (n = 1391; Table 1). Carcass measures were taken on a smaller sample of wether lambs (n = 355).

Carcass Measurements

Carcass data were obtained on all available wether lambs at Idaho and Texas and on a random sample of four wether lambs per sire (24 per sire breed group) at California. Target slaughter weight was 57 kg at Idaho and Texas, while equal numbers of lambs were slaughtered at 43, 48, 52 and 57 kg at California. Actual range in slaughter weights was 48 to 62 kg at Idaho, 43 to 60 kg at Texas and 39 to 60 kg at California. The California experiment involved measurement of feed intake and of carcass fatness as determined by specific gravity; those results have been reported elsewhere (Sakul et al., 1993).

Lambs were weighed shortly before slaughter at commercial packing plants. Other data collected included hot carcass weight, dressing percentage, KP fat expressed as a percentage of hot carcass weight, leg conformation score, back fat depth between the 12th and 13th ribs over the longissimus dorsi and USDA Yield and Quality Grades. Longissimus area at the 12th and 13th ribs was observed on 124 lambs at only one location (ID).

Statistical Analyses

The statistical analyses were performed using the Mixed Model Least-Squares and Maximum Likelihood computer program by Harvey (1990). The experimental design of this project was a nested split-plot. Therefore, Harvey's statistical model 7 was used because it allows analyses of experimental designs with nested effects that interact with a set of cross-classified fixed effects. Weaning weight and growth rate were analyzed with fixed effects for sire breed (FWM, SWM, RAMB), location (ID, CA, TX, MT), sex of lamb (ewe, wether), type of rearing (single, twin) and age of dam (2, 3, 4, 5, ≥ 6 years). Sire of lamb (n = 18) was considered a random effect. Sire effect was nested within sire breed and used as the error term for sire breed effect. Age at weaning was treated as a continuous variable. The effect of location by sire within sire breed was used as the error term for location and the location by sire breed interaction. Preliminary analyses showed all other first level interactions were not important (P > 0.10).

Carcass characteristics were analyzed using a model similar to that previously described but age at weaning and three fixed effects were not included. Because only wether lambs were slaughtered, the effect of lamb's sex was not included. Type of rearing (single vs. twin) and age of dam were shown not to be significant effects in preliminary analyses. Hot carcass weight was included as a continuous variable when analyzing the independent carcass variables of percentage KP fat, back fat depth, leg conformation score, USDA Yield and Quality Grade. Hot carcass weight and dressing percentage were analyzed without the covariate of hot carcass weight. Only three locations (ID, TX, CA) reported carcass characteristics. Because longissimus area was measured at only one location (ID), a reduced statistical model was used with only fixed effects for sire and sire breed with sires nested within sire breed and hot carcass weight as a covariate.

Statistical comparisons of sire breeds were accomplished by contrasting least-squares means (LSM) of independent variables using pairwise t-tests. When the interaction of sire breed by location was not significant, only the overall means were contrasted.

Because the sires within sire breeds were highly selected, it was also of interest to determine differences among sires within a sire breed for economically important traits. Differences among sires may indicate that further selection among all possible rams can improve economically important traits such as carcass characteristics. This was accomplished by separate statistical analyses for each sire breed. The statistical model for carcass characteristics included sire and location as fixed effects and hot carcass weight as a continuous variable when appropriate. Preliminary analysis demonstrated that the sire-by-location interaction was not significant for carcass characteristics. Sire LSM were contrasted using pairwise t-tests when sire effect was significant.

Table 1. Number of Australian Merino- and Rambouillet-sired F1 lambs by location.

Sire breed[a]	ID	TX	MT	CA	Total
FWM	120	121	112	146	499
SWM	107	145	96	154	502
RAMB	81	121	57	131	390
Total	308	387	265	431	1,391

[a] FWM = one-half Australian Merino fine-wool strain; SWM = one-half Australian Merino strong-wool strain; RAMB = purebred Rambouillet (ID, MT, TX) or one-half Rambouillet and one-half Targhee (CA).

Results and Discussion

The effect of location was significant for all variables measured; however, the objective of this study was not to compare environments because the base populations also differed in genetic background. The experimental design across locations creates confounding of breeds and data collection procedures within locations. For example, lamb carcasses were evaluated by different graders across locations. Also, the Rambouillet-type breed designation is used for purebred

Rambouillet and Rambouillet/Targhee lambs at different locations. Because breeds and data collection procedures are confounded by location, the effect of sire breed-by-location interaction was important to consider. This interaction was not significant for any independent variables in the preliminary analyses indicating that sire breeds ranked consistently in all locations. Data representing locations are reported within sire breed classifications but are not discussed.

The number of F1 Australian Merino and Rambouillet-sired lambs evaluated in this study are listed by location in Table 1. LSM for weaning weights and growth rates from birth to weaning by location and sire breeds are presented in Table 2. All fixed effects were significant except for the interaction of sire breed by location ($P = 0.36$ for weaning weight, $P = 0.24$ for growth rate). Although there were significant differences in the growth of the lambs due to location, sex of the lamb and age of dam, only the LSM for sire breed-by-location and overall sire breed classifications are reported and discussed.

Obvious differences in growth rates due to location effects were present. Montana lambs grew more slowly and weighed less at weaning than lambs raised at other locations. Differences among locations cannot be fully explained as the cause(s) is(are) most likely confounded with genetic differences among maternal populations, management and nutrition.

Lamb genotypes differed in weaning weights and growth rates. Overall, FWM lambs grew the slowest ($P < 0.01$) while RAMB lambs grew the fastest ($P < 0.01$). Weaning weight and growth rate of SWM lambs were intermediate to FWM and RAMB lambs. This is somewhat surprising because the promotional information provided with the SWM and FWM rams used in this study indicated the mature average body weight (BW) of the selected SWM rams was 13 kg greater than that of the selected FWM rams.

There was no difference ($P = 0.18$) in hot carcass weights or dressing percentages among sire breeds (Table 3). Dressing percentages differed among locations ($P < 0.05$); the lower lamb dressing percentages in Idaho were caused by depriving lambs for a shorter period of time of feed and water prior to slaughter and the carcass weight did not include the kidney and pelvic fat which was included in the carcass weight at Texas and California. Leg conformation scores and longissimus muscle areas are considered to be indicators of muscling characteristics and differed among sire breeds ($P < 0.05$). Rambouillet wether lamb carcasses had higher leg conformation scores and greater longissimus muscle area than FWM lamb carcasses. There were no significant differences between RAMB and SWM lambs for leg conformation scores and longissimus muscle areas, but means tended to consistently favor RAMB-sired lamb carcasses.

Measurements of fatness and quality grade are presented in Table 4. Percentage KP fat and back fat depth were greater for FWM than for SWM and RAMB ($P < 0.05$). Percentage KP fat was 33% greater in FWM than the other sire breeds. Carcasses of SWM and RAMB had similar percentage KP fat ($P = 0.53$), but back fat depth was lower in RAMB ($P = 0.04$).

USDA Yield Grade is determined by back fat depth which can be adjusted for asymmetric carcass fat distribution. Therefore, ranking of lamb sire breeds by yield grade and by back fat depth were identical. Most of the carcasses were evaluated "Choice" for USDA Quality Grade, thus there were no significant differences among sire breeds ($P > 0.18$).

The greater subcutaneous and intraperitoneal fat values of FWM carcasses indicate that these wethers were more physiologically mature than SWM and RAMB wethers when compared at equal carcass weight. Sakul et al. (1993) evaluated the carcass chemical composition of similar sire breeds by specific gravity and determined that on a 23% carcass fat basis, FWM lambs would have to be slaughtered at a live weight 16 kg lighter than RAMB lambs. Other authors also have suggested that FWM crossbred lambs be slaughtered at lighter weights than Rambouillet lambs (Willingham et al., 1992). A lighter slaughter weight for FWM lambs would not be desirable because of preferences by packers for heavier carcasses and U.S. consumers for larger loin chops.

The effect of sire nested within sire breed was highly significant in all

Table 2. Least-squares means (LSM) for weaning weights and growth rates from birth to weaning of Australian Merino- and Rambouillet-sired F1 lambs.[a]

Trait by location	FWM	SWM	RAMB
Weaning weight, kg			
ID	30.7	32.2	33.6
TX	30.0	29.0	30.2
MT	25.3	25.7	27.0
CA	30.4	31.0	31.9
Overall ± SE	29.1 ± 0.1[b]	29.5 ± 0.1[c]	30.6 ± 0.1[d]
Growth rate, kg/day			
ID	0.23	0.24	0.25
TX	0.23	0.22	0.23
MT	0.19	0.19	0.20
CA	0.23	0.24	0.25
Overall ± SE	0.22 ± 0.01[b]	0.23 ± 0.01[c]	0.25 ± 0.01[d]

[a] FWM = one-half Australian Merino fine-wool strain; SWM = one-half Australian Merino strong-wool strain; RAMB = purebred Rambouillet (ID, MT, TX) or one-half Rambouillet and one-half Targhee(CA).

[b,c,d] Values with different superscripts in the same row are different ($P < 0.05$).

statistical models. Therefore, the effect of sire was investigated within sire breed group. Sire effects were not important for carcass characteristics of FWM and RAMB ($P > 0.21$). Hot carcass weight, dressing percentage and quality grade were comparable among SWM sires ($P > 0.10$). Differences among SWM sires for measures related to fat were large and important; one individual ram (Sire 3) was obviously less desirable for some carcass traits (Table 5). The carcasses of offspring from Sire 3 had 41% more kidney and pelvic fat than offspring from Sires 4 and 6 ($P < 0.01$). Also, the back fat depths of carcasses of offspring from Sire 3 were 27% thicker compared to offspring from Sire 1 ($P < 0.01$).

Sheep breeders selecting Australian Merino or Rambouillet rams primarily for improved wool quality and production should realize that lamb carcass characteristics can be improved at the same time by careful genetic selection (Glimp and Snowder, 1989; Wolf et al., 1981).

Conclusions

Although some differences in carcass measures for the three sire breeds evaluated are statistically significant, these differences may not be of great commercial importance at the present time. However, if in the future, a premium is paid for lean carcasses then the U.S. Rambouillet will have a clear advantage when compared to the Australian Merino. Carcass characteristics of Australian Merino sired lambs may be improved by selection for rams superior in wool and carcass traits as observed in lambs sired by SWM rams.

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Table 3. Least-squares means (LSM) of hot carcass weight, dressing percentage, leg conformation score and longissimus muscle area of Australian Merino- and Rambouillet-sired F1 lambs.[a]

Trait by location	Number	FWM	SWM	RAMB
Hot carcass weight, kg				
ID	124	25.0	25.3	25.4
TX	160	27.1	26.6	27.8
CA	71	25.0	24.9	25.2
Overall ± SE	355	25.7 ± 0.25	25.6 ± 0.26	26.1 ± 0.27
Dressing percentage, %				
ID	124	46.8	46.6	46.7
TX	160	52.9	52.4	53.3
CA	71	51.4	50.0	50.4
Overall ± SE	355	50.4 ± 0.40	49.7 ± 0.40	50.1 ± 0.41
Leg conformation[b]				
ID	124	11.0	10.9	11.3
TX	160	11.6	11.7	11.9
CA	71	11.2	11.8	11.7
Overall ± SE	355	11.3 ± 0.09[c]	11.5 ± 0.09[cd]	11.6 ± 0.09[d]
Longissimus area, cm^2				
ID ± SE	124	11.5 ± 0.14[c]	11.9 ± 0.12[cd]	12.9 ± 0.14[d]

[a] FWM = one-half Australian Merino fine-wool strain; SWM = one-half Australian Merino strong-wool strain; RAMB = purebred Rambouillet (ID, TX) or one-half Rambouillet and one-half Targhee (CA).
[b] Leg conformation: 10 = low choice; 11 = average choice; 12 = high choice.
[c,d] Values with different superscripts in the same row are different ($P < 0.05$).

Table 4. Least-squares means (LSM) for percentage kidney and pelvic (KP) fat, back fat depth, USDA Yield and Quality Grades of Australian Merino- and Rambouillet-sired lambs.[a]

Trait by location	Number	FWM	SWM	RAMB
KP fat, %				
ID	124	3.4	2.4	2.5
TX	160	2.9	2.2	2.2
CA	71	5.6	4.4	4.0
Overall ± SE	355	4.0 ± 18[b]	3.0 ± 0.18[c]	2.9 ± 0.19[c]
Back fat depth, mm				
ID	124	6.8	6.5	6.2
TX	160	5.5	5.0	4.5
CA	71	5.4	5.4	4.6
Overall ± SE	355	5.9 ± 0.20[b]	5.6 ± 0.17[c]	5.1 ± 0.21[d]
Yield grade[e]				
ID	124	3.2	3.1	2.9
TX	160	2.6	2.2	2.1
CA	71	3.2	2.8	2.4
Overall ± SE	355	2.9 ± 0.08[b]	2.6 ± 0.08[c]	2.4 ± 0.09[d]
Quality grade[f]				
ID	124	11.3	11.1	11.7
TX	160	10.3	10.1	11.1
CA	71	11.1	11.3	10.2
Overall ± SE	355	10.9 ± 0.06	10.9 ± 0.10	10.8 ± 0.10

[a] FWM = one-half Australian Merino fine-wool strain; SWM = one-half Australian Merino strong-wool strain; RAMB = purebred Rambouillet (ID, TX) or one-half Rambouillet and one-half Targhee (CA).

[b,c,d] Values with different superscripts in the same row are different ($P < 0.05$).

[e] USDA Yield Grade scores from 1 to 5 with lower values representing higher yield of trimmed retail cuts.

[f] USDA Quality Grade: 10 = low choice; 11 = average choice; 12 = high choice.

Table 5. Least-squares means (LSM) for carcass traits of Australian strong-wool Merino sires.

		Carcass trait		
Sire	Number	KP fat, %	Back fat, mm	Yield grade[a]
1	23	3.6[b]	5.5[c]	2.6[c]
2	19	4.5[b]	5.7[c]	2.6[c]
3	30	4.8[b]	7.0[d]	3.4[d]
4	21	3.4[b]	6.4[d]	3.1[d]
5	23	3.6[b]	6.0[bc]	2.8[bd]
6	18	3.4[b]	6.5[bd]	3.2[bd]

[a] USDA Yield Grade scores from 1 to 5 with lower values representing higher yield of trimmed retail cuts.

[b,c,d] Values with different superscripts in the same row differ ($P < 0.05$).

Comparison of U.S. Fine-Wool and Australian Merino F1 Crosses: III. Lamb Production[1]

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Summary

Sheep producers in the United States have expressed interest in the inclusion of Australian Merino sheep in crossbreeding programs with U.S. fine-wool sheep to improve fleece characteristics. The impact on reproduction of the Australian Merino in a crossbreeding program is unknown. Therefore, a cooperative multi-institution research project was initiated to evaluate the reproductive performance of Australian Merino crossbred ewes. First cross (F1) ewes were produced by mating two strains (fine-wool or strong-wool) of Australian Merino rams to one of two U.S. western range breed ewes, Rambouillet or Targhee, at four different locations (ID, MT, TX, CA). Matings produced F1 lambs of one-half fine-wool Merino (FWM) or strong-wool Merino (SWM) and one-half Rambouillet or Targhee. Six Rambouillet rams were selected from flocks in Texas to produce control populations (RAMB). Reproduction was observed on F1 ewes at 2 years (n = 596) and at 3 years (n = 540) of age. Two-year-old RAMB-sired ewes had the highest overall fertility rates (average, 85%) compared with FWM (78%; P = 0.08) and SWM (79%; P = 0.12). At 3 years of age, fertility did not differ among sire breeds (P > 0.10); however, fertility of SWM (87%) was lower compared with FWM (92%; P = 0.09) and RAMB ewes (92%; P = 0.12). The RAMB ewes had higher levels of prolificacy than FWM and SWM ewes. At 2 and 3 years of age, FWM and SWM ewes weaned litters of comparable weights (P > 0.10) but lighter than RAMB ewes (P < 0.05). Litter weights for RAMB ewes were 10 to 12% heavier than the Merino-cross ewes. Large phenotypic variations among and within genotypes suggest that genetic approaches be considered to increase lamb production. When U.S. producers are considering Australian Merinos for improving wool characteristics, they must also consider sire differences for reproductive traits or any economic gains in wool production could be offset by diminished lamb production.

Key words: crossbreeding, Merino, lamb, reproduction, fertility.

Introduction

Sheep producers in the U.S. have shown interest in the inclusion of Australian Merino sheep in crossbreeding programs with domestic fine-wool sheep to improve fleece characteristics. Introduction of a foreign sheep breed into any established and adapted breed can have positive and/or negative consequences on one or all production traits. Currently, lamb production is of greater economic importance than wool production in the U.S. The impact on reproduction of modern Australian Merino sire breeds in a crossbreeding program is unknown. Therefore, a cooperative multi-institution research project was initiated to evaluate the reproductive performance of Australian Merino crossbred ewes in the western region of the U.S.

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Materials and Methods

This study involved four research locations: U.S. Sheep Experiment Station (Dubois, ID); Montana State University (Bozeman, MT); Texas Agricultural Experiment Station (San Angelo, TX); and Hopland Research and Extension Center, University of California (Hopland, CA). The objectives and breeding protocol of this project were previously described by Snowder et al. (1998).

Generation of Ewe Genotypes

First cross ewes (F1) were produced by mating two strains of Australian Merino rams to one of two U.S. western range fine-wool breed ewes (Rambouillet or Targhee) at four different locations (ID, MT, TX, CA). The same six rams from each of the two Australian Merino strains (fine-wool or strong-wool) were bred to Rambouillet (ID, MT, TX) or Targhee (CA) ewes by artificial insemination or natural mating. Mating of Australian Merino strains produced F1 lambs of one-half fine-wool Merino (FWM) or strong-wool Merino (SWM) and one-half Rambouillet or Targhee. Six Rambouillet rams were selected from flocks in Texas to produce control populations at each location. The offspring from the Texas Rambouillet rams were either Rambouillet (ID, MT, TX) or one-half Rambouillet and one-half Targhee (CA). All lambs sired by Texas Rambouillet rams were grouped as Rambouillet-type (RAMB).

The general management of ewe lambs varied by locations. Average age at weaning ranged from 94 to 150 days, depending upon location. The weaned lambs were either managed on fenced pasture, given ad libitum access to alfalfa hay, or fed a limited amount of a pelleted balanced ration. At approximately one year of age, ewes were mixed with older ewe populations and managed on fenced pastures or under herded range conditions.

Breeding of Ewes

Different groups of five to six mature Suffolk rams from the U.S. Sheep Experiment Station were provided to each location for flock mating. The same Suffolk rams were used across years within location. All ewes were exposed to rams at approximately 18 and 31 months of age. The ewes in California were exposed to rams during June while ewes at other locations were exposed to rams in the fall.

Lamb Management

Thirty days before lambing, ewes at Idaho were placed in a feedlot pen and fed chopped alfalfa hay (approximately 2 kg/(head•day) and whole corn grain (0.6 kg/(head•day). As the ewes lambed, ewes and lambs were gathered and moved into small single ewe pens (2.4 m^2) in a lambing barn. At 2 days of age, ewes and lambs were moved outside to larger mixing pens with up to 12 ewe and lamb pairs. At approximately 30 days of age, ewes and lambs were given access to fenced sagebrush grassland pasture. Ewes and lambs were trailed 30 days later to high elevation mountain meadow and tall forb grazing communities where they remained under herded conditions until weaning. The average lamb weaning age was 129 days at first parity and 124 days at second parity.

At 30 days before lambing, ewes at California grazed mature annual pastures and were supplemented with 1.0 kg/(head•day) of alfalfa hay. At 10 days before lambing, ewes were moved into the lambing shed and fed 1.8 kg/(head•day) of alfalfa hay. Ewes and lambs were shed confined after lambing for 3 to 5 days and fed approximately 2.7 kg/(head•day) of alfalfa pellets. Post lambing, ewes and lambs were maintained on subterranean clover/annual grass pastures until weaning. The average age of lambs at weaning was 109 days at first and second parities.

Management of ewes and lambs in Montana was similar to that in Idaho. Ewes were brought into feedlots with ad libitum access to alfalfa hay and supplemented with 0.6 kg/day of whole barley grain. At lambing, ewe and lamb(s) were moved into single animal pens of a lambing barn for 1 to 3 days. Afterwards ewes and lambs were moved outside to larger mixing pens with other ewe and lamb(s) pairs for approximately 40 days. Ewes and lambs were transported to the Red Bluff Research Ranch (Red Bluff, MT) to graze upland range grasses (bluebunch wheatgrass, Idaho fescue) and forbs (rubber rabbitbrush, lupine, western yarrow) until weaning. The average age of lamb at weaning was 130 days at first parity and 121 days at second parity.

In Texas, pregnant ewes were managed on fenced pasture with access to a salt-limited protein and energy supplement until lambing. At lambing, ewes and lambs were placed in small pens for 1 to 2 days and then returned to pasture. Lambs were weaned at an average age of 119 days at first parity and 109 days at second parity.

Data collected at lambing included birth date, birth type, and sex of lamb. All ram lambs were castrated shortly after birth at each location. Fertility (number of ewes lambing per ewe exposed and alive at lambing) and prolificacy (number of lambs born per ewe lambing) were recorded for sire breed classification. At weaning, date and lamb weight were recorded. Litter weight weaned was calculated for ewes with a live lamb(s).

Some locations experienced lamb losses due to predation (CA, TX). Because all ewes and their lambs were managed as one flock at each location, the effect of predation was assumed to be random. Therefore, analyses of litter weight weaned was limited to data from ewes that reared at least one lamb.

Statistical Analyses

The statistical analyses were performed using the Mixed Model Least-Squares and Maximum Likelihood computer program by Harvey (1990). The experimental design of this project was a nested split-plot design. Data were analyzed for nested effects interacting with cross-classified fixed effects. The statistical models for fertility and prolificacy included fixed effects for ewes' sire breed (FWM, SWM, RAMB) and location (ID, CA, TX, MT). Sire of dam (n = 18) was considered a random effect. Sire of dam effect was nested within sire breed and used as the error term for sire breed effect. The interaction of location by sire-of-dam nested within sire breed was used as the error term

for location and the location-by-sire breed interaction. Preliminary analyses had shown that all other first level interactions were not important ($P > 0.10$).

Litter weight weaned was analyzed by a statistical model similar to that used for fertility and prolificacy. Litter weight weaned for a dam is the sum of the lamb weaning weights corrected for sex. Type of rearing (single, twin) was included in the correction model so that estimates of correction for sex effect would be unbiased by type of rearing. Therefore, litter weight weaned for the dam is the sum of the lamb weaning weights corrected for sex. Least-square means (LSM) for litter weight were obtained from a statistical model with fixed effects and interactions for sire breed, sire of dam nested with sire breed, location, location-by-sire breed and location-by-sire of dam nested within sire breed. Age at weaning was considered a covariate in the model. The lamb's sire effect was not considered because it is confounded with location.

An inherent confounding of year and age of the ewe (all ewes were born in the same year) did not allow for separation of these effects. Therefore, statistical analyses did not include year or age of ewe effects but were conducted within age of ewe. Differences among sire breeds at a given age for reproductive traits were of greater importance than testing differences due to ewe ages which could not be accurately described due to confounding with year effects.

Statistical comparisons of sire breeds were accomplished by contrasting LSM of independent variables using pairwise t-tests. When the interaction of sire breed by location was not significant ($P \leq 0.05$), only the overall means were contrasted.

Because the sires of the dams within sire breeds were highly selected for their wool traits, it was of interest to determine if sufficient genetic variation for lamb production traits existed among sires so that selection may be used to improve reproductive traits. A statistical model to estimate sire-of-dam LSM for reproductive traits was performed within each sire breed. Sire of dam and location were fixed effects when evaluating fertility and prolificacy. The covariate of lamb age at weaning was added for analyzing litter weight weaned. Preliminary analysis showed the sire-of-dam-by-location interaction was not significant ($P > 0.10$) for the lamb production traits analyzed. LSM were contrasted using pairwise t-tests when the sire-of-dam effect was significant ($P < 0.05$).

Results and Discussion

There were 596 F1 and purebred ewes at 2 years of age and 540 at 3 years of age (Table 1). Sire breed of ewe responses for fertility and prolificacy did not differ among locations at 2 or 3 years of age ($P = 0.74$ and 0.45, respectively). Locations did vary in 2-year-old ewe fertility and prolificacy ($P < 0.01$; overall location LSM are not shown). The lower values for fertility and prolificacy in California of 2-year-old ewes is related to the breeding season used in California which was June while other locations (ID, MT, TX) exposed ewes to rams during the fall. Fertility of 2-year-old ewes was higher in Idaho and Montana flocks compared with Texas and California flocks (Table 2). Two-year-old RAMB ewes had the highest overall fertility rates (85%) compared to FWM (78%; $P = 0.08$) and SWM (79%; $P = 0.12$). At 3 years of age, there were no significant differences among sire breeds for fertility; however, fertility of SWM (87%) was lower than FWM (92%; $P = 0.09$) and RAMB ewes (92%; $P = 0.12$).

Prolificacy rates were influenced by location ($P < 0.01$; overall location LSM are not shown) and ewes' sire breed ($P < 0.05$). Prolificacy rates of 2-year-old ewes were generally higher in Idaho and Montana compared with Texas and California. At 3 years of age, Texas ewes generally had lower prolificacy rates than other locations. The ranking of sire breeds for prolificacy were consistent across ewe age or year; RAMB ewes had higher ($P < 0.05$) levels of prolificacy than FWM and SWM ewes. FWM ewes had lower prolificacy rates than SWM and RAMB ewes. Prolificacy increased with parity as expected (Bradford, 1985).

The ability to raise a lamb(s) successfully may be quantified by the total litter weight weaned. Total litter weight weaned is positively correlated with fertility, prolificacy, milking performance, lamb survival, lamb growth rate and maternal ability (Snowder et al., 1996). Litter weight weaned was influenced by location ($P < 0.01$; overall location LSM are not presented) and sire breed ($P < 0.05$) effects. The ranking of sire breeds did not differ ($P > 0.10$) among locations (Table 3). Highest litter weights weaned among sire breeds and ages were observed in Idaho. At 2 and 3 years of age, FWM and SWM ewes weaned litters of comparable weights ($P > 0.10$) but lighter than RAMB ewes ($P < 0.05$). Litter weights for RAMB ewes were 10 to 12% heavier, a very significant economic factor to consider.

Sires of dams were highly selected within their sire breeds for wool characteristics. Therefore, it was important to evaluate phenotypic differences in

Table 1. Numbers of F1 Australian Merino- and Rambouillet-sired ewes by location at two (and three) years of age.

Sire breed[a]	ID	TX	MT	CA	Total
FWM	52 (47)	49 (47)	40 (40)	61 (53)	202 (187)
SWM	61 (57)	67 (64)	39 (35)	66 (58)	233 (214)
RAMB	38 (32)	46 (41)	23 (23)	54 (43)	161 (139)
Total	151 (136)	162 (152)	102 (98)	181 (154)	596 (540)

[a] FWM = one-half Australian Merino fine-wool strain; SWM = one-half Australian Merino strong-wool strain; RAMB = purebred Rambouillet (ID, MT, TX) or one-half Rambouiller and one-half Targhee (CA).

reproductive traits among sires within a sire breed to decide if selection within a sire breed might be a possibility for improving reproductive traits. Therefore, the effects of sire-of-dam were investigated within sire breed classification. Location was an important effect ($P < 0.01$) on all reproductive traits but these are not discussed in detail because the intent of the project was to compare sire breeds under varying production systems and locations. The fact that the interaction between sire breed and location was not significant confirms that the rank of performance among sire breeds did not differ across locations. Ewe fertility and prolificacy among FWM and RAMB sires did not differ ($P > 0.22$). However, sires of SWM ewes varied in daughters' reproductive traits (Table 4). The daughters from Sires 1 and 3 had higher fertility and prolificacy rates than ewes from other sires.

The RAMB sires did not differ in their daughters' litter weight weaned ($P > 0.60$). Differences among SWM sires for their daughters' litter weight weaned approached levels of significance ($P = 0.08$ and 0.11 at 2 and 3 years of age, respectively) but were not reported. The FWM sires did not differ in their daughters' performance for litter weight weaned at 2 years of age ($P = 0.56$) but sire differences were significant at 3 years of age (Table 5). Litter weights from ewes of Sire 5 were 19% heavier ($P < 0.05$) than the average of the other sires.

Litter weight weaned is the most economically important trait measured for many producers because it represents the actual weight of product being marketed on a per ewe basis.

Genotypic variation among and within sire breeds suggests that genetic approaches for increasing lamb production might be successful. Selection of rams from three sire breeds (FWM, SWM, RAMB) for wool characteristics did result in noticeable differences among ewes for reproduc-

Table 2. Least-squares means (LSM)for fertility and prolificacy of F1 Australian Merino- and Rambouillet-sired ewes by age of ewe at lambing and location.

	2 years			3 years		
Trait/location	FWM[a]	SWM[a]	RAMB[a]	FWM[a]	SWM[a]	RAMB[a]
Fertility, %						
ID	96.2	96.7	100.0	94.6	89.2	100.0
TX	61.2	61.2	73.9	92.2	91.6	93.0
MT	97.5	92.3	95.7	90.9	78.8	83.1
CA	57.4	66.7	72.2	90.4	88.6	90.5
Overall ± SE	78.1 ± 2.7[b]	79.2 ± 2.6[b]	85.4 ± 3.2[b]	92.0 ± 2.4[b]	87.0 ± 2.3[b]	92.1 ± 2.8[b]
Prolificacy, %						
ID	126	136	139	140	162	159
TX	107	125	140	112	114	137
MT	134	121	157	124	126	142
CA	107	106	111	130	137	137
Overall ± SE	119 ± 5.9[b]	122 ± 5.6[b]	137 ± 5.9[c]	127 ± 6.0[b]	135 ± 6.1[b]	144 ± 6.4[c]

[a] FWM = one-half Australian Merino fine-wool strain; SWM = one-half Australian Merino strong-wool strain; RAMB = purebred Rambouillet (ID, MT, TX) or one-half Rambouillet and one-half Targhee(CA).
[b,c] Overall values with different superscripts within age of ewe and same row are different ($P < 0.05$).

Table 3. Least-squares means (LSM) for total litter weight weaned (kg) of F1 Australian Merino- and Rambouillet-sired ewes by age of ewe and location.[a]

	2 years			3 years		
Location	FWM	SWM	RAMB	FWM	SWM	RAMB
ID	38.9	42.6	45.4	54.3	54.5	57.3
TX	32.6	34.3	34.5	32.9	34.0	37.7
MT	36.5	35.4	39.2	40.5	42.1	49.4
CA	31.9	32.4	34.9	29.8	30.1	32.1
Overall ± SE	35.0 ± 1.21[b]	36.2 ± 1.8[b]	38.5 ± 1.9[c]	39.4 ± 1.1[b]	40.2 ± 1.1[b]	44.1 ± 1.2[c]

[a] FWM = one-half Australian Merino fine-wool strain; SWM = one-half Australian Merino strong-wool strain; RAMB = purebred Rambouillet (ID, MT, TX) or one-half Rambouillet and one-half Targhee (CA).
[b,c] Values with different superscripts in the same row and age group differ ($P < 0.05$).

tive traits. This study also identified significant differences among rams within the FWM breed. Therefore, breeders selecting rams for superior wool characteristics may also benefit from additional selection of rams with more desirable breeding values for reproduction.

Conclusions

Selection of FWM or SWM sires based only on improved wool characteristics can decrease prolificacy and total litter weight weaned per ewe in U.S. fine-wool flocks. This study clearly shows that sire differences for reproductive traits must be considered concurrently with wool traits or any economic gains in wool production could be offset by diminished lamb production.

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Table 4. Least-squares means (LSM) of ewe fertility and prolificacy rates by Australian strong-wool Merino sire of ewe and age of ewe.

		Fertility		Prolificacy	
Sire	Number[a]	2 years	3 years	2 years	3 years
1	35	94.4[b]	98.2[b]	138[b]	141[b]
2	40	71.4[c]	85.2[c]	117[c,d]	116[c,d]
3	44	87.5[d]	95.4[b]	122[c,d]	149[b]
4	30	77.0[c]	89.3[c]	111[d,e]	113[c]
5	42	70.0[c]	84.1[c]	119[c,d]	105[c]
6	38	69.0[c]	85.1[c]	105[c]	123[d]

[a] Number of 2-year-old ewes present at lambing. There were 14 less 3-years-old ewes .
[b,c,d,e] Values with different superscripts in the same column differ ($P < 0.05$).

Table 5. Sire least-squares means (LSM) of litter weight weaned of Australian fine-wool Merino ewes.

Sire	Number	3 years
1	21	38.2[a]
2	14	38.3[a]
3	22	38.2[a]
4	35	39.1[a]
5	25	45.1[b]
6	22	35.4[a]

[a,b] Means with different superscripts within a column differ ($P < 0.05$).

Effects of Electrical Stimulation and Conditioning, Calcium Chloride Injection and Aging on the Acceptability of Callipyge and Normal Lamb

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Summary

We determined the tenderization of normal (n = 22 lambs) and callipyge (n = 16 lambs) loin chops associated with low-voltage electrical stimulation of the carcasses followed by conditioning at 27 °C for approximately 1 hour postmortem (time for muscle to reach pH < 6.0; ESC), calcium chloride injection (0.3% w/w in aqueous solution to an amount equal to 10% of the fresh meat weight) into the loins at 24 hours after death (CCI), and postmortem aging at 2 °C for up to 22 days. After 15 days of aging, chops from normal carcasses that had not been electrically stimulated had the lowest ($P < 0.05$) shear values (2.5 kg) among the chops from the normal group, while ESC+CCI-treated chops had the lowest ($P < 0.05$) shear values (3.2 kg) among the callipyge group. Shear values for chops from callipyge lambs were always at least 1 kg higher than normal lambs for each treatment group. A consumer panel assigned acceptable sensory scores to 15-day aged ESC+CCI-treated callipyge chops, but their scores were lower ($P<0.01$) than those of 15-day aged nontreated normal chops for texture, flavor and juiciness. In contrast, the appearance of retail-packaged callipyge chops was preferred to that of normal chops, probably due in part to their larger loin eye area.

Key words: callipyge, lamb, meat, calcium chloride, electrical stimulation.

Introduction

Inherited muscular hypertrophy in sheep is associated with the callipyge gene located on ovine chromosome 18 (Cockett et al., 1994). The important economic benefits of muscle hypertrophy include increased size of the muscles of the loin and leg, leaner carcasses and increased feed efficiency (Jackson et al., 1997a,b,c; Snowder et al., 1994a,b). Unfortunately, the loin chops from callipyge animals have been shown to be significantly less tender than loin chops from normal lambs (Jackson et al., 1994; Rawlings et al., 1994; Koohmaraie et al., 1995).

The objective of this research was to determine if post-slaughter treatments could be employed, individually or in combination, to produce tender callipyge loin chops. Post-slaughter technologies with the potential to increase meat tenderness that were included in this investigation were low-voltage electrical stimulation combined with a conditioning period (ESC) of 27 °C for approximately 1 hour postmortem (Solomon and Lynch, 1991), calcium chloride injection into the loins at 24 hours postmortem (CCI) and aging the loins at 2 °C for up to 22 days postmortem. Electrical stimulation using low voltage can be effective in producing tender meat (Morton and Newbold 1982; Eikelenboom 1993; Aalhus et al., 1994) and may be easily adapted to the smaller processing facilities. Low-voltage stimulation (Solomon and Lynch, 1988), especially low-voltage stimulation followed by a carcass conditioning (ESC) period (Solomon and Lynch, 1991), have

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proven to be effective methods for tenderizing lamb. Similarly, prerigor infusion of calcium chloride has proven to be an effective method to accelerate tenderization of normal lamb (Koohmaraie et al., 1989; Koohmaraie and Shackelford, 1991). Injection of calcium chloride at 24 hours postmortem tenderizes normal and callipyge lamb (Clare et al., 1997) and may be more convenient for processors than early postmortem injection times. Postmortem aging is the traditional method for tenderizing meat by allowing time for the endogenous proteases to work (Dransfield, 1993).

In this study, Experiment 1 determined which treatments of ESC and CCI (alone or in combination) provided the most tender normal and callipyge loin chops after different periods of aging. Tenderness was evaluated by measuring Warner-Bratzler shear. Nontreated normal chops and ESC+CCI-treated callipyge chops tended to have the lowest shear force values among the normal and callipyge chops, respectively. Thus, sensory characteristics of nontreated normal chops were compared with those of ESC+CI-treated callipyge chops in Experiment 2.

Materials and Methods

Animal Selection

To produce animals for this project, normal Columbia ewes were mated with heterozygous callipyge rams (1/4 Dorset x 3/4 Columbia). From 3 weeks of age until slaughter, the progeny were visually classified as "callipyge" or "normal" based on muscle conformation in the hind saddle and legs. The wether lambs were scored by the same two people every two weeks according to degree of muscle hypertrophy with 1 = definite normal, 2 = most likely normal, 3 = most likely callipyge and 4 = definite callipyge. Lambs were sheared a month before slaughter to facilitate grading. The scores were averaged over the judging period and animals exhibiting mean scores between "2" and "3" were eliminated from the study.

Experiment 1 (Shear Values)

Normal (22) and callipyge (16) wether lambs (about 10 months old, 51 to 55 kg live weight) were slaughtered at Utah State University under USDA inspection guidelines. Eleven normal and eight callipyge intact carcasses were electrically stimulated, immediately after death and decapitation, using a stimulator unit producing a rectangular wave of 21 V, 60 Hz, 0.25 amp alternating current (model BV80 Low Voltage Stimulator; Jarvis Products, Middletown, CT). Stimulation was applied in six impulses of 20 seconds each, with 5 to 10 seconds gaps to allow the carcass to relax between impulses. Nonstimulated carcasses were placed directly into the cooler. Stimulated carcasses were conditioned at 27 °C until pH < 6.0 was obtained in the longissimus, which usually was within 1 hour of stimulation, and were then placed in the cooler. The pH was confirmed to be less than 6.0 by inserting a pH probe 2.5 cm into the center of the longissimus at the 12^{th} to 13^{th} rib location.

The loin from each carcass (ESC and nonstimulated) was removed at 24 hours postmortem (bone-in). Each loin was split through the midline of the backbone using a bandsaw. One half of each loin was injected with an aqueous solution of 0.3% calcium chloride (CCI) to an amount equal to 10% of the fresh loin weight. A multi-needle stitch pump (Fomaco model FGM 2020S; Robert Reiser Distributors, Canton, MA) was used. After a 4-hour equilibration period, two chops (1.90 cm thick) were removed (using a band saw) from the posterior end of each half-loin loin, double-wrapped in plastic freezer film and white butcher paper and stored at -34 °C.

The remainder of each half-loin was divided into three equal sections and vacuum packaged after a CO_2 flush using a Multivac (model 855F; Multivac Inc., Kansas City, MO) form-fill seal, vacuum-packaging machine. The packaging films were Cryovac (W.R. Grace & Company, Duncan, SC) R169B film [O_2 transmission rate of 1 $cm^3/(645\ cm^2 \cdot 24$ hours) at 0% relative humidity and 23 °C and water transmission rate of 0.4 $g/(645\ cm^2 \cdot 24$ hours) at 100% relative humidity and 23 °C] for the pocket and R665B film [O_2 transmission rate of 1 $cm^3/(645\ cm^2 \cdot 24$ hours) at 0% relative humidity and 23 °C and water transmission rate of 0.5 $g/(645\ cm^2 \cdot 24$ hours) at 100% relative humidity and 23 °C] for the top.

Loin sections were stored at 2 °C until 8, 15 or 22 days post-slaughter (aging period). Equal numbers of each half-loin section (anterior to posterior) were assigned to each of the aging periods so that loin position was not a confounding factor. At the end of the aging period, two chops were cut from each section. The chops were double-wrapped in plastic freezer film and butcher paper and stored frozen at -34 °C for about a month. Chops were thawed at 4 °C for 24 hours and grilled to 68 °C internal temperature. Temperature was monitored by placing a thermometer into the center of each of the chops. Shear values were measured using a Warner-Bratzler shear device on three 1.27-cm cores removed perpendicular to each chop.

This created a 2 (normal phenotype vs. callipyge phenotype) x 2 (ESC vs. no ESC) x 2 (CCI vs. no CCI) x 4 (1, 8, 15, 22 days of aging) = 32 factorial arrangement in a split, split-plot design. The data were analyzed by MANOVA (STATISTICA/Mac program; StatSoft, Inc., Tulsa, OK) with phenotype and electrical stimulation as between-group factors and calcium injection and days of aging as within-group factors. Mean shear values of treatment groups were compared using Duncan's multiple range test.

Experiment 2 (Sensory Panels)

Chops from 15-day aged nontreated normal loins were compared to chops from 15-day aged ESC+CCI-treated callipyge loins using a sensory panel. These treatments were chosen because in Experiment 1 they produced the lowest shears among the normal and callipyge chops, respectively. Lambs (n = 10 normal wethers; n = 10 callipyge wethers) were slaughtered at about ten months of age and 51 to 55 kg live weight. Slaughter and processing procedures followed those

described for Experiment 1, except that the half-loins were left intact for aging. After aging, the entire half-loins were double-wrapped and stored frozen at -34 °C for 1 to 2 months until they could be evaluated for sensory characteristics.

For each of 10 sessions on separate days, the half-loins from a single normal and a single callipyge lamb were removed from the freezer. Each half-loin was cut while frozen into 10 chops (1.90 cm thick). This resulted in 20 normal chops and 20 callipyge chops for each session. The normal and callipyge chops were then paired so that they were from the same relative position in the loins. The chops were thawed at 4 °C for 4 hours and then grilled to 71 °C internal temperature. Three samples of approximately 1 x 2 cm were cut from the center of each chop. A maximum of 60 panelists were served a callipyge and a normal sample at each of 10 sessions. Thus, chops from lambs of each phenotype were evaluated 579 times during the course of the study (i.e., 57 to 60 panelists at each of the 10 sessions). The panelists were untrained consumers solicited by advertising the sessions with posters placed on the Utah State University campus in the Nutrition and Food Sciences building and the Dairy Bar. Half the panelists evaluated a callipyge sample first and half evaluated a normal sample first. Samples were evaluated using a hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely) for texture, flavor and juiciness.

Before tasting, the panelists also rated uncooked chops for appearance in standard retail packages (white styrofoam tray overwrapped with clear plastic stretch film). All chops were trimmed to 3 mm of external fat. Typically, two callipyge chops were of approximately equal weight to three normal chops (reflecting the greater loin eye area of callipyge lamb) and were packaged as such so that the displayed packages were of approximately equal weight and total price. Panelists were asked which package they would purchase if they were to buy lamb chops. Sensory results were analyzed by ANOVA (MINITAB Statistical software; State College, PA).

Results and Discussion

Experiment 1

The pooled mean shear force values of cooked loin chops by main effects are presented in Table 1 and portray the magnitude of the significant effects of phenotype, postmortem aging and CCI treatment on shear values. The overall ANOVA identified only one significant ($P < 0.05$) interaction (three-way for phenotype, CCI and aging). However, comparisons of the pooled means by treatment groups (Table 2) suggested the possibility of other interactions and are discussed in the following paragraphs.

Cooked callipyge chops had higher shear force values than normal chops (Table 1). This is consistent with other observations of decreased sensory (Jackson et al., 1994; Rawlings et al., 1994) and instrumental (Koohmaraie et al., 1995) tenderness of callipyge chops. The decreased tenderness of callipyge chops may be related to the altered histochemical and compositional characteristics of callipyge longissimus muscle that include a greater predominance of fast-twitch glycolytic fibers, a higher protein concentration and a lower fat content (Carpenter et al., 1996). More specifically, the cause of toughness in callipyge loin chops may be due to the higher levels of calpastatin found in callipyge longissimus (Koohmaraie et al., 1995; Clare et al., 1997).

As expected, aging decreased shear force values (Table 1). However, the mean decrease in shear values between days 1 and 15 after slaughter was greater ($P < 0.05$) for the nontreated normal chops (2.4 kg) than for the nontreated callipyge chops (1.4 kg). Tenderization with aging occurs in most muscles largely as the result of proteolysis by the calpains, a family of calcium-activated proteases (for reviews see: Dransfield, 1993; Koohmaraie, 1992 and 1994). Because proteolysis by the calpains is

Table 1. Pooled mean shear force values of cooked lamb loin chops by main effect.[a]

Effect and grouping	Mean shear force, kg	Significance, P value
Phenotype		
Normal	3.2	< 0.001
Callipyge	4.6	–
Days of aging[b]		
1	5.3	< 0.001
8	3.8	–
15	3.4	–
22	3.0	–
ESC[c]		
no	3.8	0.41
yes	4.0	–
CCI[d]		
no	4.1	0.003
yes	3.7	–

[a] Chops were cooked to 71 °C internal temperature and shear values determined on 1.27-cm cores using a Warner-Bratzler shear device.
[b] Days of aging = total days after slaughter; loin sections were stored, vacuum-packaged, at 2 °C beginning 1 day post-slaughter. Group means are all significantly different ($P < 0.05$; Duncan's multiple range test).
[c] ESC = low voltage electrical stimulation and conditioning at 27 °C until pH < 6.0.
[d] CCI = injection of calcium chloride (0.3% aqueous solution) to 10% of loin weight at 1 day after slaughter.

inhibited by calpastatin, the lesser tenderization of callipyge loin chops during aging may have been due to the greater calpastatin activity in callipyge muscle (Koohmaraie et al., 1995; Clare et al., 1997). Similarly, aging has been shown to be less effective in tenderizing hypertrophied muscles from lambs fed a ß-agonist (Kretchmar et al., 1990; Koohmaraie and Shackelford, 1991), also likely a result of the higher levels of calpastatin in muscles from lambs fed a ß-agonist (Higgins et al., 1988; Kretchmar et al., 1990; Koohmaraie et al., 1991).

Electrical stimulation and conditioning had no overall effect on shear force values (Table 1). This was unexpected since low-voltage ESC (Solomon and Lynch, 1988) or low-voltage ESC followed by a conditioning period (Solomon and Lynch, 1991) have proven to be effective methods for tenderizing normal lamb. In those reports, the tenderizing effects of ESC and conditioning were attributed to prevention of cold shortening with ESC accelerating rigor so that muscles did not shorten upon chilling. Callipyge longissimus has been reported as susceptible to cold shortening (Clare et al., 1997). In our study, however, the failure of ESC to decrease shear values suggested that cold shortening may not have been a problem in either normal or callipyge lambs.

Comparison of average shear values of treatment groups suggested that ESC had different effects on the normal lambs as compared to the callipyge lambs (Table 2). Electrical stimulation and conditioning increased the average shear values of normal chops, but had no effect on shear values of callipyge chops. In the absence of cold shortening, ESC (Pomier et al., 1987; Dransfield et al., 1992b) or conditioning (Hertzman et al., 1993) can toughen muscle by promoting rigor (heat) shortening. Combining low-voltage stimulation with slower-than-normal chilling can cause toughening of beef (Unruh et al., 1986). Normal chops may have been more susceptible to toughening because stimulation induces more rigor shortening in oxidative muscles than in glycolytic muscles (Hertzman et al., 1993), and because normal longissimus has more oxidative fibers than does callipyge longissimus (Koohmaraie et al., 1995; Carpenter et al., 1996). Toughening may also have been associated with the rapid postmortem pH decline of ESC longissimus muscles to pH < 6.0 during conditioning (approximately 1 hour). Rapid rates of pH decline are correlated with decreased tenderness independent of shortening (Smulders et al., 1990). Tenderness is highest when glycolysis proceeds at an intermediate rate (corresponding in beef to pH of about 5.9 at 3 hours after death) and declines at both slower and faster rates of glycolysis. At present, it is not known how the relationship between pH decline and tenderness varies with muscles of different fiber type composition, such as normal and callipyge chops.

The overall effect of CCI was a decrease in shear values (Table 1). Infusion or injection of calcium chloride is believed to increase tenderization by activating the calpains, especially calpain II (approximately 200 to 300 µm) which has a higher calcium requirement than calpain I (10 mM) and which is active for a much longer period postmortem (for reviews see: Croall and Demartino, 1991; Koohmaraie, 1992a and 1994). The level of calcium used here (27 mM added to increase meat weight by 10%) was less than that commonly employed (150 to 300 mM added to increase meat weight by 10%), but it was theoretically sufficient to create a calcium level in meat that would activate calpain II. The minimum use-levels of calcium chloride necessary to achieve tenderization of meat are not well established and the effective level likely varies with factors such as the manner of calcium addition, pre- versus post-rigor addition and post-mortem handling of the carcass. In one report where a minimum use-level has been indicated for lamb, solutions of 150 and 300 mM calcium chloride, but not 75 mM calcium chloride, caused tenderization of lamb when arterially infused into the carcasses to 10% of the live weight (Koohmaraie et al., 1989). Thus, it is of some interest that the low level of calcium chloride employed here caused tenderization. As compared to arterial infusion, our injection technique was possibly more efficient at distributing calcium both into the muscle itself and into the muscle compartments containing the

Table 2. Pooled mean shear force values of cooked lamb loin chops by treatment group.[a]

Treatment			Mean shear, kg[b]	
Phenotype	ESC[c]	CCI[d]	Pooled means for all days of aging[e]	15 days of aging[e]
Normal	no	yes	2.7[f]	2.4[f]
Normal	no	no	2.9[f,g]	2.3[f]
Normal	yes	yes	3.2[g]	3.1[g]
Normal	yes	no	3.7[h]	3.1[g]
Callipyge	yes	yes	4.2[i]	3.2[g]
Callipyge	no	yes	4.6[i,j]	4.0[h]
Callipyge	no	no	4.8[j]	4.8[i]
Callipyge	yes	no	4.9[j]	4.7[i]

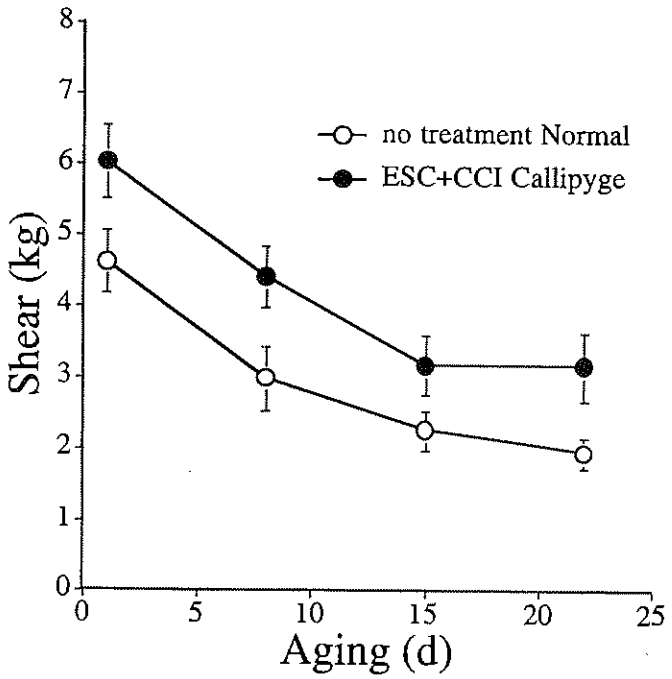
[a] Chops were cooked to 71 °C internal temperature and shear values determined on 1.27-cm cores using a Warner-Bratzler device. Treatment groups are ranked in order of increasing mean shear values pooled for all aging days (1, 8, 15 and 22 days post-slaughter).
[b] Average SEM for all groups was 0.22 kg.
[c] ESC = low-voltage electrical stimulation and conditioning at 27 °C until pH < 6.0.
[d] CCI = injection of calcium chloride (0.3% in aqueous solution) to 10% of loin weight at 1 day after slaughter.
[e] Days of aging = total days after slaughter; loin sections were stored, vacuum-packaged, at 2 °C beginning 1 day post-slaughter.
[f-j] Values in the same column sharing a superscript letter are not significantly different (P < 0.05; Duncan's multiple range test).

calpains. Although a problem with purge could possibly be expected when cutting the loins into sections at 4 hours after injection, very little purge was observed before packaging or during storage. Optionally, our postmortem handling of the carcasses may have enhanced the tenderizing effects of calcium from the holes produced in the meat from the needles.

Between-group comparisons suggested that the tenderizing effect of CCI was dependent on whether or not the carcasses had undergone ESC (Table 2). Calcium chloride injection did not affect shear values of normal or callipyge chops from nonstimulated carcasses, but CCI decreased shear values in both normal and callipyge chops from ESC-treated carcasses. We hypothesize two possible mechanisms by which ESC may function to enhance tenderization after CCI, especially when using a low concentration of calcium as was employed in this study. First, ESC may affect the structural integrity of the muscle so that calcium can more easily equilibrate into the same compartment with the calpains. If calcium is not excluded from the muscle compartment that contains calpain, the equilibrium concentration of calcium obtained by our injection of 0.3% calcium chloride should be sufficient to activate calpain II. Second, ESC may alter the components of the calpain system such that the calcium level required to stimulate proteolysis is lowered. Electrical stimulation and conditioning produce early postmortem conditions that activate calpain I, which is capable of lysing itself, calpain II and calpastatin (Dransfield, 1992, 1993 and 1994; Dransfield et al., 1992a,b; Koohmaraie, 1992b). Lysis of calpastatin removes its inhibitory effect on calpain activity, while lysis of calpain II greatly lowers its calcium requirement for half-maximal activity to about 10 mM (for review see: Croall and Demartino, 1991).

For normal lambs, the nontreated and CCI-treated chops had the lowest shear values after 15 days of aging, whereas ESC+CCI-treated chops had the lowest shear values among those from callipyge lambs (Table 2). However, the ESC+CCI-treated callipyge chops had about 1 kg greater shear values than nontreated normal chops after all aging times (Figure 1). The parallel aging curves indicated that rates and extent of postmortem tenderization were similar in nontreated normal and ESC+CCI-treated callipyge chops. These results suggest that postmortem proteolytic activity was similar in the nontreated normal and ESC+CCI-treated callipyge chops, but that they possibly differed in some other morphological or biological property affecting tenderness. Factors effecting tenderness include degree of shortening of the sarcomeres (Hertzman et al., 1993), type and content of connective tissue (Totland et al., 1988; Maiorano et al., 1993) or compactness of the muscle structure (i.e., more protein and less fat; Lee and Kim, 1994). Compared with normal longissimus, callipyge longissimus has considerably larger and more fast twitch fibers, higher concentration of protein and lower concentration of fat (Carpenter et al., 1996). Callipyge longissimus also has a lower concentration of connective tissue and a lower concentration of hydroxylysylpyridinoline crosslinks (Field et al., 1996). In our study, tenderization of chops continued through 22 days of aging for normal loins and through 15 days of aging for callipyge loins, suggesting a prolonged period of active tenderization compared with the 5 to 7 days of active tenderization reported for lamb (Stolarz et al., 1984; Wheeler and Koohmaraie, 1994). Nevertheless, shear values after 15 days of aging were 2.2 ± 0.3 kg (mean ± SEM) for nontreated normal chops and 3.2 ±

Figure 1. Effect of aging at 2 °C on the shear values of loin chops from normal and callipyge lambs.



Callipyge carcasses were treated with low-voltage electrical stimulation and conditioned at 27 °C (ESC) until pH < 6.0, followed by calcium chloride (0.3% aqueous solution) injection to 10% of the loin weight at 1 day after slaughter (CCI). The loin sections from both callipyge and normal lambs were vacuum-packaged and stored at 2 °C beginning 1 day post-slaughter. The days of aging equal the total days after slaughter. Values are means ± SEM (n = 11 normal lambs; n = 8 callipyge lambs).

0.4 kg for ESC+CCI-treated callipyge chops, similar to the 2.5 to 3 kg values for cooked lamb longissimus reported by Stolarz et al. (1984) and Wheeler and Koohmaraie (1994).

Experiment 2

More panelists said that they would buy the callipyge chops as compared to the normal chops (73 vs. 26%; P< 0.01). Consumers evaluate their retail meat purchases in terms of size, fat content and color (Chambers and Bowers, 1993). With regard to size, consumers generally prefer products that fulfill a serving size need; in many cases, a larger size is equated with quality. Additionally, smaller amounts of visible fat increase the likelihood that consumers will purchase fresh meat cuts (Diamant et al., 1976). Recently, health concerns have added a driving force toward consumer selection of meats with low fat content.

Consumer panelists gave the 15-day aged ESC+CCI-treated callipyge chops lower mean sensory scores than the 15-day aged nontreated normal chops for texture, flavor and juiciness (Table 3). The lower sensory texture scores for callipyge chops reflected their higher shear force values, while their lower juiciness and flavor scores may be due to the lower fat concentrations in callipyge longissimus. Although lower than for normal chops, the mean sensory scores for 15-day aged ESC+CCI-treated callipyge chops were still acceptable (i.e., in the "like" range) for texture, flavor and juiciness. This indicates that the ESC+CCI treatment with aging improved the sensory texture of callipyge chops enough to allow them to be scored as acceptable, when they would otherwise have been considered unacceptable (Rawlings et al., 1994).

Conclusions

Lack of tenderness may make callipyge lamb unacceptable to consumers, thus negating the benefits of increased lean meat yield. Before promoting these animals in the sheep meat industry, the palatability of meat from these animals must be acceptable. Results of this research study suggest that tenderness of callipyge chops can be improved with post-slaughter processing techniques including aging, electrical stimulation and calcium chloride injection, but even with such treatment callipyge lamb is less tender, less juicy and less flavorful than is normal lamb.

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Table 3. Sensory scores[a] of lamb loin chops.

Sensory attribute	ESC + CCI callipyge[b]	Normal[c]	Significance, P value
Texture	6.3 ± 1.8	7.1 ± 1.5	0.001
Flavor	6.5 ± 1.7	6.9 ± 1.7	0.002
Juiciness	6.3 ± 1.6	7.2 ± 1.4	0.001

[a] Values are means ± SD, using a hedonic scale where 1 = dislike extremely, 5 = neither like nor dislike and 9 = like extremely. All loins were aged for 15 days before cutting into chops and cooking to 68 °C internal temperature.

[b] ESC+CCI = low-voltage electrical stimulation and conditioning at 27 °C until pH < 6.0, followed by injection of calcium chloride (0.3% aqueous solution) to 10% of loin weight at 1 day after slaughter.

[c] Normal chops were neither treated by ESC nor CCI.

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Sheep Diets and Performance from Two Rotational Grazing Methods

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Summary

A study was conducted during the growing seasons of 1986 and 1989 on the Texas A&M University Research Station near Sonora, TX, to compare two rotational grazing methods. Each treatment had seven pastures. Grazing treatments were short graze and rest periods (49-day cycle: 7 days graze, 42 days rest) and moderate graze and rest periods (98-day cycle: 14 days graze, 84 days rest). Stocking rates for both treatments were moderate at 16.2 hectare/animal unit years (AUY) in 1986 and 10.8 hectare/AUY in 1989. Total standing crop, live standing crop and crude protein (CP) were higher in 1986 than 1989, ($P < 0.01$, $P < 0.01$ and $P < 0.001$, respectively). For both years, cumulative grazing pressure was greater for the 98-day cycle than for the 49-day cycle. Animal performance was not different between grazing methods. Sheep diets in 1986 consisted mainly of sodgrasses, forbs and midgrasses. In 1989, the diet was predominantly midgrasses, browse and cool season grasses. Dietary CP was higher in 1986 than 1989 ($P < 0.01$), but grazing method did not differ. There was a tendency for organic matter digestibility of diets in the 49-day cycle to be higher than those in the 98-day cycle ($P < 0.12$). Diets collected in the first two days of each grazing period were higher in organic matter digestibility than those collected during the last two days (days 6 and 7 for 49-day cycle and days 13 and 14 for the 98-day cycle) ($P < 0.07$). The grazing method treatments used in this study had minimal effects on diet quality. The moderate stocking rates used in this study may have reduced the potential effects of grazing methods.

Key words: grazing method, rotational stocking, animal performance, standing crop, diet quality, botanical composition.

Introduction

Unrestricted selective grazing of specific plant species throughout the grazing season often leads to overgrazing and eventual changes in plant composition (Butler and Briskie, 1988). Selective grazing is generally at its greatest under yearlong continuous grazing. The problem with yearlong continuous grazing is that livestock have preferred areas for grazing; even under light stocking rates, these areas will often receive excessive usage. Compared to yearlong continuous grazing, rotational grazing methods provide a greater opportunity to manage the frequency, intensity and uniformity of plant defoliation with the objective of improving plant composition and increasing carrying capacity of the range (Heitschmidt et al., 1982).

Various grazing methods have been examined on rangelands over the years (Kothmann, 1980a; Holochek et al., 1989; Heitschmidt and Taylor, 1991). In Texas, the Merrill grazing system (four pastures for three herds) has proven to be superior to yearlong continuous grazing from the standpoint of sustained livestock, forage and wildlife production (Kothmann et al., 1971; Reardon and Merrill, 1976).

Over the past two decades, considerable emphasis has been given to grazing methods that utilize recurring periods of stocking and rest among two or more paddocks in a grazing management unit (i.e., rotational stocking). These have been described as time-controlled, short duration grazing, intensive grazing systems, high intensity-low frequency, etc. (Hart et al., 1991 and 1993; Taylor et al., 1993a).

Improved carrying capacity of rangelands has been attributed to the effect of these rotational stocking systems (Savory and Parsons 1980). Despite

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the fact that these systems have not proven to be superior to other grazing systems such as the Merrill four-pasture (Taylor 1988), interest in their use by land managers continues.

Previous studies on the Texas A&M University Research Station at Sonora, TX, (Taylor et al., 1980 and 1993a,b) reported that the dominant midgrasses in a seven-pasture management unit responded more favorably to a rotational grazing cycle of 98 days than a shorter grazing cycle of 49 days. When a major objective of rotational grazing is to increase midgrass composition, then the longer grazing cycle is recommended (Taylor et al., 1993a). However, the needs of the grazing animal should also be considered (Kothmann, 1980b). Long rest periods allow growth and senescence of vegetation thus reducing the opportunity for animals to harvest vegetation when it is most nutritious. Long rest periods also result in long graze periods which increase cumulative grazing pressure which may force animals to consume lower quality forages. This can reduce animal production.

This study tested the hypothesis that diet selection, diet quality and sheep performance differ between two rotational grazing methods with the same number of pastures but different grazing cycles. The objectives were to determine if the length of the grazing cycle in rotational stocking affected animal performance and diet selection.

Materials and Methods

The study was conducted during the summer (May through September) of two years (1986, 1989) on the 1,377-hectare Texas A&M University Research Station located on the southern edge of the Edwards Plateau resource region (31° N, 100° W) at Sonora, TX. Elevation is about 640 m. The average growing season is about 240 days (March through October). Long-term average annual precipitation (1918 to 1994) is 60.9 cm. Peak precipitation months are May, June and September. Growing season precipitation averaged 40.9 cm over 70 years. Growing season precipitation totaled 45 cm in 1986 and 24 cm in 1989.

The study site was characterized by shallow soils on rolling stony-hill topography typical of this land resource area. Original vegetation was predominately a midgrass savannah. Major midgrass species include sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], cane bluestem [*Bothriochloa barbinodis* (Lag.) Herter] and Texas cupgrass [*Eriochloa sericea* (Scheele) Munro]. Major sodgrass species include common curlymesquite [*Hilaria belangeri* (Steud.) Nash], hairy tridens [*Tridens pilosum* (Buckl.) Nash] and red grama (*Bouteloua trifida* Thurb.). Texas wintergrass (*Stipa leucotricha* Trin. A. Rupr.) is the major cool season grass. Juniper (*Juniperus spp.*), honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*), liveoak [*Quercus fusiformis* (Small) Sarg] and Mexican persimmon (*Diospyros texana* Scheele) are woody plant species that have increased with livestock grazing.

Treatments

Treatments consisted of two seven-pasture, one-herd rotational grazing methods, one with a 49-day cycle and the other a 98-day cycle. The two management units were created by dividing seven 32.4-hectare pastures into 14 16.2-hectare pastures; thus, both treatments were equally influenced by use prior to this study. The treatments had equal stocking rates throughout this study. In 1986 both treatments were stocked at 16.2 hectare/AUY (17 Rambouillet ewes and 21 Angora does per grazing method) with a sheep-to-goat ratio of 1:1, based on animal unit equivalents. Cattle (seven crossbred heifers per grazing method) had been removed because of the previous year's drought and lack of precipitation for the early part of the following spring. In 1989 both treatments were stocked at 10.8 hectare/AUY with a sheep-to-goat-to-cattle ratio of 1:1:1, based on animal unit equivalents. Salt and phosphorus minerals were provided free choice. Animals were supplemented with 41% cotton seed cake from January 1 to March 15. Ewes were bred in the fall (60-day breeding season) to lamb in February and March the following year. Lambs were weaned in July.

Vegetation Sampling

In both years, forage standing crop was measured in every pasture before and after each grazing period (Table 1) and analyzed for percent live and dead material. In 1986, 50 plots (0.2 × 1.0 m) per pasture were clipped and samples were dried and separated by vegetative class: sodgrasses, midgrasses, cool-season grasses, threeawn (*Aristida spp.*), bitterweed (*Hymenoxys odorata* DC), twin leaf senna [*Senna roemeriana* (Scheele)], and miscellaneous forbs. Forage samples were analyzed for CP (AOAC, 1984) and in vitro organic matter digestibility (IVOMD; Van Soest et al., 1966).

In 1989, foliar cover of plant species was estimated from 100 plots (0.2 × 1.0) per pasture. Seventy-five of the plots were located in herbaceous dominated vegetation and 25 in brush dominated vegetation. Data from the 100 plots were pooled for analysis. Standing crop was estimated using the procedures of Anderson and Kothmann (1982). Clipped samples were dried, weighed and analyzed for CP and IVOMD. A sample size of 100 plots was determined to be adequate as indicated by species-to-area curves (Oosting, 1956).

Percent relative cover of browse was estimated for each pasture along four transect lines (30.5 m/line) located in the four cardinal directions from five randomly located points. Browse cover was determined within 1 m of the ground. Browse cover was measured on line intercept and percent relative cover was calculated.

Cumulative Grazing Pressure

Cumulative grazing pressure (CGP) is the animal-to-forage relationship measured in animal units per unit weight of forage over a specified time (SRM, 1989). The CGP was calculated for both 1986 and 1989 as follows:

$$CGP = (AU \times DR \times D)/(SC^{before} + SC^{after})/2$$

Where:

AU = the number of animal units per pasture;

DR = demand rate (12 kg/day);

D = the number of days in the grazing period;

SC^{before} = standing crop (in kg) just prior to the grazing period; and
SC^{after} = standing crop (in kg) immediately after the grazing period.

Collection and Processing of Diet Samples

Diet samples for each grazing period were obtained from four esophageally fistulated sheep per treatment. Diets were collected from the study animals the first two mornings (days 1 and 2 from both grazing cycles, designated Period A) and last two mornings (days 6 and 7 for the 49-day cycle and days 13 and 14 for the 98-day cycle, designated Period B; Table 1). Diets collected during Period A were representative of low CGP and diets collected during Period B of a higher CGP. At dawn on each collection day, sheep were fitted with collection bags and released to graze freely for approximately 1 hour. After the collections, the sheep were released into the pasture to continue grazing.

After each collection, diet samples were subsampled, frozen, freeze dried and ground through a Wiley mill (Burritt et al., 1988; Acosta and Kothmann, 1978). CP was analyzed by the micro-Kjeldahl method (AOAC, 1984). Botanical composition of diets was determined by microhistological analysis at Colorado State University in Fort Collins, CO (Sparks and Malechek, 1968).

Animal Performance Data

The sheep were from a registered flock that had been owned by the Experiment Station for over 50 years. Age distribution was typical of many commercial flocks in the region. Ewes were randomly assigned to the treatments two years prior to the current study. Ewes were weighed three times (January, July, October) while lambs were weighed twice.

Data Summarization and Statistical Analyses

This experiment represents a case study where grazing treatments were replicated in time but not in space. Percent composition of vegetation classes and the chemical analysis data were subjected to analysis of variance utilizing a split-block model (Hicks, 1973). Main effects were grazing methods, years and pastures. The error term for testing significant effects of grazing methods (G) was pastures (P) within G with 1 degree of freedom. Error term used for testing year (Y), G×Y and P within G was P×Y(G). Error term P×Y(G) was used to test for Periods A and B and interactions. All percentage data were transformed using the square root, arcsine transformation (Sokal and Rohlf, 1981). Statistical analyses were done with the SAS General Linear Model procedure (SAS Institute, 1985). Duncan's multiple range test was used to evaluate differences among means.

Results and Discussion

Standing Crop

Standing crop was different between years ($P < 0.01$) but not between grazing method ($P > 0.05$). Standing crop reached a maximum of 2,700 kg/hectare in 1986 and a maximum of 1550 kg/hectare in 1989 (Figure 1). Standing crop was low during the early part of the growing season for 1986 but quickly increased in response to precipitation. Compared to 1986, total standing crop was lower but more consistent in 1989.

Live standing crop (LSC) was not different between GM ($\bar{x}$ = 580 kg/hectare and 583 kg/hectare for 49-day vs. 98-day cycle, respectively). LSC represented a large part of the total standing crop in both systems in

Table 1. Grazing schedule for the pastures that were sampled in 1986 and 1989.

49-day cycle[a]				98-day cycle[a]			
Pasture	Date in[b]	Date out[c]	Year	Pasture	Date in	Date out	Year
1 to 49	5/28	6/04	1986	1 to 98	5/28	6/11	1986
3 to 49	6/11	6/18	1986	2 to 98	6/11	6/25	1986
5 to 49	6/25	7/02	1986	3 to 98	6/25	7/09	1986
7 to 49	7/09	7/16	1986	4 to 98	7/09	7/23	1986
2 to 49	7/23	7/30	1986	5 to 98	7/23	8/06	1986
4 to 49	8/6	8/13	1986	6 to 98	8/06	8/20	1986
6 to 49	8/20	8/27	1986	7 to 98	8/20	9/03	1986
5 to 49	6/07	6/14	1989	3 to 98	6/07	6/21	1989
7 to 49	6/21	6/28	1989	4 to 98	6/21	7/05	1989
2 to 49	7/05	7/12	1989	5 to 98	7/05	7/19	1989
4 to 49	7/19	7/26	1989	6 to 98	7/19	8/02	1989
6 to 49	8/02	8/09	1989	7 to 98	8/02	8/16	1989
1 to 49	8/16	8/30	1989	1 to 98	8/16	9/06	1989
3 to 49	9/6	9/13	1989	2 to 98	9/06	9/20	1989

[a] Dates that livestock entered a pasture were the same for both treatments; however, because the 98-day treatment had a 14-day grazing period and the 49-day treatment had a 7-day grazing period, pasture exit dates were different.
[b] Date in is the start of diet sampling designated as Period A.
[c] Date out is the end of diet sampling designated as Period B.

Figure 1. Total, live and dead standing crop for all grazing periods for 1986 and 1989.

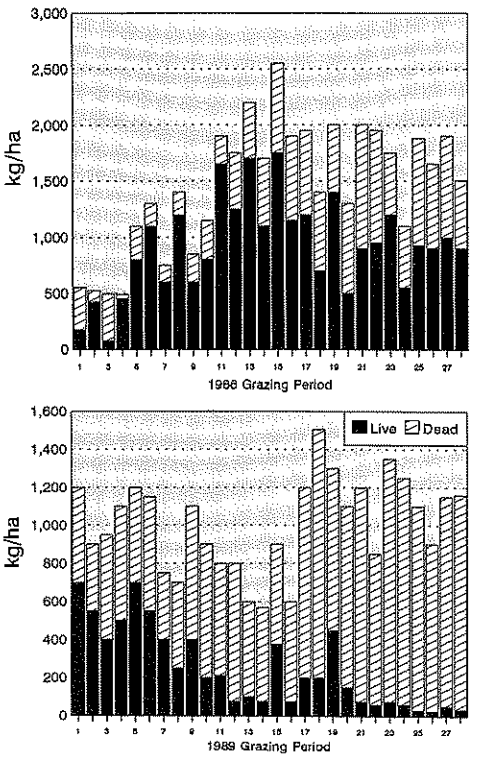
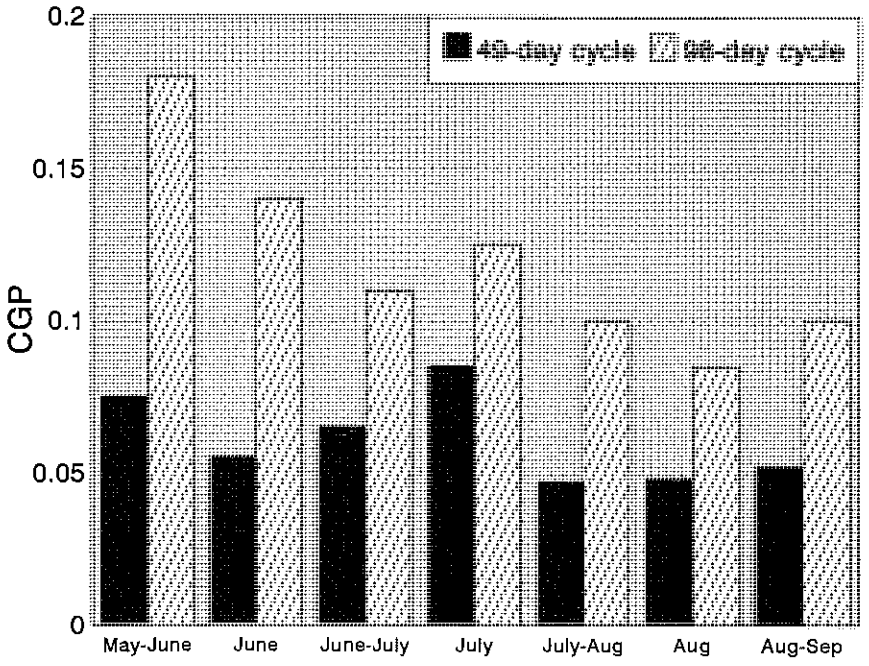


Figure 2. Cumulative grazing pressure (CGP) for total standing crop for both grazing methods averaged across years for each pasture.



1986 but was considerably lower for 1989 ($P < 0.001$). LSC was low at the beginning of the 1986 trial, but increased by the second sampling period and remained high for the remainder of the summer (Figure 1). In 1989, LSC represented a small part of the total and decreased as the summer progressed. LSC decreased from each grazing Period A to grazing Period B due to selective grazing for live forage.

Forage Quality

The mean CP for total forage was greater in 1986 (7.8%) than in 1989 (5.0%; $P < 0.001$). Mean CP values for total forage were not different between grazing methods ($P > 0.25$). The mean CP values for forage during both years were greater for Period A (7.0%) than for Period B (6.6%; $P < 0.05$).

IVOMD of forage was not different between grazing methods ($\bar{x}$ = 50.0 and 50.5% for 49- and 98-day cycles, respectively). IVDOM was 55.0 and 45.1% for 1986 and 1989, respectively; however, between year differences in IVDOM were confounded with batch analysis in the two years (different standards were used for different years). Digestibility values did not differ between Periods A and B.

Cumulative Grazing Pressure

CGP was greater for the grazing method with a 98-day grazing cycle than for the 49-day grazing cycle because of the longer grazing periods (Figure 2). At the beginning of 1986, CGP for live standing crop was near 0.2 and 0.4 for the 49- and 98-day grazing methods (Figure 3) due to low precipitation and a slow forage growth rate. After precipitation occurred in June of 1986, CGP for live forage remained below 0.2 for both grazing methods. In 1989, CGP for live forage was low but increased as the season progressed. It was anticipated that CGP values would help explain sheep diet quality and selection from the two grazing methods. Theoretically, the 14-day graze period would have been long enough to affect diet selection. Long graze periods characterized by high CGP have caused major shifts in composition of cattle diets (Taylor et al.,

1980); however, this was not recorded in the current study.

Animal Performance

Both sheep and heifer production from the same treatments but over a four-year period (1985 to 1989) revealed no difference between grazing methods (Taylor et al., 1993c). Although the data were not reported, Angora goat production from the same study was also similar for grazing methods.

Taylor and Garza (1986) reported that yearly differences in animal production resulting from variations in weather conditions were larger than differences caused by grazing methods. Also, sheep may not show obvious decreases in either performance or diet quality because of their ability to select alternative forages and maintain a stable nutritive intake under suboptimal foraging conditions (Edlefsen et al., 1960; Ralphs et al., 1986). This also might explain why sheep diets were not affected by the higher CGP encountered from the 98-day cycle treatment.

Botanical and Chemical Composition of Diets

Botanical compositions of sheep diets was similar for both grazing methods (Figure 4). Forbs and cool-season grasses tended to be higher ($P < 0.169$ and $P < 0.142$, respectively) for the 49-day cycle than for the 98-day cycle. No significant interactions were observed between grazing methods and years for any of the forage species. Botanical composition of diets varied between years (Figure 5). Sheep selected more midgrasses, cool-season grasses and browse in 1989 as compared to 1986. Precipitation might explain the low levels of sodgrasses in 1989 diets, since most sodgrasses during this dry summer offered only dead leaves. The major browse species in the diet was oak, with minor amounts of mesquite and juniper.

A significant year-by-collection period interaction was noted for forbs and woody species ($P < 0.10$ and $P < 0.002$, respectively). In 1986, forbs averaged 32.4 and 27.3% for Periods

Figure 3. Cumulative grazing pressure (CGP) for live standing crop for both grazing methods by years and months.

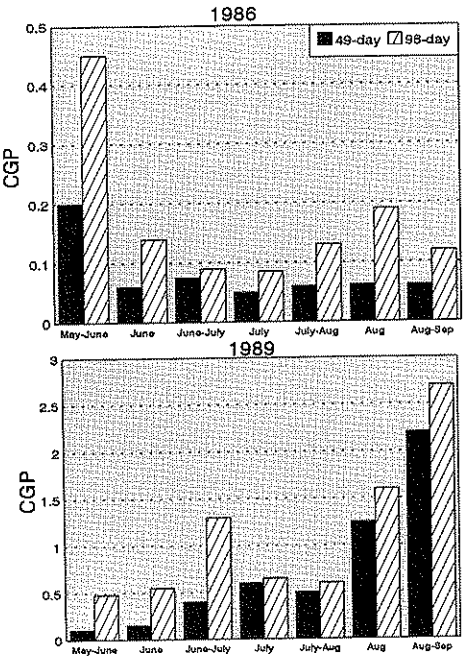
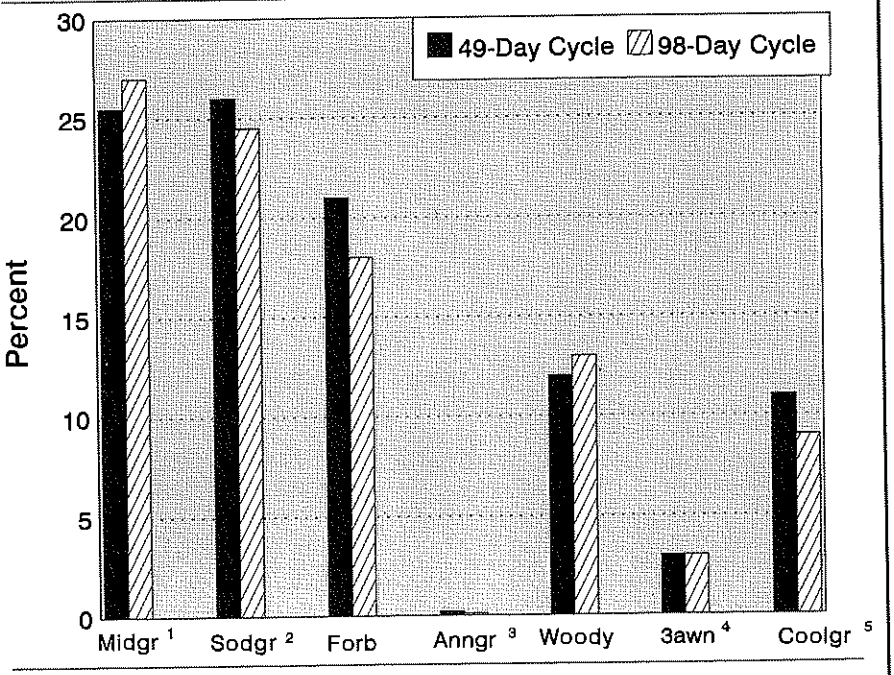


Figure 4. Sheep diet composition for two grazing methods averaged across years, pastures, and collection periods.



Grazing methods means within forage class did not differ significantly (1Midgr = Midgrass; 2Sodgr = Sodgrass; 3Anngr = Annual grass; 43awn = *Aristida* spp.; 5Coolgr = Cool-season grass).

A and B, respectively. In 1989, forbs averaged 9.0 and 8.4%. Woody species averaged 5.1 and 4.6% for Periods A and B, respectively, in 1986 and 16.9 and 24.6%, respectively, in 1989. Sodgrasses and midgrasses also had a significant interaction between years and collection periods ($P < 0.012$ and $P < 0.122$, respectively). In 1986 sodgrasses averaged 35.7 and 38.6% for Periods A and B, respectively, and 12.3 and 10.6%, respectively, in 1989. Midgrasses averaged 19.5 and 20.6% in 1986 and 42.6 and 21.5% for Periods A and B, respectively, in 1989.

Differences in precipitation between years caused the significant interaction between years and collection periods. The above-average precipitation during the summer of 1986 resulted in an abundance of the preferred forages such as forbs and new growth of warm season grasses. Because of this abundance of preferred forage diet selection changed very little from grazing Periods A to B. Sheep were not forced to select from the less preferred species such as cool season grasses, threeawn grasses, annual grasses and browse, regardless of grazing period. However, in 1989 with much lower precipitation sheep made major shifts in diet selection from Periods A to B, especially for midgrasses and browse.

Dietary CP was similar between grazing methods ($P > 0.05$; x = 11.3 and 11.7% for the 49- and 98-day cycles, respectively) but differed between years ($P < 0.001$). Mean dietary CP was 12.9% for 1986 and 9.4% for 1989. Because of the dry summer in 1989, the sheep consumed greater quantities of senescent forage and browse which resulted in lower dietary protein. Villena and Pfister (1990) reported that dietary CP decreased linearly as oak increased in the diet. Levels of CP did not differ between the A and B grazing periods. There was no year-by-grazing method interaction.

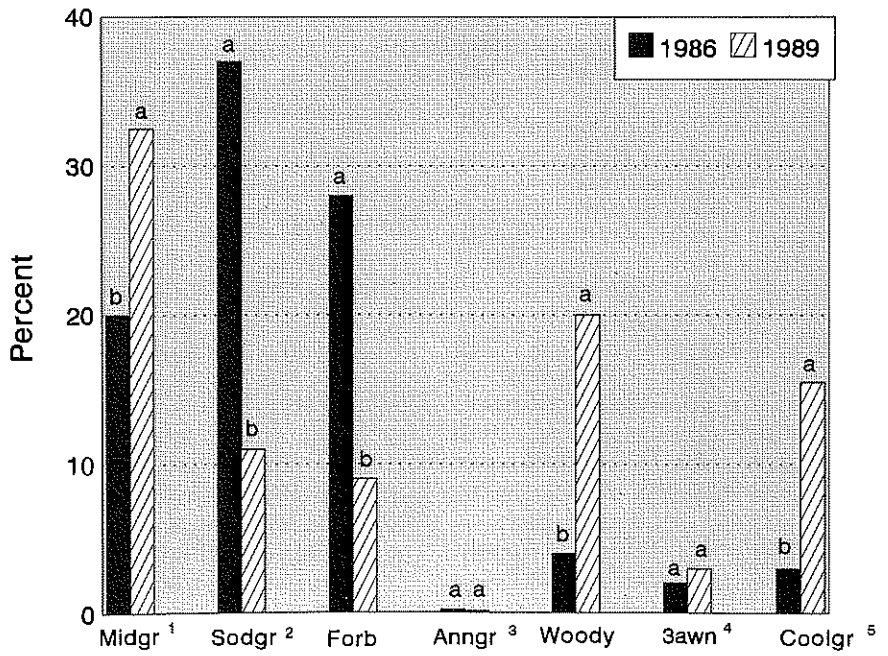
Organic matter digestibility was almost identical for the 49-day cycle (65.0%) and the 98-day cycle (64.0%; $P > 0.05$). Digestibility declined from grazing Period A (66.5%) to Period B (63.0%; $P < 0.07$).

Conclusions

Forage production and forage quality were affected more by year (i.e., precipitation) than grazing method. Although CGP increased significantly, diet quality decreased only slightly from grazing period A to B. Diet quality was also affected more by growing conditions than length of grazing cycle. Previous research demonstrated that longer graze and rest periods coupled with moderate stocking rates promote the production of midgrasses over sodgrasses (Taylor et al., 1993a). Furthermore, the longer grazing cycle did not reduce sheep performance in either a dry or wet growing season in this study. Therefore, the longer grazing cycle is recommended for rotational grazing on these rangelands, at least during the major part (May through September) of the growing season.

Although the two grazing cycles were not evaluated under different stocking rates, the authors feel that a moderate stocking rate is the key to successfully implementing rotational grazing on rangeland. For example, in the early growing season of 1986 with a low standing crop, growth rate was greater than demand rate, thus allowing animal nutrient requirements to be met. In 1989, characterized by below-average precipitation and a low forage growth rate but high standing crop, animals were able to shift to select alternative forages to maintain diet quality. Diet quality was well above the average quality of the forage indicating the ability of sheep to select the high-quality components. Heavy stocking rates for either year would have reduced this opportunity to select and consequently reduce livestock production regardless of type of grazing method.

Figure 5. Sheep diet composition for 1986 and 1989.



Similar letters above bars indicate no significance differences between treatments ($P > 0.05$).
[1] Midgr = Midgrass.
[2] Sodgr = Sodgrass.
[3] Anngr = Annual grass.
[4] 3awn = *Aristida* spp..
[5] Coolgr = Cool-season grass.

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Effect of Passive Immunization against Inhibin on Serum Antibody Titers, FSH and Reproductive Performance of Rambouillet Ewes

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Summary

Two experiments were conducted in the fall of consecutive years to evaluate the effect of passive immunization with an inhibin antibody (Ab) on reproduction in Rambouillet ewes. Ninety-six ewes were used in each experiment. In Experiment 1, inhibin-Ab was administered at -48, -24 or 0 hours in relation to removal of a progesterone-releasing device (CIDR). In Experiment 2, inhibin-Ab was injected at 0 hours. Results of the two experiments were similar and have been combined for presentation. Passive immunization with inhibin-Ab increased inhibin-Ab titers ($P < 0.01$). Serum follicle stimulating hormorne (FSH) concentrations were greater ($P < 0.01$) in inhibin-Ab-treated than control ewes 24 hours following immunization in Experiments 1 and 2. Timing of passive immunization in relation to CIDR removal had no effect on inhibin-Ab titer or FSH levels. Passive immunization increased ($P < 0.01$) ovulation rate 2-fold in Experiment 1 and 1.3-fold in Experiment 2. Passive immunization at -24 hours increased ovulation rate to a greater degree than when inhibin-Ab was injected at -48 or 0 hours. Fertility (percentage of ewes lambing of ewes exposed), lambs per ewe exposed and prolificacy (lambs born per ewe lambing) were not influenced by passive immunization with inhibin-Ab. Ovulatory response to passive immunization was positively associated with body weight (BW) at breeding. Passive immunization with inhibin-Ab increased serum FSH concentrations and ovulation rate but did not enhance reproductive performance of Rambouillet ewes.

Key words: sheep, inhibin, FSH, antibody, ovulation rate, prolificacy.

Introduction

Improvement of reproductive efficiency has long been a major focus of sheep research because of its importance to overall efficiency of meat production (Large, 1970). Genetic approaches to improve reproductive efficiency have included within breed selection or crossbreeding to prolific breeds. Alternatively, physiological approaches have attempted to manipulate the endocrine environment through the use of exogenous hormones or immunization against endogenous hormones. Immunization against endogenous hormones has the potential to elicit an immediate response, which can be long-term (active immunization) or short-term (passive immunization). Research evaluating active immunization against androstenedione has shown that reproductive performance can be increased, but these increases generally have been considered excessive for range production of sheep (Willingham et al., 1991).

Recent developments in the isolation of inhibin, a naturally occurring glycoprotein in the ewe (Burger, 1988; Ying, 1988), development of antisera (Meyer et al., 1991) and positive earlier trials (Kusina et al., 1995a,b) have increased interest in the potential use of immunization against inhibin for improving reproduction. The purpose of these trials was to evaluate passive immunization against inhibin for effects on antibody titers, serum FSH concentrations, ovulation rate and reproductive performance of

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Rambouillet ewes maintained on range.

Materials and Methods

Experiment 1

In September of 1994, ninety-six, 5-year-old Rambouillet ewes (55.1 ± 0.54 kg) were randomly assigned to control or one of three passive immunization treatments. All ewes were treated intravaginally with a controlled internal drug release device (CIDR) containing progesterone for 13 days to synchronize estrus. Treated ewes (n = 72) were passively immunized with an i.m. injection of an inhibin-Ab at either -48, -24 or 0 hours before CIDR removal. Control ewes (n = 24) were not immunized. Ewes were further assigned equally within treatment or control to three breeding groups [Breeding Group 1 (BG1), Breeding Group 2 (BG2), Breeding Group 3 (BG3)]. Each breeding group had 32 ewes. BG1 ewes (eight control ewes and eight ewes from each of the three treatment groups) were initially placed with three fertile rams at the time of CIDR removal. BG2 and BG3 ewes were placed with four vasectomized rams. Each ram was fitted with a marking harness. A timeline of events is shown in Table 1. Ewes were checked daily for estrus throughout the first 18 days, then every other day for another 36 days. Ovulation rates were observed laparoscopically in all ewes 7 days after CIDR removal. Ovulation rates were observed in BG2 and BG3 ewes approximately 7 days after their second observed estrus and again in BG3 ewes 7 days after the third estrus. One control ewe was removed from the trial after the first laparoscopy because she had lost her CIDR and no corpora lutea (CL) were observed. One 0-hours ewe was later removed because of failure to cycle at the first or second laparoscopic observation and the ovaries appeared abnormal. Following the first laparoscopic evaluation, BG2 ewes were placed with fertile rams. BG3 ewes were placed with fertile rams after the second laparoscopy. Blood samples were collected by venipuncture from all treated ewes 24 hours after passive immunization and from all controls at CIDR removal. Serum was separated and stored at -4 °C for later determination of inhibin-Ab titer and FSH concentrations. Eight ewes were selected randomly from each treatment group and were bled weekly until ovulation rate following the third estrus was observed.

Experiment 2

A second experiment was initiated in September of 1995, using 96 Rambouillet ewes (49.3 ± 0.86 kg). Ewes were assigned randomly within age (3 years, 6 years) to two treatments groups (control, 0 hours) for passive immunization. Whereas immunization at -24 (Experiment 1) resulted in the largest increase in ovulation rate, 0 hours was chosen for Experiment 2 to more closely simulate application under extensive conditions. Method of passive immunization, dosage of inhibin-Ab and estrous synchronization were the same as in the first experiment. At the time of CIDR removal (0 hours), treated ewes were passively immunized against inhibin. Then all ewes were placed with 15 fertile rams, most of which

Table 1. Timeline for Experiment 1.[a]

Day	Activity
-13	Insert CIDRs.
-2	Immunize -48 hour group.
-1	Immunize -24 hour group; Bleed all -48 hour ewes.
0	Remove CIDRs; Immunize 0 hour group; Bleed all -24 hour and control ewes; BG1 with fertile males; BG2 & BG3 with vasectomized males.
1	Bleed all 0 hour ewes.
7	Bleed 8 ewes from control, BG1, BG2 aud BG3; Observe ovulation rate in all ewes; BG2 with fertile males.
14	Bleed the same 8 ewes from control, BG1, BG2 and BG3.
21	Bleed the same 8 ewes from control, BG1, BG2 and BG3.
28	Bleed the same 8 ewes from control, BG1, BG2 and BG3; Observe ovulation rates in BG2 and BG3; BG3 ewes with fertile males.
35	Bleed the same 8 ewes from control, BG1, BG2 and BG3.
42	Bleed the same 8 ewes from control, BG1, BG2 and BG3; Observe ovulation rates in BG3.

[a] BG1, BG2 and BG3 are the three breeding groups that were assigned equally within treatment and control for Experiment 1.

Table 2. Least-squares means (LSM) of blood serum inhibin-ab titer and FSH from animals sampled 24 hours after passive immunization with an inhibin-ab or at CIDR removal in control ewes (Experiment 1).

	Control	Immunized	Pr>|T|	0 hours	-24 hours	-48 hours
Number	23	71	–	23	24	24
Inhibin-ab titer RP-2 units	31.70 ± 4.56	338.29 ± 2.60	0.01	341.01 ± 4.56	336.02 ± 4.46	337.83 ± 4.46
FSH, ng/ml	13.33 ± 1.04	19.78 ± 0.59	0.01	20.28 ± 1.04	20.16 ± 1.02	18.91 ± 1.02

were fitted with a marking harness. Ovulation rates were observed laparoscopically 9 days after CIDR removal. Blood samples were collected from all ewes 24 hours after CIDR removal.

Both years, ewes were maintained on native range near Brady, TX. Approximately 7 to 10 days prior to lambing, ewes were transported to the Texas Agricultural Experiment Station near San Angelo, TX. Ewes were lambed in confinement. Birth type, birth date, sex, dam and birth weight were recorded. Ewes and lambs were moved to small grain fields 2 to 5 days after lambing, depending on weather.

Inhibin-Ab and Radioimmunoassays

Details regarding preparation of inhibin-Ab have been reported previously (Meyer et al., 1991; Kusina et al., 1995a,b). Dosage of inhibin-Ab was 10,000 reference preparation-2 (RP-2) units/kg, calculated for a mean BW of 55.1 kg. RP-2 refers to a selected sample of ovine inhibin-antiserum designated for use as a laboratory standard (Kusina et al., 1995a). Serum inhibin-Ab titers and FSH concentrations were determined as described previously (Meyer et al., 1991; Kusina et al., 1995a). Components of the FSH assay were NIDDK-anti-oFSH-1 serum, NIAMDD-oFSH-13 for reference and USDA-oFSH-19-SIAPP-I-2 for radioiodination. Sensitivity was 2.1 ng/ml and intraassay CV was 7.2%.

Statistical Analysis

Data analyses were performed using the GLM procedure of SAS (1989). The model used in Experiment 1 to estimate treatment differences for inhibin-Ab titer and FSH concentrations included a fixed effect for treatment. The model used for reproductive traits included a fixed effect for treatment and a linear covariate for BW at breeding within treatment. The covariate for BW was used because BW has been shown to affect reproductive performance (Smith, 1988). Breeding group and breeding group-by-treatment interactions also were evaluated for fertility and prolificacy. Preliminary analysis showed no significant effect of breeding group or interactions on prolificacy; however, breeding group had a significant effect on fertility.

The model used to estimate treatment differences in Experiment 2 for inhibin-Ab titer and serum FSH concentrations included a fixed effect for treatment-by-age interaction. Analyses of reproductive traits included a fixed effect for treatment-by-age interaction and a covariate for BW at breeding-within-treatment.

The mean ovulation rate was estimated for immunized and control ewes at the 10^{th} and 90^{th} percentiles for BW, 45 and 59 kg, respectively. These estimates were functions of the fixed effects and the regression coefficients from the models of analyses. The means for treated ewes in Experiment 1 were a function of the average of the regression coefficients for 0, -24 and -48 hours. The estimates were plotted separately for each year

Figure 1. Least-square means (LSM) blood serum inhibin-ab titers at seven sampling times after CIDR removal (Experiment 1).

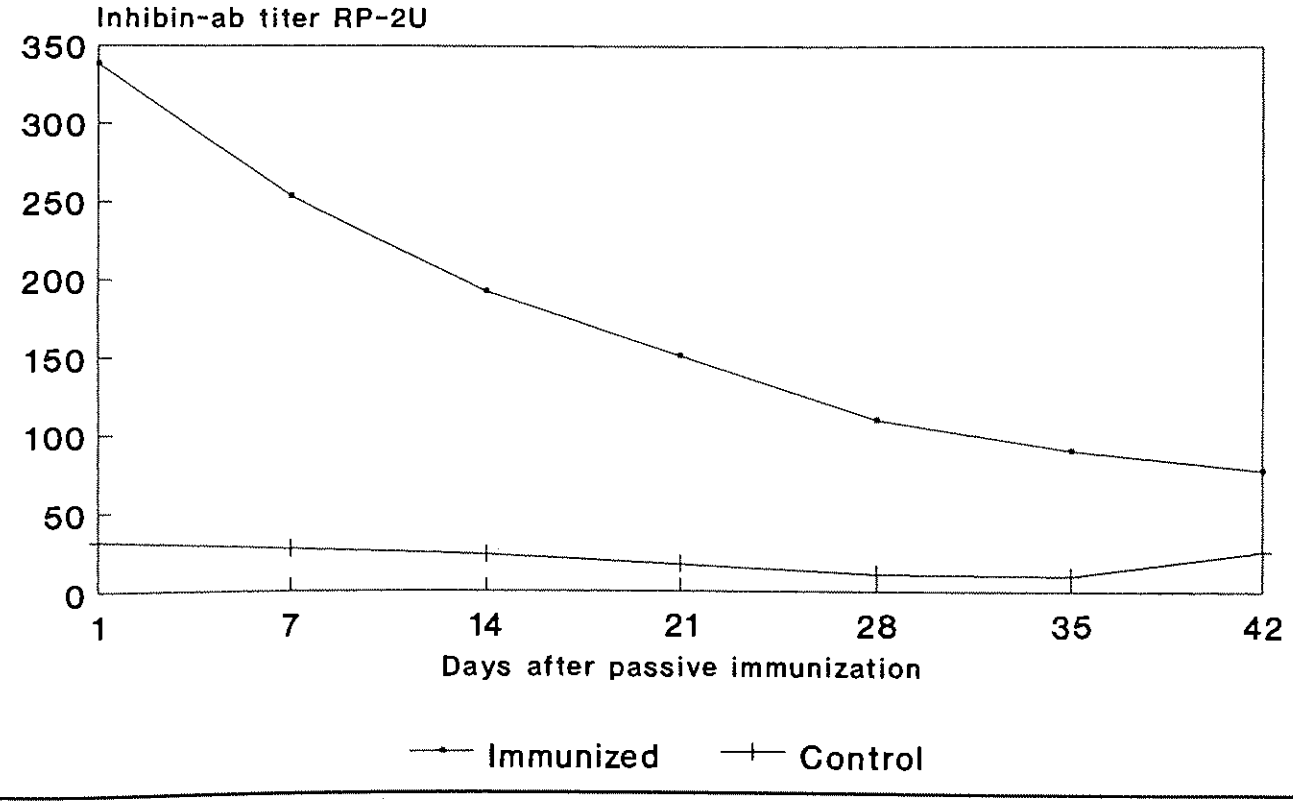

Figure 2. Least-square means (LSM) blood serum FSH at seven sampling times after CIDR removal (Experiment 1).

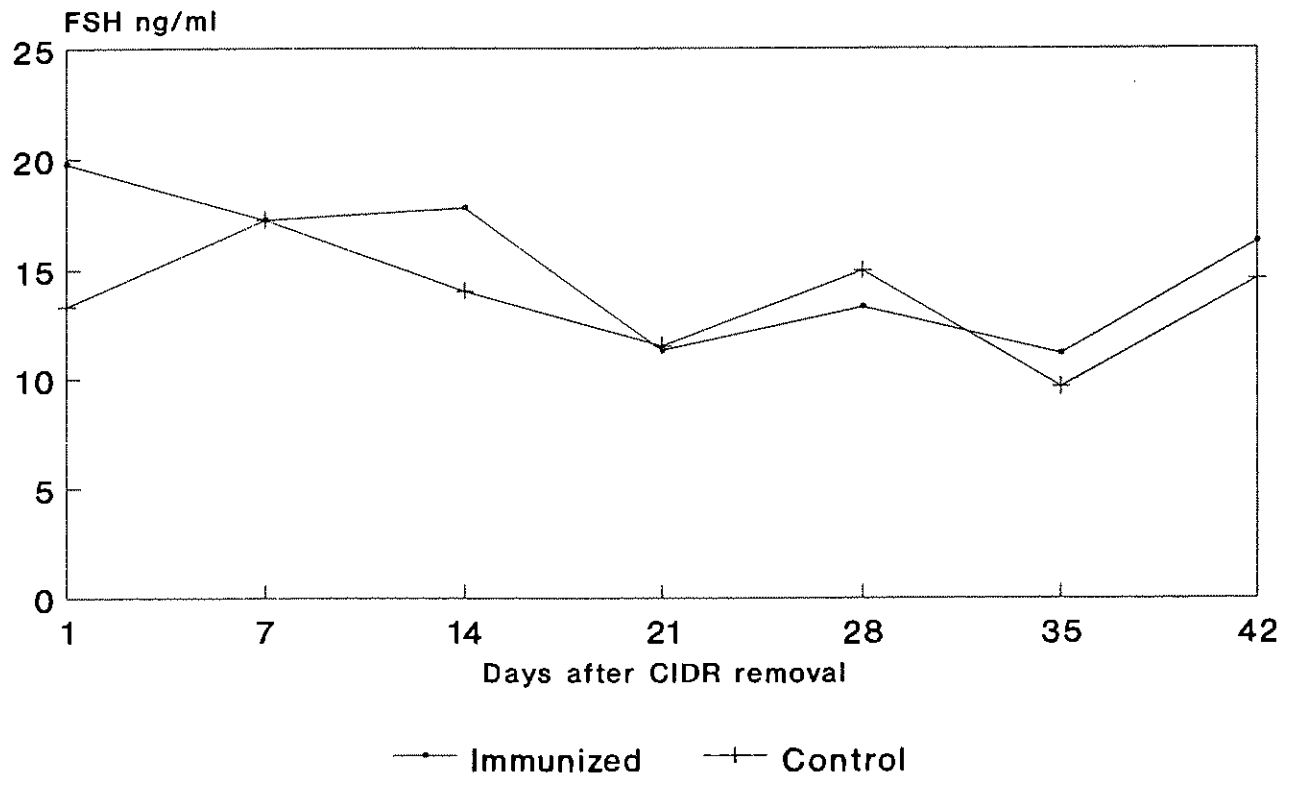

Table 3. Least-squares means (LSM) of days to first estrus after CIDR removal and ovulation rate at three consecutive cycles after passive immunization with an inhibin-ab (Experiment 1)

	Control		Immunized			0 hours		-24 hours		-48 hours	
	n	LSM	n	LSM	Pr>|T|	n	LSM	n	LSM	n	LSM
Days to first estrus after CIDR removal	22	1.87 ± 0.22	65	1.86 ± 0.13	0.98	22	2.04 ± 0.22	23	1.43[a] ± 0.21	20	2.11 ± 0.23
First ovulation rate	23	1.61 ± 0.28	71	3.18 ± 0.16	0.01	23	2.83 ± 0.28	24	3.74[a] ± 0.27	24	2.99 ± 0.27
Second ovulation rate	15	1.93 ± 0.11	47	1.78 ± 0.06	0.22	15	1.80 ± 0.11	16	1.86 ± 0.10	16	1.68 ± 0.10
Third ovulation rate	8	2.00 ± 0.13	24	1.65 ± 0.07	0.03	8	1.62 ± 0.13	8	1.75 ± 0.13	8	1.64 ± 0.13

[a] Significantly different (P>.05) from 0 hours.

because the treatments of Experiment 1 were different from those of Experiment 2.

Results and Discussion

Experiment 1

Inhibin-Ab titers in treated ewes increased ten-fold over the control ewes within 24 hours after immunization (Table 2) and remained higher ($P < 0.01$) than controls throughout the 42-day sampling period (Figure 1). Inhibin-Ab titers 24 hours following immunization were similar for animals injected at -48, -24 or 0 hours. Inhibin-Ab titers declined steadily following the 24 hours postinjection peak. Serum FSH levels in immunized ewes were 1.5-fold higher ($P < 0.01$) than controls 24 hours after inhibin-Ab injection (Table 2). Serum FSH concentrations 24 hours after passive immunization were similar in ewes injected at -48, -24 or 0 hours. Serum FSH concentrations were similar in immunized and control ewes from 7 to 42 days after CIDR removal (Figure 2). Magnitude of increases in serum inhibin-Ab titers, FSH secretion and ovulation rate in the present study were similar to those in Polypay ewes that had been passively immunized with the same dose of inhibin-Ab (Kusina et al., 1995ab). Similar FSH levels in immunized and control ewes from day 7 to 42 are consistent with the short-lived FSH-secretory response induced by inhibin-Ab in the studies of Kusina et al., 1995a,b.

Intervals to first estrus were similar in control and immunized ewes (Table 3). Within immunized ewes, duration of intervals to estrus were shorter when ewes were injected at -24 hours versus 0 hours ($P = 0.04$). Ovulation rate in immunized ewes was two-fold higher than in control ewes during the first estrous cycle after inhibin-Ab injection. Ewes injected at -24 hours had a greater ovulation rate than ewes injected at 0 hours. This may mean that inhibin-Ab, via FSH, has a greater effect on recruitment of follicles rather than on preventing atresia, or the injection at -24 hours may have elevated FSH at 0 hours and did prevent atresia. Ovulation rate following the second estrus was similar for control and treated ewes. Ovulation rate following the third estrus was lower in immunized than control ewes. One possible explanation is that the increased ovulation rate of immunized ewes, after the first estrus may lead to a period of below average reproductive performance,

Table 4. Least-squares means (LSM) of reproductive performance of Rambouillet ewes passively immunized with inhibin-ab (Experiment 1).

	Control		Immunized			0 hours		-24 hours		-48 hours	
	n	LSM	n	LSM	Pr>|T|	n	LSM	n	LSM	n	LSM
Fertility	23	0.69 ± 0.09	71	0.73 ± 0.05	0.73	23	0.78 ± 0.09	24	0.62 ± 0.09	24	0.79 ± 0.09
Lambs born per ewe exposed	23	1.21 ± 0.18	71	1.21 ± 0.10	0.98	23	1.30 ± 0.18	24	1.03 ± 0.18	24	1.29 ± 0.18
Prolificacy	16	1.76 ± 0.14	52	1.68 ± 0.08	0.64	18	1.69 ± 0.13	15	1.68 ± 0.15	19	1.64 ± 0.13

Table 5. Least-squares means (LSM) for inhibin-ab titer, FSH and days to estrus after CIDR removal in Rambouillet ewes (Experiment 2).

	Control		Immunized		
Trait	n	LSM	n	LSM	Pr>|T|
Inhibin-ab titer	48	1.05 ± 6.68	48	206.77 ± 6.68	0.01
FSH, ng/ml	48	13.87 ± 1.53	48	19.47 ± 1.53	0.01
Days to estrus	46	1.65 ± 0.13	44	1.72 ± 0.14	0.15

	3-year-old control		3-year-old immunized		6-year-old control		6-year-old immunized	
Trait	n	LSM	n	LSM	n	LSM	n	LSM
Inhibin-ab titer	29	$0.86^{b} \pm 5.98$	29	$212.97^{a} \pm 5.98$	19	$1.25^{b} \pm 7.39$	19	$200.57^{a} \pm 7.39$
FSH, ng/ml	29	$16.96^{ab} \pm 1.37$	29	$19.68^{a} \pm 1.37$	19	$10.78^{b} \pm 1.69$	19	$19.27^{a} \pm 1.69$
Days to estrus	27	$1.63^{a} \pm 0.12$	26	$1.50^{a} \pm 0.12$	19	$1.52^{a} \pm 0.15$	18	$1.95^{a} \pm 0.16$

[a,b] LSM within rows having different superscripts are significantly different ($P > 0.05$).

due possibly to over stimulation of the ovaries. This has been suggested in earlier work (Willingham et al., 1991) done with active immunization against androstenedione. Because of the small number of ewes in the present study, this should be interpreted with caution.

Fertility, prolificacy and the number of lambs born per ewe exposed, did not differ for passively immunized ewes when compared to controls (Table 4). The failure of increased ovulation rate to be realized as increased number of lambs born is not readily explained by these data. It has been well documented (Casida et al., 1966; Dolling and Nicolson, 1967) that as ovulation rate increases, reproductive wastage increases.

Experiment 2

Results of Experiment 2 support the findings of the first experiment. Inhibin-Ab titers (Table 5) increased markedly 24 hours after passive

Figure 3. Relationship of ovulation rate to body weight (BW) by treatment (Experiment 1).

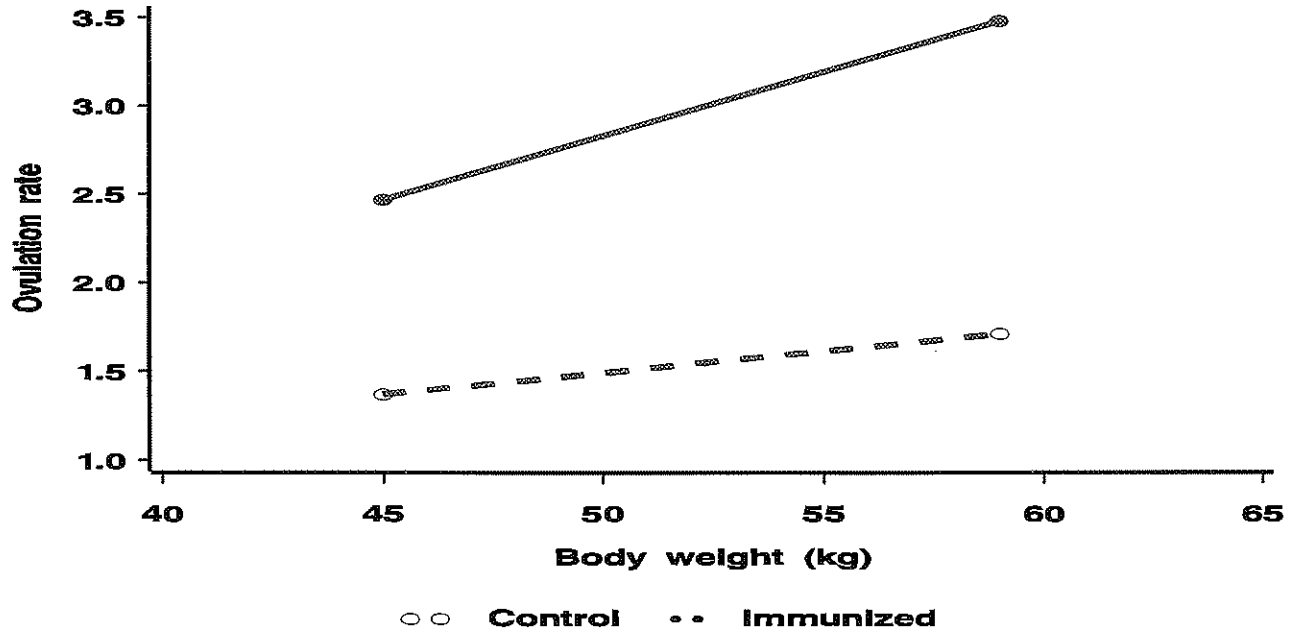

Table 6. Least-squares means (LSM) of reproductive performance of Rambouillet ewes passively immunized with inhibin-ab (Experiment 2).

	Control		Immunized		
Trait	n	LSM	n	LSM	Pr>|T|
Ovulation rate	48	1.50 ± 0.24	48	1.96 ± 0.25	0.02
Fertility	48	0.64 ± 0.13	48	0.52 ± 0.14	0.25
Lambs per ewe exposed	48	0.90 ± 0.22	48	0.73 ± 0.23	0.33
Prolificacy	29	1.38 ± 0.19	26	1.40 ± 0.24	0.84

	3-year-old control		3-year-old immunized		6-year-old control		6-year-old immunized	
Trait	n	LSM	n	LSM	n	LSM	n	LSM
Ovulation rate	29	1.28[b] ± 0.20	29	2.14[a] ± 0.21	19	1.73[ab] ± 0.27	19	1.79[ab] ± 0.29
Fertility	29	0.46[a] ± 0.11	29	0.63[a] ± 0.12	19	0.83[a] ± 0.15	19	0.41[a] ± 0.16
Lambs per ewe exposed	29	0.59[a] ± 0.19	29	0.83[a] ± 0.19	19	1.21[a] ± 0.25	19	0.63[a] ± 0.27
Prolificacy	14	1.30[a] ± 0.20	15	1.31[a] ± 0.21	15	1.45[a] ± 0.19	11	1.45[a] ± 0.19

[a,b] LSM within rows having different superscripts are significantly different (P > 0.05).

immunization. FSH levels (Table 5) were greater in immunized ewes. Because of an age-by-treatment interaction the only meaningful difference ($P < 0.05$) in FSH concentrations was when comparing 6-year-old immunized ewes to 6-year-old controls. Days to estrus after CIDR removal was similar for treatments. Reproductive performance is shown in Table 6. The immunized 3-year-old ewes had a higher ($P < 0.01$) ovulation rate (2.14 vs. 1.28) than the 3-year-old control ewes. However, the ovulation rate of the 6-year-old immunized ewes was not significantly different (1.79 vs. 1.73) from the 6-year-old control ewes. Fertility, lambs per ewe exposed and prolificacy were not affected by immunization. The probability of a single ovum resulting in a lamb born was similar (0.54 vs. 0.50) for control and immunized ewes. The probability of an ovum in twin ovulating ewes was 0.56 versus 0.44 in control or immunized ewes, respectively. Ewes having ovulation rates of 3 or more were too few for comparison. Because of the limited number of ewes lambing at first ovulation in Experiment 1, probabilities of ova survival were not calculated.

Body Weight

The mean BW did not differ among treatments in Experiment 1 or among the treatment by age cells in Experiment 2. When the effect of inhibin-Ab treatment was estimated at a BW of 45 kg, ewes were estimated to produce 1.10 ± 0.68 ($P = 0.11$) more ova in Experiment 1 and 0.34 ± 0.26 ($P = .20$) more ova in Experiment 2. At a BW of 59 kg, the estimated effect was larger and significantly different from zero, 1.77 ± 0.41 more ova ($P = 0.01$) in Experiment 1 and 0.75 ± 0.34 more ova ($P = 0.03$) in Experiment 2 (Figures 3 and 4). These differences suggest that the effect of immunization is greater at higher BW. Figures 3 and 4 illustrate the same pattern of increased effect at greater BW. This pattern indicates that the effect of immunization is a function of BW. It cannot be determined from the present data set whether this is a body condition or body size effect. Further research should be conducted to substantiate the apparent differential effect of immunization as a function of BW.

Conclusions

The data from these two experiments suggest that passive immunization with inhibin-ab increased ovulation rate but did not result in a significant increase in lambs produced. The increase in ovulation rate is greater in younger ewes (3-year-old vs. 6-year-old; Experiment 2) and the effect is greater (Experiments 1 and 2) at higher BW. The use of passive immunization against inhibin caused a marked increase in Ab titers and FSH. FSH concentrations declined rapidly while Ab titers declined gradually. Passive immunization failed to improve fertility, lambs per ewe exposed or prolificacy in Rambouillet ewes maintained under extensive Texas range conditions.

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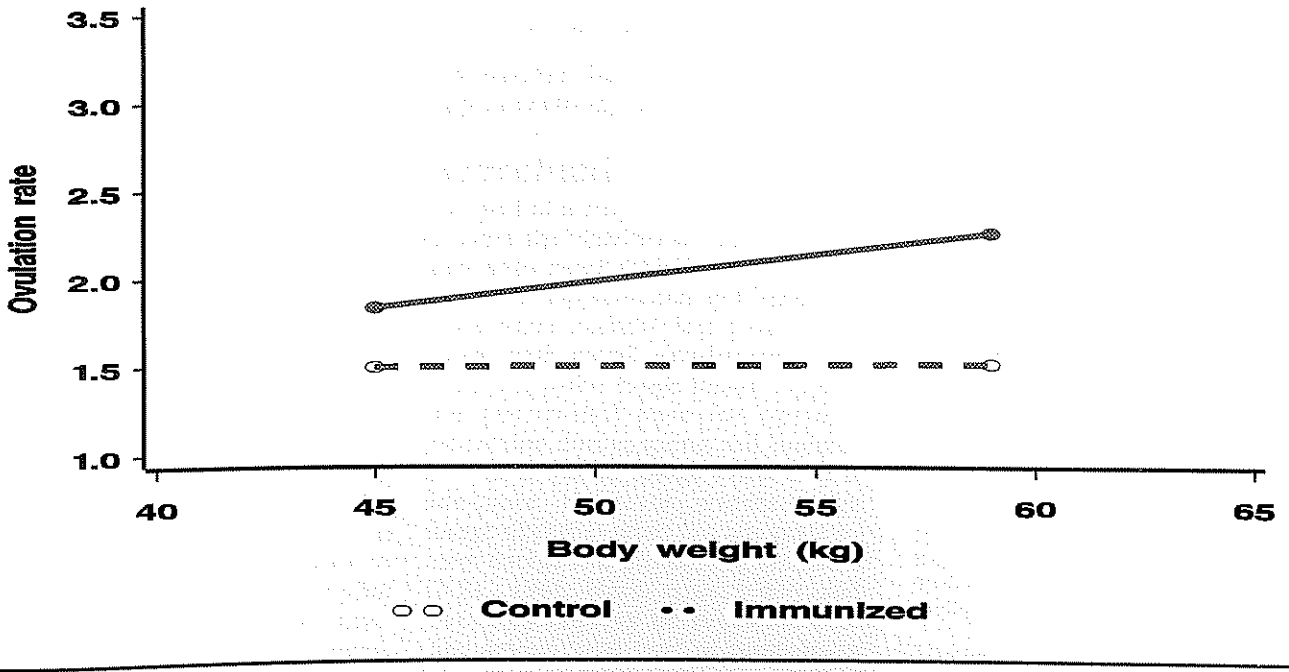
Figure 4. Relationship of ovulation rate to body weight (BW) by treatment (Experiment 2).



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Influence of Energy or Protein Supplementation during Midpregnancy on Lamb Production of Ewes Grazing Winter Range[1]

Patrick G. Hatfield[2,3], Verl M. Thomas[2,4] and Rodney W. Kott[2]

Summary

A two-year experiment was conducted to determine the effects of energy or type of protein supplementation during midpregnancy on lamb production by grazing ewes. Rambouillet and Targhee ewes (N = 350) were assigned randomly, within age and breed, to one of four supplement treatments: 1) no supplement; 2) barley; 3) feather meal plus blood meal (FM-BM); and 4) feather meal, blood meal and urea (FM-BM-U). Supplements were fed on alternate days. A supplement × year interaction ($P = 0.01$) was detected for body weight (BW) change. Nonsupplemented ewes lost more ($P < 0.10$) BW than supplemented ewes each year. During Year 1, FM-BM-U supplemented ewes gained more ($P < 0.10$) BW than FM-BM or barley ewes; however, during Year 2 no differences ($P > 0.10$) were detected between FM-BM and FM-BM-U supplemented ewes. Barley supplemented ewes lost more ($P < 0.10$) BW than protein supplemented ewes in Year 2. Lamb mortality from birth to weaning was higher ($P < 0.10$) for nonsupplemented lambs than lambs born to supplemented ewes. Lambs born to barley supplemented ewes had higher ($P < 0.10$) mortality than those born to FM-BM supplemented ewes. Lambs weaned per ewe exposed to the ram was higher ($P < 0.10$) for FM-BM and FM-BM-U than barley and nonsupplemented ewes. Lamb weaning weights were higher ($P < 0.10$) for lambs from ewes supplemented with FM-BM and FM-BM-U than for lambs born to nonsupplemented ewes. Feeding protein supplements containing a high proportion of undegraded intake protein (UIP) on alternate days during midpregnancy improved the percentage of lambs weaned per ewe exposed to the ram.

Key words: sheep, protein, energy, supplementation, range.

Introduction

The goal of a range sheep operation is to meet the nutritional needs of the flock with range forage and minimize the use of supplemental and harvested feeds while maintaining economical lamb and wool production. In Montana, native range forage supplies the nutritional base for optimal production during spring and summer months provided forage availability is adequate. However, winter range forage quality is often not adequate to meet energy and protein requirements (NRC, 1985; Harris et al., 1989), and ewes may need to be supplemented. The amount and type of supplement needed are extremely variable among ranges and years. Clanton (1957) and Van Horn et al. (1959) reported that increasing supplemental crude protein (CP) content with a natural protein source (cottonseed or soybean meals) improved BW change and kilograms of lamb weaned by pregnant ewes grazing Utah and Montana winter range. UIP sources such as feather meal (FM) and blood meal (BM) improved nutritional status in ewes fed a low-quality forage, probably due to increased protein reaching the small intestine (Hoaglund et al., 1992). UIP supplements may be suitable substitutes for natural proteins supplied to sheep consuming low-quality forages where the objective of the feeding program is either maintenance of BW or limited BW lose. Soder et al. (1995), in a forage intake

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[4] Deceased.

and metabolism trial conducted at the same time as the current experiment, found that supplementation during midpregnancy with the same energy and protein supplements had no effect on ewe forage dry matter (DM) intake. This experiment was conducted to determine the influence of energy or protein supplementation on the BW change and lamb production of ewes grazing winter range during midpregnancy.

Materials and Methods

A winter feeding trial conducted over two years was initiated at the Montana State University Red Bluff Research Ranch near Norris, MT. Ewes were maintained on winter range from day 24 to day 100 of pregnancy. The first trial (Year 1) was conducted from December 17, 1991, to March 7, 1992. The second trial (Year 2) was conducted from December 22, 1992, to March 5, 1993. Elevations, annual precipitation range and vegetation type have been previously described by Soder et al. (1995) in a companion trial that was conducted at the same time with a subsample of ewes from the present experiment.

Beginning approximately November 12 in both trails, 350 range ewes (aged 2 to 6 years) of two breed groups (Rambouillet and Targhee) were exposed to a similar breed of ram during a 21-day breeding season to produce purebred lambs. Following the 21-day period, ewes were combined and exposed to Suffolk rams for the final 14 days of the breeding period. After breeding, ewes were assigned randomly, within age and breed, to groups that were fed one of four supplement treatments (Table 1). Treatments were: 1) no supplement; 2) barley; 3) feather meal, blood meal supplement (FM-BM); and 4) feather meal, blood meal, urea supplement (FM-BM-U). Supplements were fed on alternate days at 0700 hours. Thomas et al. (1994) reported no differences in ewe productivity by supplementing pregnant ewes on alternate days versus daily supplementation. Barley supplement was fed at a rate of 0.27 kg/ewe on alternate days. Protein supplements (FM-BM; FM-BM-U) were fed at 0.14 kg/ewe on alternate days to provide the daily equivalent of 30 g of CP daily. This rate was chosen because Harris et al. (1989) determined that ewes grazing Montana winter range were deficient in CP intake by approximately 30 g/day. Daily CP and metabolizable energy (ME) intakes of the barley supplement were approximately 18 g of CP and 0.38 Mcal of ME (Table 2). Daily intakes of CP and ME from the protein supplements were approximately 32 g of CP and 0.16 Mcal of ME. Protein supplements were formulated to be isonitrogenous and isocaloric. Approximately 70% of the total protein in the FM-BM supplement was UIP from FM and BM. In the FM-BM-U supplement, approximately 50% of the total CP was degradable intake protein (DIP) due to the addition of urea in this supplement. Urea was incorporated to determine if DIP enhanced ewe production.

Supplementation began approximately 120 days prior to lambing (Year 1: December 17, 1991; Year 2:

Table 1. Ingredient and nutrient composition of supplements (dry matter basis).

	Supplement		
Item	Barley	FM-BM[a]	FM-BM-U[b]
Ingredient, %			
Barley	90.4	36.7	46.9
Feather meal	–	28.0	25.3
Blood meal	–	18.1	6.8
Urea	–	–	3.5
Bentonite	1.8	1.8	1.8
Molasses, beet	2.7	5.4	5.4
Nutrient, %			
CP	13.6	47.9	44.5
NDF	16.8	23.0	20.9
ADF	6.5	13.9	11.3
Sulfur	1.0	2.3	1.9
ME, Mcal/kg[c]	3.0	2.6	2.7
DIP[d]	73.0	29.5	49.1
UIP[e]	27.0	70.5	50.9

[a] BM-FM = blood meal, feather meal.
[b] FM-BM-U = feather meal, blood meal, urea.
[c] Calculated from NRC (1985) values.
[d] DIP = degradable intake protein.
[e] UIP = undegradable intake protein.

Table 2. Daily supplement dry matter (DM) and nutrient intake by ewes.

	Supplement		
Item	Barley	FM-BM[a]	FM-BM-U[b]
DM, g	136.0	68.0	68.0
CP, g	18.4	32.6	33.4
DIP[c], g	13.5	9.6	16.3
UIP[d], g	4.9	23.0	17.1
ME, Mcal	0.38	0.16	0.17

[a] FM-BM = feather meal, blood meal.
[b] FM-BM-U = feather meal, blood meal, urea.
[c] DIP = degradable intake protein
[d] UIP = undegradable intake protein.

December 22, 1992) and continued for approximately 80 days (Year 1: March 7, 1992; Year 2: March 5, 1993). Ewes were approximately 23 (Year 1) and 25 days (Year 2) pregnant at the beginning of each trial. Ewes were penned on alternate days in the morning for approximately 1 hour, sorted and group-fed their supplements (88 ewes per treatment). Nonsupplemented ewes were also penned for this period of time. After feeding, all ewes were allowed to graze the same 1,618 hectare paddock. All sheep had free access to trace mineral salt mix (composition of trace mineral salt: NaCl, 98%; Zn, 0.35%; Mn, 0.28%; Fe, 0.175%; Cu, 0.035%; I, 0.007%; Co, 0.007%). Sheep were attended by a full-time herder whose responsibilities were to feed the sheep, protect the ewes from predation and control where they grazed in the paddock.

All ewes were weighed on two consecutive days at the beginning and end of each trial. Ewes were also assigned a body condition score (BCS) at the beginning and end of each trial. Body condition was based on a scale of 1 to 5 with a score of "1" designating an emaciated ewe and "5" designating an obese ewe (Russell et al., 1969). Body condition scores were estimated by the same individual in each trial. Ewes were shorn at the end of the wintering period and fleece weights recorded. At the conclusion of the wintering period, all ewes were removed from winter range and fed a common diet that was formulated to meet their nutrient requirements (NRC, 1985). The diet was 2.3 kg of alfalfa hay and 0.45 kg of barley grain daily. This diet was fed through lambing and until ewes and their lambs were moved onto summer range pastures (May 28, both trials).

Immediately after giving birth, ewes with lambs were individually confined in 1.46 m^2 pens with their lambs. Lambs were weighed, ear-tagged and had their tails docked at less than 24 hours of age. Ewes and lambs remained in the lambing pens for 24 hours (singles) or 48 hours (multiples); then they were moved into mixing pens with 8 to 10 ewes and their lambs per pen. Approximately one week after lambing, ewes and their lambs were moved from the mixing pens into larger pens containing 15 to 20 ewes and remained there until being moved onto summer range.

Lamb mortality data were collected. Ewes and lambs were observed closely each day and excessive BW loss by the lamb (10% BW) was the primary reason for removing a lamb from the ewe. Lambs removed from ewes were classified as a mortality because they would have died had they not been removed from the ewe.

Supplements were subsampled before the trials began. Samples were ground through a 1-mm screen in a Wiley mill and analyzed for DM, ash, CP, sulfur (AOAC, 1984), neutral detergent fiber and acid detergent fiber (NDF and ADF, respectively; Van Soest and Wine, 1967).

Data were analyzed by least-squares procedures of SAS (1993). The statistical model used for ewe traits included the fixed effects of supplement, ewe age ["2 years" or "mature" (3 to 6 years old)], trial (year), breed and birth type ["single" or "twin" (triplet births were only 0.4% of all births and were included with twins)]. Date of parturition was included as a covariate in the least-squares model. The experimental unit was the ewe. The use of animals as experimental units provided a conservative analysis because animals were group-fed rather than individually-fed. Group feeding results in greater variation among animals within a treatment as a result of uncontrolled and varied feed consumption by individuals. Hence any significant differences observed among treatments are valid (Pitts et al., 1992).

A similar model was used for lamb traits except that sex of the lamb was added. All models included all possible interactions. After the full models were run, nonsignificant interactions were removed from these models. Means were separated using the LSD procedure. A significance level of $P < 0.10$ was established for all analyses.

Table 3. Influence of supplementation on ewe body weight (BW), body condition score (BCS) and wool production over two years.

	Supplement				
Item	None	Barley	FM-BM[a]	FM-BM-U[b]	SE[c]
Winter range					
Initial BW, kg	66.6	65.7	66.1	66.2	0.58
Final BW, kg	63.1[d]	64.7[e]	66.5[f]	66.6[f]	0.49
Change, kg	-3.6[d]	-1.0[e]	0.4[f]	0.5[f]	0.19
Initial BCS, kg	3.6	3.6	3.6	3.6	0.02
Final BCS, kg	2.9[d]	3.2[e]	3.3[f]	3.3[f]	0.03
Change, kg	-0.57[d]	-0.38[e]	-0.30[f]	-0.33[ef]	0.02
Fleece wt, kg	4.1	4.2	4.1	4.1	0.04

[a] FM-BM = feather meal, blood meal.
[b] FM-BM-U=feather meal, blood meal, urea.
[c] SE = standard error.
[d,e,f] Means in the same row lacking a common superscript differ ($P < 0.10$).

Results and Discussion

In both years, ewes fed either FM-BM or FM-BM-U were heavier ($P < 0.10$) at the end of the winter supplementation period than either barley or nonsupplemented ewes (Table 3). Barley supplemented ewes weighed more ($P < 0.10$) than nonsupplemented ewes. A supplement × year interaction ($P = 0.01$) was detected for BW change (Table 4). In Year 1, only nonsupplemented ewes lost BW, whereas in Year 2 all ewes lost BW. Nonsupplemented ewes lost more

(P < 0.10) BW than supplemented ewes each year. During Year 1, FM-BM-U supplemented ewes gained more (P < 0.10) BW than FM-BM and barley ewes. However, during Year 2 no differences (P > 0.10) were detected between FM-BM and FM-BM-U supplemented ewes. Barley supplemented ewes lost more (P < 0.10) BW than protein supplemented ewes in Year 2.

A supplement × birth type interaction was detected (P = 0.08) for ewe BW change (Table 5). Within birth type, nonsupplemented ewes lost more (P < 0.10) BW than supplemented ewes, and ewes supplemented with FM-BM and FM-BM-U either lost (P < 0.10) less BW or gained more (P < 0.10) BW than barley supplemented ewes.

Final ewe BCS score on winter range was higher (P < 0.10) for FM-BM and FM-BM-U supplemented ewes than barley and nonsupplemented ewes (Table 3). Barley supplemented ewes had higher (P < 0.10) BCS than nonsupplemented ewes. Nonsupplemented ewes lost more (P < 0.10) body condition while grazing winter range than supplemented ewes, with barley supplemented ewes losing more (P < 0.10) body condition than FM-BM ewes. Ewe fleece weight were not influenced (P > 0.10) by supplement fed during the winter period.

Percentage of ewes lambing, lambs born per ewe lambing and the percentage of lambs sold or grafted of

Table 4. Interaction of supplementation and year on winter range body weight (BW) change, kg.

	Supplement[a]			
Year	None	Barley	FM-BM[b]	FM-BM-U[c]
1	-1.7[d]	0.93[e]	1.2[e]	2.0[f]
2	-5.3[d]	-2.9[e]	-0.42[f]	-1.0[f]

[a] Standard error (SE) of least-square mean (LSM) = 0.27. Probability value for the significance of the interaction: P = 0.01.
[b] FM-BM = feather meal, blood meal.
[c] FM-BM-U = feather meal, blood meal, urea.
[d,e,f] Means in the same row lacking a common superscript differ (P < 0.10).

Table 5. Interaction of supplement and birth type on winter range body weight (BW) change, kg.

	Supplement[a]			
Birth type	None	Barley	FM-BM[b]	FM-BM-U[c]
Single	-3.8[d]	-1.2[e]	-0.45[f]	-0.01[f]
Multiple	-3.3[d]	-0.7[e]	1.3[f]	0.9[f]

[a] Standard error (SE) of least-square mean (LSM) = 0.28. Probability value for significance of the interaction: P = 0.08.
[b] FM-BM = feather meal, blood meal.
[c] FM-BM-U = feather meal, blood meal, urea.
[d,e,f] Means lacking a common superscript differ (P < 0.10).

Table 6. Effects of supplementation on reproduction and lamb body weight (BW) and mortality.[a]

	Supplement[b]				
Item	None	Barley	FM-BM[b]	FM-BM-U[c]	SE[d]
Ewes lambing, % ewes exposed	95.2	91.1	93.4	94.8	2.0
Lambs born per 100 ewes exposed	147.7[e]	127.7[f]	133.7[ef]	137.4[ef]	5.2
Lambs born per 100 ewes lambing	155.2	140.7	143.6	144.3	4.4
Sold or grafted lambs, % lambs born	4.0	4.9	2.9	3.4	1.3
Lamb mortality, % of lamb born					
Birth to turnout	14.4[e]	10.0[ef]	6.2[f]	8.1[f]	1.9
Turnout to weaning	12.8[e]	9.6[ef]	7.0[f]	6.6[f]	1.7
Total	25.3[e]	17.8[f]	12.3[g]	12.9[fg]	2.3
Lambs weaned per 100 ewes exposed	101.2[e]	101.4[e]	113.3[f]	113.6[f]	4.7
Lambs weaned per 100 ewes lambing	122.4	124.4	126.9	128.8	4.2
Lamb BW, kg					
Turnout	13.3[e]	13.9[ef]	14.2[f]	14.0[ef]	0.27
Weaning	31.5[e]	32.3[ef]	32.7[f]	32.7[f]	0.42

[a] Each value represents the mean of the following number of observations: ewes lambing, lambs born, lambs weaned (n = 186); lamb mortality and birth weight (n = 256); lamb turnout weight (n = 235); lamb weaning weight (n = 207).
[b] FM-BM = feather meal, blood meal.
[c] FM-BM-U = feather meal, blood meal, urea.
[d] SE = standard error.
[e,f,g] Means lacking a common superscript differ (P < 0.10).

lambs born did not differ (P > 0.10) among supplements (Table 6). Lambs born per ewe exposed to the ram were higher (P < 0.10) for nonsupplemented ewes than barley ewes. No difference was detected (P > 0.10) between nonsupplemented ewes and protein supplemented ewes.

A supplement × year interaction (P = 0.01) was detected for lamb mortality from birth to turnout on summer range (Table 7). Lamb mortality was greater (P < 0.10) for lambs born to nonsupplemented ewes during Year 2 than all other supplement treatments. Mortality from turnout to weaning was higher (P < 0.10) for lambs born to nonsupplemented ewes than those born to ewes supplemented with FM-BM and FM-BM-U (Table 6). Lamb mortality from birth to weaning (total mortality) was higher (P < 0.10) for nonsupplemented than supplemented ewes. Lambs born to barley ewes had higher (P < 0.10) mortality than those born to FM-BM ewes. Total lamb mortality did not differ (P > 0.10) between barley and FM-BM-U, and FM-BM and FM-BM-U lambs.

Lambs weaned per 100 ewes exposed to the ram were higher (P < 0.10) for FM-BM (113.3%) and FM-BM-U (113.6%) than barley (101.4%) and nonsupplemented ewes (101.2%; Table 6). Lambs weaned per 100 ewes lambing was not affected (P > 0.10) by winter supplement treatment.

A supplement × ewe age interaction was detected (P < 0.10) for lamb birth weight (Table 8). Ewes lambing for the first time (2-year-olds) had lambs with lower (P < 0.10) birth weight than lambs born to mature ewes. Birth weight of lambs born to 2-year-old FM-BM supplemented ewes was lower (P < 0.10) than birth weight of lambs born to all other 2-year-old ewes. Birth weight of lambs born to mature ewes supplemented with FM-BM was greater (P < 0.10) than birth weight of lambs born to nonsupplemented and barley supplemented ewes, but did not differ (P > 0.10) from birth weight of lambs born to FM-BM-U supplemented ewes.

Lamb turnout BW was higher (P < 0.10) for lambs born to ewes fed FM-BM than lambs born to nonsupplemented ewes (Table 6). No differences were detected (P > 0.10) between nonsupplemented, barley and FM-BM-U lambs. Lamb weaning weight was greater (P < 0.10) for FM-BM and FM-BM-U than lambs born to nonsupplemented ewes and not different (P > 0.10) from lambs born to barley ewes.

Improved BW change and less BCS score loss by protein (FM-BM; FM-BM-U) and energy (barley) supplemented ewes compared to nonsupplemented ewes was probably due to factors other than the influence of supplementation on forage intake. A 2-year experiment conducted concurrently with this study found that the same supplements did not influence forage intake of ewes grazing winter range (Soder et al., 1995). Harris et al. (1989), working at the same location, found that daily supplementation of 0.15 kg/ewe of an 18% CP supplement did not affect forage intake compared to nonsupplemented ewes. Huston et al. (1994) also reported that supplementation of goats grazing a low-quality rangeland with varying levels of UIP did not affect forage DMI.

Greater BW gains by protein supplemented ewes compared with energy supplemented ewes agrees with results of Harris et al. (1989) who reported that protein was more limiting than energy in winter range forage. This observation was also supported by Van Horn et al. (1959) who found that increasing the protein content of supplements fed to ewes grazing winter range increased ewe BW gain. In the present studies, protein supplements provided approximately 55% less ME (0.17 vs. 0.38 Mcal) and 79% more CP (33 vs. 18.4 g) than the barley supplement. Urea was added to the FM-BM supplement to determine if additional DIP would improve ewe BW change. Although FM-BM-U ewes gained more BW than FM-BM ewes during Year 1, ewe BW change between protein supplemented ewes was similar during Year 2 when ewes

Table 7. Influence of supplement and year on lamb mortality from birth to turnout on summer range.

	Supplement[a]			
Year	None	Barley	FM-BM[b]	FM-BM-U[c]
1	8.6	12.3	5.3	10.0
2	20.2[d]	7.6[e]	7.1[e]	6.3[e]

[a] Standard error (SE) of least-square mean (LSM) = 0.28. Probability value for the F-test for supplement by year interaction: P = .01.
[b] FM-BM = feather meal, blood meal.
[c] FM-BM-U = feather meal, blood meal, urea.
[d,e] Means in the same row lacking a common superscript differ (P < .10).

Table 8. Influence of supplement and ewe age on lamb birth weight, kg.

	Supplement[a]			
Ewe age	None	Barley	FM-BM[b]	FM-BM-U[c]
2-year-old	4.67[d]	4.73[d]	4.42[e]	4.89[d]
Mature	5.07[d]	5.07[d]	5.23[e]	5.16[de]

[a] Standard error (SE) of least-square mean (LSM) = 0.09. Probability value for the F-test for supplement by year interaction: P = 0.01.
[b] FM-BM = feather meal, blood meal.
[c] FM-BM-U = feather meal, blood meal, urea.
[d,e] Means in the same row lacking a common superscript differ (P < 0.10).

lost BW. Difference in ewe BW change between protein supplemented ewes was probably not of enough magnitude during Year 1 to be of biological importance. These data suggest that additional DIP was not required over that already provided by the range forage and FM-BM supplement.

Thomas et al. (1994) reported that replacement of SBM with FM in supplements for sheep fed a maintenance straw diet prevented BW loss and maintained ruminal fiber digestion, despite decreased ruminal NH_3 N concentrations as dietary FM increased. Therefore, improved BW gain by FM-BM and FM-BM-U supplemented ewes compared with barley was due to increased UIP intake. Hoaglund et al. (1992) reported that nutritional status of pregnant ewes fed at or near maintenance was enhanced by replacing SBM with BM. Less body condition loss by FM-BM supplemented ewes than barley and nonsupplemented ewes suggests that adipose reserves were being mobilized but increased UIP intake probably provided sufficient protein to maintain muscle mass or allow for a small amount of protein accretion compared with barley and nonsupplemented ewes (Vipond et al., 1989; Thomas et al., 1994).

Greater BW loss during Year 2 compared to Year 1 for all supplement treatments was probably due to differences in winter forage and other environmental conditions. Soder et al. (1995) reported that ruminal ingesta collected from cannulated ewes contained approximately 7.1% CP during Year 1 but only 4.5% CP during Year 2. Year 1 was a mild winter with little snow cover and moderate temperatures. The daily low and high temperatures averaged -7 °C and 2 °C during January and -5 °C and 7 °C during February of 1991 and 1992, respectively. Low and high temperatures during Year 2 were -26 °C and -15 °C in January and -4 °C and 2 °C in February for 1992 and 1993, respectively. Although February was warmer than January in Year 2, more snow cover (2 to 10 cm) was present during February of Year 2 than either January or February of Year 1 or January of Year 2. Soder et al. (1995) also reported lower forage DMI during Year 2 than Year 1 (1.7 vs. 1.2% of ewe BW). In addition to the low forage CP value in Year 2, forage intake may have been lower during Year 2 because of greater snow cover.

Nutritional regimes imposed during midpregnancy did not affect percentage of ewes lambing, lambs born per ewes lambing or the percentage of lambs weaned per ewe. The reason that a higher percentage of lambs born per ewes exposed for nonsupplemented ewes compared to barley supplemented ewes is not clear. Parr et al. (1987) suggested that ewes fed high levels of feed during early pregnancy may exhibit an increased incidence of embryonic mortality. In addition, Parr et al. (1993) found an inverse relationship between level of feed intake and plasma progesterone concentration due to differences in metabolic clearance rate of progesterone. Supplement intake by barley supplemented ewes was approximately 100% greater than those fed the protein supplements. However, quantitative differences were probably not sufficient in our study to cause the response reported by Parr et al. (1987).

The supplementation regimes imposed during midpregnancy affected lamb mortality. Higher lamb mortality for nonsupplemented ewes may be related to retarded placental growth caused by feed restriction during midpregnancy (Everett, 1964; Mellor, 1983). McCrabb et al. (1992a) found lower placental weight in ewes fed restricted diets between days 30 and 96 of pregnancy; however, these researchers reported that lamb birth weight was not affected by feed restriction during midpregnancy when ewes were fed adequately in late pregnancy. It was concluded that the early stage (days 30 to 50) of pregnancy is a critical time when placental growth is sensitive to maternal feed restriction.

In our study, lamb birth weights tended to be higher for those born to protein supplemented ewes than those born to nonsupplemented or barley supplemented ewes. The exception to this was in the 2-year-old ewes fed FM-BM supplements who had lower birth weights than the other supplement treatments. Greater BW gain or less BW loss, less body condition loss for protein supplemented ewes and the trend for increased birth weights suggest that protein supplementation during midpregnancy may have influenced placental growth. Uterine blood flow and uptake of substrate by the conceptus within ewe age group probably returned to levels sufficient to provide for normal fetal development during late pregnancy (McCrabb et al., 1992b); however, this may have not been great enough in some cases to offset the earlier effects of midpregnancy nutrition on placental growth and development. Kelly et al. (1992) found a significant linear relationship between lamb birth weight and rate of lupin feeding during midpregnancy. Lynch et al. (1990) suggested that protein-rich supplements fed over the midpregnancy period would increase lamb birth weight.

Improved turnout and weaning weights for lambs born to protein supplemented ewes suggests that midpregnancy nutrition may have influenced milk production. Protein supplemented ewes were in better body condition at the end of midpregnancy than nonsupplemented ewes and this could have provided more adipose tissue to meet the high energy demands of lactation (Robinson, 1986). Kelly et al. (1992) reported that for both single and twin born lambs, increased rates of lupin feeding during midpregnancy increased lamb growth during the first four weeks of lactation despite the ewes being adequately fed in late pregnancy. Greater lamb production per 100 ewes exposed to the ram for protein supplemented ewes than nonsupplemented ewes was due to the influence of supplement on lamb mortality since all treatments had similar conception rates and percentage lambs born. Barley supplemented ewes had lower productivity than protein supplemented ewes due to the cumulative effects on reproduction and lamb mortality. These data agree with early work of Clanton (1957) who reported that supplemen-

tation of pregnant ewes with a 25% protein pellet while grazing winter and spring range improved lamb weaning weights over those of lambs born to ewes fed corn or no supplement. In contrast, Van Horn et al. (1959) reported that increasing the protein content of a barley supplement with a DIP, soybean meal increased BW gain in ewes grazing winter range; however, feeding a high protein pellet did not improve lamb production over those supplemented with a low protein barley pellet.

Conclusions

Feeding protein supplements containing a high proportion of UIP on alternate days during midpregnancy improved lamb weaning weights and the percentage of lambs weaned per ewe exposed to the ram. This response could be due to an influence of protein on placental development and lamb birth weight which affected lamb mortality. Protein supplemented ewes weaned approximately 5 kg more lamb per ewe exposed than nonsupplemented ewes. No advantage to feeding a barley supplement compared to no supplementation was found and barley supplemented ewes weaned only 0.9 kg more lamb per ewe than nonsupplemented ewes.

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The Influence of Lamb Chronological Age, Slaughter Weight and Gender on Carcass and Meat Quality[1]

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Summary

A total of 1,660 lambs representative of the Canadian market lamb population were slaughtered and evaluated for carcass and meat quality. Ewe carcasses generally had the most uniform fat covers, while ram carcasses generally had the least uniform fat covers. Uniformity of fat cover generally increased with slaughter weight, but decreased with advancing age on heavyweight ram carcasses (greater than 58.6 kg). Rams generally produced carcasses with the least white fat and the highest incidence of carcasses with yellow fat. The fat on heavyweight lambs (greater than 67.7 kg) became less white with advancing age, but became whiter with increasing slaughter weight on ram carcasses 3 to 6 and 9 to 12 months of age and ewe carcasses 3 to 6 months of age. Ewe carcasses generally had the most marbling, ribcage feathering, flank streaking, the firmest flanks and the most opaque ribcages; ram carcasses were at the other extreme. Marbling increased with increasing slaughter weight in older ram and ewe carcasses (greater than 12 months) and decreased in young ram and wether carcasses (less than 9 months); flank streaking increased with slaughter weight in young lambs (less than 9 months) and ribcages became more opaque with increasing slaughter weight, particularly in young lambs (less than 9 months). Percent transmission (a measure of protein denaturation and functionality of carcass lean) increased with advancing age in ram and wether lambs slaughtered between 32 and 40 kg and in ewes exceeding 68 kg in slaughter weight. Expressible juice tended to increase with advancing age and the carcass lean from ram carcasses had the most expressible juice while carcass lean from ewe carcasses had the least. Ram carcasses generally had the lightest colored and most yellow loin-eyes. Loin-eye color became darker with increasing slaughter weight in young rams and ewes (less than 9 months) and lighter in older ewe and wether lambs (greater than 9 months). Loin-eye color also became lighter with advancing age in carcasses from heavyweight lambs (greater than 67.7 kg). The redness of loin-eyes increased with slaughter weight only in older wether carcasses (greater than 12 months), but increased with advancing age. The yellowness of loin-eyes decreased with slaughter weight in young lamb carcasses (greater than 12 months). Darker and redder cuts required longer cooking times and sustained lower cooking losses from both drip and evaporation. In addition, redder cuts were perceived: 1) to be less well done when cooked to the same internal temperature; and 2) to contain less connective tissue and exhibited more intense lamb flavor. Redness of muscle color was also associated with greater consumer acceptability of tenderness and overall palatability in butt leg roasts while lightness of muscle color was associated with greater tenderness acceptability in shank leg roasts. Higher intramuscular fat content was associated with longer cooking times, lower apparent degrees of doneness, higher cooking losses, greater tenderness, less perceptible connective tissue, lower juiciness, more intense lamb flavor, more acceptable flavor, juiciness, tenderness and overall palatability to consumers. Higher percent transmission and percent expressible juice were associated with higher cooking losses,

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while lower percent transmission and percent expressible juice were associated with greater tenderness and less perceived connective tissue. Higher percent transmission and percent expressible juice were also associated with more intense lamb flavor. In addition, higher percent transmission was associated with greater juiciness and acceptability of juiciness and overall palatability in butt leg roasts, while greater amounts of expressible juice were associated with greater acceptability of leg roast tenderness.

Key words: lamb, chronological age, slaughter weight, gender, carcass quality, meat quality.

Introduction

The ultimate desirability of lamb carcasses is determined by the yield of edible portion and the quality of the muscle which comprises this portion, as it relates to palatability and consumer acceptance.

Carpenter (1966) expressed the need for definitive research to provide guidelines to optimize the balance between carcass weight, quantitative yield of retail cuts and meat quality. In this regard, it is evident fatness and muscling of lamb carcasses differ considerably due to differences in age, weight, breed, sex and management (Carpenter et al., 1965).

Channon (1990) reported production of larger lamb carcasses would increase profitability. Bruwer et al. (1987) reported the influence of carcass weight on muscle quality was generally negligible and Sanudo et al. (1996) indicated carcass weight did not influence water holding capacity. However, Kemp et al. (1976) indicated both slaughter weight and gender influenced carcass quality, and Ray and Kronmann (1971) reported carcass conformation, ribcage feathering, marbling and carcass grade increased with time on feed. Sanudo et al. (1996) observed increases in muscle pH and darker redder lean color with increases in slaughter weight, and Jacobs (1972) reported the consumer acceptability of lamb from wethers increased with slaughter weight. However, Channon (1990) reported 45% of the retailers in an Australian survey would not purchase larger lamb carcasses due to excessively large primal and retail cuts and the perception that larger lamb carcasses were overfat and had lower meat quality.

Also, no detectable gender differences in meat quality were reported (Anonymous, 1984) and Dransfield et al. (1990) reported marbling and muscle color did not differ due to gender. However, Wiggins et al. (1976) observed ewe carcasses to have more marbling than ram and wether carcasses and wether and ewe carcasses to have firmer muscle than ram carcasses.

Although reports show (Anonymous, 1984) that production of entire male sheep resulted in faster production of leaner meat, Kruggel et al. (1982) observed ram lambs accumulated more lutein in their fat depots, which resulted in ram carcasses having yellower fat than wether carcasses. Busboom et al. (1981) and Crouse et al. (1981) also reported ram carcasses had softer, yellower fat than wether carcasses. Jabet (1993) reported that soft, yellow fat intensified flavor and made cut preparation more difficult, and Crouse et al. (1981) indicated gender differences in fat softness were exacerbated by advancing chronological age.

Although many studies have evaluated the influence of chronological age, slaughter weight and gender on carcass and meat quality (Burton and Reid, 1969; Wood et al., 1980), these studies have tended to evaluate only one or two factors in isolation. There have been no comprehensive studies completed to examine the influence of such traits on carcass and meat quality of a sample representative of the Canadian market lamb population. The present study was designed to provide an evaluation of the influences of chronological age, slaughter weight and gender on carcass and meat quality.

Materials and Methods

A total of 1,660 commercial lambs were selected on the basis of age, slaughter weight, gender and fatness to fill specific subclasses in an experimental design grid (Jeremiah et al., 1997). The lambs evaluated were a representative sample of the entire range of lambs currently being marketed in Canada rather than a set of animals of controlled breeding and dietary management, slaughtered at different weights and/or ages. The lambs in the present study were purchased from commercial sheep producers with breeding records and certified birth dates for the lambs purchased so that both the breeding and chronological ages could be ascertained. The lambs were predominantly crossbreds, involving some combination of the following breeds: Cheviot, Columbia, Dorset, Finnish Landrace, Hampshire, Leicester, Montadale, Rambouillet, Romanoff, Romney, Shropshire, Southdown, Suffolk, Targhee or Texel. Breeds and breed-crosses were allocated as evenly as possible among age/slaughter weight/gender subclasses and care was taken to prevent a given breed or breed-cross from constituting a majority in any given age/slaughter weight/gender subclass.

Fatness and gender were ascertained the day prior to slaughter. Fatness was ascertained both subjectively, by a trained and experienced evaluator, and ultrasonically. The same fatness criteria were applied to all age/slaughter weight subclasses, but was relatively constant within subclasses. Since the lambs were purchased from different producers, it is possible they were fed differently and it is possible this may have influenced compositional properties. The actual frequency distribution of lambs evaluated has been presented by age, weight, gender and fatness subclass (Jeremiah et al., 1997).

All lambs were slaughtered at the Lacombe Meat Research Centre (Lacombe, Alberta, Canada) under simulated commercial conditions. At 24 hours postmortem, subcutaneous fat color (1 = white; 5 = yellow) and uniformity (1 = devoid of fat; 5 = complete fat cover) were subjectively evaluated on the cold carcass. The transmission of light through the ribcage was subjectively scored (1 = opaque; 5 = translucent). Flank firmness (1 = soft; 5 = very firm),

streaking (1 = devoid; 6 = abundant) and color (1 = light red; 5 = dark red) were also subjectively evaluated, as was the amount of feathering between the ribs (1 = devoid; 6 = abundant). Marbling was subjectively evaluated (1 = abundant; 9 = traces) and muscle color coordinates (Hunter "L," "a" and "b" values) of the Longissimus lumborum muscle were obtained using the Macbeth Series 1500 color measuring system (Macbeth; Newbergh, NY) at a specific anatomical location between the 12th and 13th thoracic vertebra on the muscle cross-section.

All wholesale cuts from the left carcass sides were then separated into fat, lean and bone. The lean from all cuts was pooled and ground twice through a 3-mm plate. Percent transmission and proportion of expressible juice were determined by procedures previously described (Murray et al., 1989).

Loin roasts between the 12th thoracic and the last lumbar vertebra were removed from the right side of each lamb carcass within the sample of 1,660 lambs previously described (Jeremiah et al., 1997). Each wholesale loin was weighed, vacuum packaged and frozen at -30 °C in still air. They were then held at this temperature until evaluated (90 to 180 days). Upon removal from the freezer all loins were thawed at 4 °C for 48 hours and then reweighed to determine thaw-drip losses. A saber thermocouple was then inserted into the center of each loin and they were roasted in an electric convection oven, preheated to 177 °C, to an internal temperature of 75 °C. Upon removal from the oven each loin and the associated drip were weighed to determine drip, evaporative and total cooking losses. Each loin was also subjectively evaluated for degree of doneness (1 = rare; 5 = well done) and cooking times were recorded. Six cubes (1.9 × 1.9 × 1.9 cm) were then removed from each loin, taking care to avoid large pieces of fat and connective tissue, and randomly assigned to an experienced six-member taste panel screened and trained according to AMSA guidelines (AMSA, 1978). Subsamples were held in covered glass containers in a 70 °C water bath until evaluated (10 to 15 minutes).

Panel sessions were conducted in well-ventilated temperature-controlled partitioned booths under 1,076 lux of incandescent and fluorescent white light. Room temperature distilled water and unsalted soda crackers were provided to remove flavor residues between sample evaluations (Larmond, 1977). Panelists evaluated subsamples using eight-point descriptive scales for initial and overall tenderness (8 = extremely tender; 1 = extremely tough), amount of perceptible connective tissue (8 = no perceptible connective tissue; 1 = abundant perceptible connective tissue), juiciness (8 = extremely juicy; 1 = extremely dry) and flavor intensity (8 = extremely intense lamb flavor, 1 = extremely bland lamb flavor). The presence of any off-flavor was also noted.

Three cores (13-mm) were also removed parallel to the muscle fibers from each loin using a mechanical cork borer after the loins had been refrigerated overnight at 4 °C. Each core was then sheared three times using the Ottawa Texture Measuring System fitted with a Warner-Bratzler blade (Canners Machinery Ltd., Simcoc, ON, Canada) and mean shear force values were calculated and recorded.

A total of 3,320 lamb leg roasts (1,660 shank and 1,660 butt halves) were distributed to lamb-consuming households in 21 central Alberta regions for evaluation of acceptability of flavor, juiciness, tenderness and overall palatability. A total of 1,528 and 1,529 responses were obtained for shank and butt leg roasts, respectively.

The consuming households were instructed to prepare the roasts which they received using the method they normally employed for preparation of lamb leg roasts, but to record the cooking methods and times employed and the degree of doneness at the point of consumption. Following preparation each household was asked to reach a consensus rating for the acceptability of the flavor, juiciness, tenderness and overall palatability of the roasts which they received using a 5-point hedonic scale (1 = dislike extremely; 5 = like extremely).

Data for carcass and meat quality traits were analyzed using the general linear model (GLM) procedures of SAS (SAS, 1985). Sources of variation were: age, slaughter weight, gender, and the two-way and three-way interactions. Mean separation of significant main effects was by single degree of freedom linear contrast. Linear regression was used to detect significant relationships with advancing age and increasing slaughter weight and to evaluate relationships with cooking palatability and consumer acceptance traits (Puri and Mullen, 1980).

Results and Discussion

Ewe lamb carcasses generally had the most uniform and ram lamb carcasses generally had the least uniform fat covers (Table 1). Positive relationships in fat cover uniformity scores were observed with increasing slaughter weight in ram carcasses in age group 3 ($r^2 = 0.80$; $P < 0.05$); ewe carcasses in age groups 2, 3 and 4 ($r^2 = 0.90$, 1.00 and 0.94, respectively; $P < 0.01$); and wether carcasses in age groups 1, 2 ($r^2 = 0.86$ and 0.79; $P < 0.05$, respectively) and 4 ($r^2 = 0.92$; $P < 0.01$), indicating fat covers generally became more uniform as slaughter weight increased. Negative relationships in fat cover uniformity scores were observed with advancing age in ram carcasses in weight groups 4 and 5 ($r^2 = 0.89$ and 0.90; $P < 0.05$, respectively), indicating the fat cover on heavyweight ram lambs (greater than 58.6 kg) became less uniform as their chronological age increased.

Although the majority of all carcasses were determined to have either cream or pink colored fat, ram lambs produced a higher proportion of carcasses with slightly yellow and yellow subcutaneous fat than ewe lambs ($P < 0.05$; data not shown in tabular form). Ram lambs also produced a higher proportion of carcasses with slightly yellow fat than wether lambs ($P > 0.05$). These findings are consistent with previous results (Busboom et al., 1981; Crosue et al., 1981; Kruggel et al., 1982).

Ram carcasses generally had the least white fat and wether carcasses generally had whiter fat than ewe carcasses when they were 3 to 6 months of age, while ewe carcasses generally had whiter fat than wether carcasses when they were 9 to 12 months of age (Table 1). Negative relationships in subjective fat color scores were observed in ram and ewe carcasses in age group 1 ($r^2 = 0.82$; $P < 0.05$ and 0.91; $P < 0.05$, respectively); and ram carcasses in age group 3 ($r^2 = 0.72$; $P < 0.05$) with increasing slaughter weight, indicating the fat on carcasses in these subgroups became whiter as liveweight increased. A positive relationship in subjective fat color scores was observed with advancing age in ram carcasses in weight group 5 ($r^2 = 0.96$; $P < 0.01$), indicating that the fat on heavyweight ram carcasses (greater than 67.7 kg) became less white as they became chronologically older, supporting the results of Crouse et al. (1981).

Ewe carcasses generally had the most highly marbled loin-eyes and ram carcasses generally had the loin-eyes with the least marbling (Table 2) which supports the findings of Wiggins et al. (1976) but is contrary to the report of Dransfield et al. (1990). Negative relationships in marbling scores with increasing slaughter weight were detected in ram carcasses in age groups 1 ($r^2 = 0.79$; $P < 0.05$) and 2 ($r^2 = 0.86$; $P < 0.01$); and wether carcasses in age groups 1 ($r^2 = 0.85$; $P < 0.05$) and 2 ($r^2 = 0.92$; $P < 0.01$), but positive trends were observed with increasing slaughter weight in ram and ewe carcasses in age group 4 ($r^2 = 0.98$; $P < 0.01$ and $r^2 = 0.74$; $P < 0.05$, respectively). Such findings indicate marbling increased in young ram and wether carcasses (less than 9 months) with increasing slaughter weight which supports the findings of Ray and Kronmann (1971). However, the marbling decreased in older ram and ewe carcasses (greater than 12 months) as the slaughter weight increased. A positive relationship in marbling scores with advancing age was observed only in ewe carcasses in weight group 3 ($r^2 = 0.98$; $P < 0.01$). Such findings indicate marbling was not generally related to chronological age.

Since lamb carcasses have traditionally not been broken in commercial prac-

Table 1. Least-square means (LSM) and standard errors (SE) for subjective carcass traits.

		Slaughter weight group									
		1 31.8 to 40.4 kg		2 40.5 to 49.5 kg		3 50.0 to 58.6 kg		4 58.9 to 67.7 kg		5 68.2 to 76.8 kg	
Age group	Gender	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE
						Fat cover uniformity score					
1	Ram	2.21[b]	0.16	2.93[b]	0.15	3.36[b]	0.14	4.60[a]	0.13	4.50	0.55
(3 to 6	Ewe	2.44[b]	0.16	3.46[a]	0.15	4.11[a]	0.13	4.29[b]	0.15	–	–
months)	Wether	2.78[a]	0.15	3.27[a]	0.15	4.08[a]	0.16	4.29[b]	0.16	–	–
2	Ram	3.00	0.55	2.72[c]	0.12	3.16[b]	0.12	3.80[b]	0.12	4.25	0.13
(6 to 9	Ewe	3.00	0.78	3.40[a]	0.12	3.85[a]	0.12	4.24[a]	0.12	4.42	0.13
months)	Wether	–	–	3.00[b]	0.11	3.32[b]	0.11	3.98[b]	0.12	4.19	0.13
3	Ram	1.00[b]	0.78	1.76[c]	0.14	1.95[c]	0.12	2.59[c]	0.12	3.78[b]	0.13
(9 to 12	Ewe	–	–	3.08[a]	0.13	3.91[a]	0.12	4.16[a]	0.13	4.31[a]	0.13
months)	Wether	3.00[a]	0.78	2.53[b]	0.13	2.66[b]	0.12	3.18[b]	0.13	3.97[b]	0.13
4	Ram	–	–	3.00[ab]	0.78	2.18[c]	0.13	2.72[c]	0.13	3.03[b]	0.13
(12 to 15	Ewe	3.00	0.78	4.00[a]	0.45	3.83[a]	0.13	4.39[a]	0.13	4.54[a]	0.12
months)	Wether	–	–	2.50[b]	0.55	3.53[b]	0.13	3.86[b]	0.13	4.61[a]	0.11
						Fat color score					
1	Ram	3.29[a]	0.15	2.89[a]	0.14	2.82	0.13	2.14[b]	0.13	2.00	0.53
(3 to 6	Ewe	2.88[b]	0.15	2.69[a]	0.15	2.63	0.13	2.38[a]	0.15	–	–
months)	Wether	2.44[c]	0.15	2.38[b]	0.15	2.79	0.15	2.17[b]	0.15	–	–
2	Ram	3.00	0.53	2.46	0.12	2.51[ab]	0.11	2.22	0.12	2.36	0.13
(6 to 9	Ewe	3.00	0.75	2.42	0.11	2.27[b]	0.12	2.07	0.12	2.31	0.13
months)	Wether	–	–	2.54	0.11	2.56[a]	0.11	2.07	0.12	2.17	0.13
3	Ram	4.00[a]	0.75	3.81[a]	0.13	3.36[a]	0.11	3.42[a]	0.11	2.67	0.13
(9 to 12	Ewe	–	–	2.63[c]	0.12	2.36[c]	0.11	2.37[b]	0.12	2.47	0.12
months)	Wether	2.00[b]	0.75	3.05[b]	0.12	2.98[b]	0.11	3.18[a]	0.12	2.45	0.13
4	Ram	–	–	2.00	0.75	3.53[a]	0.13	2.86[a]	0.13	3.19[a]	0.12
(12 to 15	Ewe	2.00	0.75	2.00	0.43	2.26[b]	0.13	1.92[b]	0.13	2.03[b]	0.12
months)	Wether	–	–	2.00	0.53	2.50[b]	0.13	2.11[b]	0.12	2.07[b]	0.11

[a,b,c] Means in the same column and age group without a superscript or bearing a common superscript do not differ significantly ($P > 0.05$).

Table 2. Least-square means (LSM) and standard errors (SE) for marbling scores and Hunter color coordinates of the longissimus muscle of lambs in various age, weight and gender subclasses.

		Slaughter weight group									
		1 31.8 to 40.4 kg		2 40.5 to 49.5 kg		3 50.0 to 58.6 kg		4 58.9 to 67.7 kg		5 68.2 to 76.8 kg	
Age group	Gender	LSM	SE	LSM	SE	LSM	SE	Mean	SE	LSM	SE
						Marbling score					
1	Ram	7.92	0.22	7.79[a]	0.20	7.24[a]	0.19	7.31	0.18	7.00	0.77
(3 to 6	Ewe	7.96	0.23	7.04[b]	0.21	6.58[b]	0.18	7.12	0.22	–	–
months)	Wether	7.74	0.21	7.35[b]	0.21	6.96[ab]	0.22	7.12	0.22	–	–
2	Ram	9.00	1.08	7.10[a]	0.17	7.29[a]	0.16	6.95	0.17	7.06[a]	0.18
(6 to 9	Ewe	7.00	1.08	6.74[b]	0.17	6.73[b]	0.17	6.62	0.17	6.89[ab]	0.18
months)	Wether	–	–	7.08[ab]	0.16	6.84[b]	0.15	6.76	0.17	6.59[b]	0.19
3	Ram	7.00	0.77	7.62[a]	0.18	7.90[a]	0.17	7.38[a]	0.17	6.86	0.18
(9 to 12	Ewe	–	–	7.05[b]	0.18	6.77[c]	0.17	6.71[b]	0.18	6.74	0.18
months)	Wether	7.00	1.08	7.21[b]	0.18	7.28[b]	0.17	6.90[b]	0.17	6.71	0.18
4	Ram	–	–	7.00[a]	1.08	7.25[a]	0.19	7.37[a]	0.18	7.40[a]	0.18
(12 to 15	Ewe	6.00	1.08	6.67[b]	0.62	6.85[b]	0.19	6.51[c]	0.18	6.87[b]	0.18
months)	Wether	–	–	–	–	6.72[b]	0.18	6.89[b]	0.18	6.53[b]	0.17
						Hunter "L" values					
1	Ram	32.53[a]	0.44	31.31	0.40	30.04[b]	0.36	31.25	0.38	29.33	1.41
(3 to 6	Ewe	31.83[ab]	0.41	30.96	0.41	31.22[a]	0.35	30.83	0.41	–	–
months)	Wether	31.19[b]	0.39	30.57	0.39	30.32[ab]	0.41	30.96	0.41	–	–
2	Ram	34.64	1.41	30.81[a]	0.34	30.34[a]	0.30	30.04	0.31	29.65	0.33
(6 to 9	Ewe	34.85	1.99	30.62[a]	0.30	29.99[ab]	0.32	29.74	0.31	29.65	0.33
months)	Wether	–	–	29.24[b]	0.29	29.31[b]	0.28	29.19	0.31	29.93	0.33
3	Ram	32.36	1.41	30.81	0.34	30.37	0.31	30.37	0.31	30.48	0.35
(9 to 12	Ewe	–	–	30.55	0.32	30.42	0.30	30.13	0.34	30.25	0.35
months)	Wether	29.56	1.99	29.99	0.38	30.19	0.31	30.11	0.35	30.33	0.34
4	Ram	–	–	30.04	1.99	30.44[a]	0.35	29.74[a]	0.35	30.58	0.37
(12 to 15	Ewe	30.05	1.99	31.60	1.41	30.11[ab]	0.34	28.83[b]	0.34	30.46	0.33
months)	Wether	–	–	26.73	1.99	29.44[b]	0.34	30.01[a]	0.34	30.49	0.30
						Hunter "a" values					
1	Ram	6.12	0.23	6.15	0.20	6.36	0.19	6.95	0.20	7.16	0.72
(3 to 6	Ewe	5.97	0.21	6.00	0.21	6.14	0.18	6.70	0.21	–	–
months)	Wether	5.76	0.20	6.15	0.20	5.93	0.21	6.81	0.21	–	–
2	Ram	6.37	0.72	6.41	0.16	6.73	0.15	6.90	0.16	6.68	0.17
(6 to 9	Ewe	6.91	1.02	6.39	0.15	6.63	0.16	6.95	0.16	6.23	0.17
months)	Wether	–	–	6.51	0.15	6.52	0.14	6.66	0.16	7.12	0.17
3	Ram	6.64	0.72	6.22	0.17	6.59	0.16	6.63	0.16	6.86	0.18
(9 to 12	Ewe	–	–	6.74	0.16	6.70	0.15	6.79	0.17	6.48	0.18
months)	Wether	7.20	1.02	6.42	0.20	6.31	0.16	6.31	0.18	6.76	0.17
4	Ram	–	–	6.84	1.02	6.62	0.18	7.32	0.18	6.67	0.19
(12 to 15	Ewe	6.74	1.02	9.02	0.72	7.07	0.17	7.40	0.17	6.96	0.17
months)	Wether	–	–	5.80	1.02	6.85	0.17	7.27	0.17	7.29	0.15
						Hunter "b" values					
1	Ram	5.06[a]	0.15	4.68	0.14	4.37	0.12	4.78[a]	0.13	4.65	0.48
(3 to 6	Ewe	4.84[a]	0.14	4.56	0.14	4.61	0.12	4.35[b]	0.14	–	–
months)	Wether	4.40[b]	0.13	4.47	0.13	4.28	0.14	4.60[ab]	0.14	–	–
2	Ram	5.29	0.48	4.29[ab]	0.11	4.53[a]	0.10	4.48[a]	0.11	4.34[a]	0.11
(6 to 9	Ewe	6.36	0.68	4.58[a]	0.10	4.43[ab]	0.11	4.45[a]	0.11	3.96[b]	0.11
months)	Wether	–	–	4.22[b]	0.10	4.23[b]	0.10	4.14[b]	0.10	4.47[a]	0.11
3	Ram	4.68	0.48	4.07	0.12	4.26	0.10	4.10[ab]	0.11	4.05	0.12
(9 to 12	Ewe	–	–	4.22	0.11	4.16	0.10	4.20[a]	0.11	4.08	0.12
months)	Wether	4.24	0.68	4.08	0.13	4.00	0.11	3.85[b]	0.12	3.94	0.11
4	Ram	–	–	4.49	0.68	4.09	0.12	4.37	0.12	4.16	0.13
(12 to 15	Ewe	4.15	0.68	4.88	0.48	4.25	0.12	4.32	0.12	4.15	0.11
months)	Wether	–	–	3.46	0.68	4.08	0.12	4.22	0.11	4.16	0.10

[a,b,c] Means in the same column and age group without a superscript or bearing a common superscript do not differ significantly ($P > 0.05$).

tice, a number of carcass traits have been utilized to estimate marbling. Four of these traits are: 1) ribcage feathering; 2) light transmission; 3) flank firmness; and 4) streaking. These traits were all highly related to marbling score (ribcage feathering: r = 0.17; ribcage light transmission: r = 0.24; flank firmness: r = 0.24; flank streaking: r = -0.24) but accounted for 6% or less of the variation in marbling score.

Ewe carcasses generally had the most ribcage feathering and ram carcasses generally had the least ($P < 0.05$; data not shown in tabular form). Positive relationships in ribcage feathering scores with increasing slaughter weight were observed in ram carcasses in age groups 3 and 4 ($r^2 = 0.78$ and 0.82; $P < 0.05$, respectively); ewe carcasses in age groups 1 ($r^2 = 0.88$; $P < 0.05$), 3 and 4 ($r^2 = 0.95$ and 0.93; $P < 0.01$, respectively); and wether carcasses in age groups 2 ($r^2 = 0.88$; $P < 0.05$), 3 ($r^2 = 0.96$; $P < 0.01$) and 4 ($r^2 = 0.80$; $P < 0.05$), indicating the amount of ribcage feathering increased with slaughter weight, particularly in older lambs (greater than 9 months), which is consistent with the report of Ray and Kronmann (1971). A negative relationship in ribcage feathering scores with advancing age was observed only in ewes in weight group 2 ($r^2 = 0.88$; $P < 0.05$) indicating, in general, that the amount of ribcage feathering was not related to chronological age.

Ram carcasses generally had the most translucent ribcages and ewe lamb carcasses generally had the most opaque ribcages ($P < 0.05$; data not presented in tabular form). Negative relationships in ribcage light transmission scores were detected with increasing slaughter weight in ram lamb carcasses in age groups 1 and 2 ($r^2 = 0.83$ and 0.78; $P < 0.05$, respectively) and 3 ($r^2 = 0.91$; $P < 0.01$); ewe carcasses in age groups 1 ($r^2 = 0.97$; $P < 0.01$) and 2 ($r^2 = 0.73$; $P < 0.05$); and wether carcasses in age groups 1, 2 and 4 ($r^2 = 0.86$, 0.84 and 0.91; $P < 0.05$, respectively), indicating the ribcages of lambs became more opaque as slaughter weight increased particularly in young lambs (less than 9 months). No relationships in ribcage light transmission scores were detected with advancing age ($P > 0.05$), indicating the translucency of lamb ribcages is not related to chronological age.

Ewe carcasses generally had the firmest flanks and ram carcasses generally had the least firmness in their flanks ($P < 0.05$; data not presented in tabular form) which is contrary to the report of Wiggins et al. (1976). Positive relationships in flank firmness scores with increasing slaughter weight were observed in ram carcasses in age groups 1 ($r^2 = 0.89$; $P < 0.01$) and 2 ($r^2 = 0.72$; $P < 0.05$); ewe carcasses in age groups 1, 2 and 3 ($r^2 = 0.98$, 0.95 and 0.98; $P < 0.01$, respectively); and wether carcasses in age group 2 ($r^2 = 0.90$; $P < 0.05$), indicating flank firmness generally increased with slaughter weight, particularly in young lamb carcasses (less than 9 months). Negative relationships in flank firmness scores with advancing age were detected only in ewe and wether carcasses in weight group 3 ($r^2 = 0.86$ and 0.83, respectively; $P < 0.05$) indicating flank firmness was not generally related to chronological age.

Ewe carcasses generally had the most flank streaking and ram carcasses generally had the least ($P < 0.05$; data not presented in tabular form). Positive relationships in flank streaking scores were observed with increasing slaughter weight in ewe carcasses in age groups 1 ($r^2 = 0.81$; $P < 0.05$), 3 ($r^2 = 0.93$; $P < 0.01$) and 4 ($r^2 = 0.68$; $P < 0.05$); and wether carcasses in age groups 2 and 4 ($r^2 = 0.94$ and 0.96; $P < 0.01$, respectively), indicating flank streaking increased with slaughter weight in ewe and wether carcasses. A negative relationship in flank streaking scores with advancing age was detected in wether carcasses in weight group 2 ($r^2 = 0.89$; $P < 0.05$). However, a positive relationship in flank streaking scores with advancing age was observed in ewe carcasses in weight group 2 ($r^2 = 0.91$; $P < 0.01$). This lack of consistency in relationships with advancing age indicates flank streaking is not related to chronological age except in specific subgroups.

Although Dransfield et al. (1990) reported muscle color did not differ due to gender, ram carcasses tended to have the lightest colored loin-eyes, based upon Hunter "L" values (Table 2). Negative relationships in Hunter "L" values with increasing slaughter weight were observed in ram loins in age groups 1 ($r^2 = 0.72$; $P < 0.05$), 2 ($r^2 = 0.95$; $P < 0.01$) and 3 ($r^2 = 0.89$; $P < 0.05$); and ewe loins in age groups 1 ($r^2 = 0.85$; $P < 0.05$) and 2 ($r^2 = 0.93$; $P < 0.01$). However, positive relationships in Hunter "L" values with increasing liveweight were detected in wether loins in age group 3 and 4 ($r^2 = 0.98$ and 1.00; $P < 0.01$, respectively). These findings indicate the loin-eyes of young (less than 9 months) ram and ewe carcasses generally became darker with increases in slaughter weight, while the loin-eyes of older (greater than 9 months) wether carcasses generally became lighter with increases in slaughter weight. Positive relationships in Hunter "L" values with advancing age were detected in ram loins in weight groups 3 ($r^2 = 0.88$; $P < 0.05$) and 5 ($r^2 = 0.91$, $P < 0.01$); ewe loins in weight group 5 ($r^2 = 1.00$; $P < 0.001$); and wether loins in weight group 5 ($r^2 = 1.00$; $P < 0.001$). However, negative relationships in Hunter "L" values with advancing age were observed in ram loins in weight group 2 ($r^2 = 0.87$; $P < 0.05$); and ewe loins in weight group 4 ($r^2 = 0.77$; $P < 0.05$). Such findings indicate the color of the loin-eyes of heavy lamb carcasses (greater than 67.7 kg live) became lighter with advancing age.

Differences among genders in Hunter "a" values were not observed ($P > 0.05$) in any of the age/weight subclasses (Table 2). Therefore, the redness of the loin-eye muscle was not influenced by gender. The only positive relationships in Hunter "a" values with increasing slaughter weight was in wether loins in age group 4 ($r^2 = 0.98$; $P < 0.01$), indicating the redness of the loin-eye muscle increased with slaughter weight only in older wether loins (greater than 12 months; hue angle decreased progressively, $r^2 = 0.57$; $P < 0.10$). Positive relationships in Hunter "a" values with advancing age were detected in ewe loins in

weight group 3 (r^2 = 0.96; P < 0.01); and wether loins in weight group 3 (r^2 = 0.77; P < 0.05), indicating the redness of the loin-eye muscle generally increased with advancing age in these subclasses (hue angle decreased progressively, r^2 = 0.97 and 0.97, respectively; P < 0.001).

Ram loin-eyes generally had the highest Hunter "b" values and contained the most yellow in their color (Table 2). Negative relationships in Hunter "b" values with increasing slaughter weight were observed in ram loins in age groups 2 (r^2 = 0.76; P < 0.05; hue angle decreased, r^2 = 0.90; P < 0.01) and 3 (r^2 = 0.82; P < 0.05; hue angle decreased, r^2 = 0.89; P < 0.01); ewe loins in age groups 1 (r^2 = 0.85; P < 0.05; hue angle decreased, r^2 = 0.72; P < 0.10) and 2 (r^2 = 0.94; P < 0.01; hue angle decreased, r^2 = 0.96; P < 0.001); and wether loins in age group 3 (r^2 = 0.86; P < 0.01; no change in hue angle, r^2 = 0.00). However, a positive relationship in Hunter "b" values with increasing slaughter weight was detected in wether loins in age group 4 (r^2 = 0.95; P < 0.01; no change in hue angle, r^2 = 0.56). Such findings indicate the amount of yellow in the color of loin-eye muscles generally decreased with increases in the slaughter weight of young ram and ewe lambs (less than 12 months). Negative relationships in Hunter "b" values with advancing age were detected in ram loins in weight group 5 (r^2 = 0.81; P < 0.05; no change in hue angle, r^2 = 0.32), ewe loins in weight group 3 (r^2 = 0.80; P < 0.05; hue angle decreased, r^2 = 0.97; P < 0.001); and wether loins in weight group 2 (r^2 = 0.86; P < 0.05; hue angle decreased, r^2 = 0.95; P < 0.01). However, a positive relationship in the Hunter "b" values of ewe loins in weight group 5 (r^2 = 0.99; P < 0.01; hue angle decreased, r^2 = 0.75; P < 0.10) was detected. Such results indicate the amount of yellow in loin-eye color was generally not related to chronological age.

Percent transmission of the carcass lean, a chemical measure of protein denatuation and muscle functional properties, did not differ among

Table 3. Least-square means (LSM) and standard errors (SE) for percent transmission and percent expressible juice of the pooled carcass lean from lamb carcasses in various age, weight and gender subclasses.

		Slaughter weight group									
		1 31.8 to 40.4 kg		2 40.5 to 49.5 kg		3 50.0 to 58.6 kg		4 58.9 to 67.7 kg		5 68.2 to 76.8 kg	
Age group	Gender	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE
		Percent transmission									
1	Ram	32.34	2.43	34.32	2.17	33.88	1.98	33.09	2.09	28.70	7.67
(3 to 6	Ewe	34.85	2.21	38.69	2.21	39.79	1.92	42.22	2.26	–	–
months)	Wether	38.41	2.13	34.42	2.13	38.92	2.21	40.63	2.21	–	–
2	Ram	40.10	7.67	36.42	1.76	37.91	1.62	39.17	1.72	37.89	1.81
(6 to 9	Ewe	21.55	10.85	33.45	1.65	32.59	1.76	35.66	1.69	41.46	1.81
months)	Wether	–	–	31.95	1.57	36.64	1.53	42.15	1.67	45.05	1.81
3	Ram	51.00	7.67	47.51	1.86	47.16	1.67	48.33	1.72	46.73	1.89
(9 to 12	Ewe	–	–	43.17	1.76	43.24	1.64	52.72	1.83	46.61	1.92
months)	Wether	41.80	10.85	40.92	2.09	42.15	1.72	44.82	1.92	41.62	1.83
4	Ram	–	–	42.65	10.85	42.31	1.92	37.59	1.89	42.28	2.01
(12 to 15	Ewe	36.95	10.85	58.57	7.67	41.59	1.86	39.05	1.86	52.06	1.81
months)	Wether	–	–	55.65	10.85	39.81	1.86	41.88	1.83	47.43	1.62
		Proportion expressible juice (g/kg^{-1})									
1	Ram	20.52	0.61	22.29^{a}	0.55	21.64	0.50	22.16	0.53	21.55	1.94
(3 to 6	Ewe	19.76	0.56	21.35^{ab}	0.56	22.13	0.49	21.78	0.57	–	–
months)	Wether	20.96	0.54	20.36^{b}	0.54	22.17	0.56	22.12	0.56	–	–
2	Ram	25.12^{a}	1.94	21.44^{a}	0.45	21.59	0.41	22.30	0.43	21.78^{a}	0.46
(6 to 9	Ewe	16.75^{b}	2.74	20.21^{ab}	0.42	20.51	0.45	21.59	0.43	21.12^{b}	0.46
months)	Wether	–	–	19.30^{b}	0.40	20.61	0.39	22.06	0.42	22.00^{a}	0.46
3	Ram	21.37	1.94	22.66^{a}	0.47	22.43	0.42	22.08	0.43	21.55^{ab}	0.48
(9 to 12	Ewe	–	–	21.16^{b}	0.45	21.58	0.41	22.40	0.46	22.19^{a}	0.49
months)	Wether	23.90	2.74	19.74^{c}	0.53	21.51	0.43	21.51	0.49	20.62^{b}	0.46
4	Ram	–	–	18.05^{b}	2.74	21.78^{a}	0.49	21.18^{a}	0.48	21.28	0.51
(12 to 15	Ewe	22.55	2.74	21.07^{ab}	1.94	20.20^{b}	0.47	19.67^{b}	0.47	22.27	0.46
months)	Wether	–	–	25.50^{a}	2.74	19.77^{b}	0.47	20.44^{ab}	0.46	22.10	0.41

^{a,b,c} Means in the same column and age group without a superscript or bearing a common superscript do not differ significantly (P > 0.05).

genders ($P > 0.05$) in any of the age/weight subclasses (Table 3). Positive relationships in percent transmission with increasing slaughter weight were detected in ewe carcasses in age group 2 ($r^2 = 0.95$; $P < 0.01$) and wether carcasses in age group 2 ($r^2 = 0.86$; $P < 0.05$). However, a negative relationship in percent transmission with increasing slaughter weight was observed in ram carcasses in age group 3 ($r^2 = 0.78$; $P < 0.05$). Such inconsistency in relationships indicates percent transmission generally was not related to slaughter weight. Positive relationships in percent transmission with advancing age were observed in ewe carcasses in weight group 5 ($r^2 = 0.93$; $P < 0.01$), indicating a progressive decrease in meat quality with advancing age in heavyweight ewe lamb carcasses (greater than 68.2 kg live).

Ram carcass lean generally had the lowest water binding capacity based upon expressible juice determinations, and ewe carcass lean had the highest (Table 3). Positive relationships in the expressible juice from carcass lean with increasing slaughter weight were detected in ram carcasses in age group 4 ($r^2 = 0.85$; $P < 0.05$); ewe carcasses in age groups 1 ($r^2 = 0.91$; $P < 0.05$) and 2 ($r^2 = 0.93$; $P < 0.01$); and wether carcasses in age group 2 ($r^2 = 0.87$; $P < 0.05$). However, a negative relationship in expressible juice with increasing slaughter weight was observed in ram carcasses in age group 2 ($r^2 = 0.70$; $P < 0.05$). Such inconsistency in relationships indicates the water binding capacity of carcass lean generally is not related to slaughter weight, which supports previous findings (Sanudo et al., 1996). Positive relationships in expressible juice with advancing age were detected in ewe carcasses in weight group 5 ($r^2 = 0.95$; $P < 0.05$), indicating the water binding capacity of carcass lean decreased with advancing age in heavyweight ewe carcasses (greater than 68.2 kg live).

Cooking times were positively related to ribcage feathering ($r = 0.40$, $P < 0.001$), flank firmness ($r = 0.47$, $P < 0.001$) and flank streaking ($r = 0.43$; $P < 0.001$) scores and Hunter "a" values ($r = 0.10$; $P < 0.001$). Cooking times were negatively related to marbling ($r = -0.17$; $P < 0.001$) and ribcage light transmission ($r = -0.47$; $P < 0.001$) scores and Hunter "L" values ($r = -0.08$; $P < 0.01$). These results indicate darker and redder cuts with higher intramuscular fat contents require longer cooking times.

Perceived degree of doneness was positively related to marbling ($r = 0.07$; $P < 0.01$) and ribcage light transmission ($r = 0.10$; $P < 0.001$) scores; and negatively related to ribcage feathering ($r = -0.07$; $P < 0.001$), flank firmness ($r = -0.05$; $P < 0.05$) and flank streaking ($r = -0.05$; $P < 0.05$) scores and Hunter "a" values ($r = -0.08$; $P < 0.01$). These results indicate redder cuts with higher intramuscular fat contents were perceived to be less well done when cooked to the same internal temperature.

Drip, evaporative and total cooking losses were negatively related to marbling ($r = -0.20$, -0.10 and -0.17, respectively; $P < 0.001$) and ribcage light transmission ($r = -0.50$, -0.32 and -0.47, respectively; $P < 0.001$) scores and Hunter "L" ($r = -0.05$; $P < 0.05$, -0.09; $P < 0.001$ and -0.08; $P < 0.01$, respectively) and "b" values ($r = -0.10$, -0.11 and -0.12; $P < 0.001$, respectively); and positively related to ribcage feathering ($r = 0.54$, 0.34 and 0.50; $P < 0.001$, respectively), flank firmness ($r = 0.59$, 0.27 and 0.59; $P < 0.001$, respectively) and flank streaking ($r = 0.69$, 0.28 and 0.57; $P < 0.001$, respectively) scores, Hunter "a" values ($r = 0.14$, 0.10 and 0.14; $P < 0.001$, respectively) and percent transmission ($r = 0.22$, 0.13 and 0.20; $P < 0.001$, respectively). Evaporative and total cooking losses were also positively related to percent expressible juice ($r = 0.08$ and 0.07; $P < 0.01$, respectively). These findings indicate redder and darker cuts, with less yellow, lower percent transmission and expressible juice and lower intramuscular fat contents sustained lower cooking losses, from both drip and evaporation.

Initial and overall tenderness and amount of perceptible connective tissue were negatively related to marbling ($r = -0.08$; $P < 0.01$, -0.09; $P < 0.01$ and -0.10; $P < 0.001$, respectively) and ribcage light transmission ($r = -0.19$, -0.21 and -0.12; $P < 0.001$, respectively) scores; and positively related to ribcage feathering ($r = 0.19$, 0.20 and 0.19; $P < 0.001$, respectively), flank firmness ($r = 0.26$, 0.28 and 0.27; $P < 0.001$, respectively) and flank streaking ($r = 0.27$, 0.29 and 0.29; $P < 0.001$, respectively) scores and percent expressible juice ($r = 0.08$; $P < 0.01$, 0.05; $P < 0.05$ and 0.12; $P < 0.001$, respectively) which supports the findings of Smith et al. (1976) that fatness increased tenderness. Amount of perceptible connective tissue was also negatively related to Hunter "b" values ($r = -0.07$; $P < 0.01$) and positively related to Hunter "a" values ($r = 0.06$; $P < 0.05$) and percent transmission ($r = 0.23$; $P < 0.001$). Shear force values were negatively related to ribcage feathering, ($r = 0.15$; $P < 0.001$), flank firmness ($r = -0.10$; $P < 0.001$) and flank streaking ($r = -0.23$; $P < 0.001$) scores, percent transmission ($r = -0.17$; $P < 0.001$), percent expressible juice ($r = -0.11$; $P < 0.001$) and Hunter "L" values ($r = -0.06$, $P < 0.05$); and positively related to marbling ($r = 0.10$; $P < 0.001$) and ribcage light transmission ($r = 0.08$; $P < 0.01$) scores. These results indicate cuts with higher intramuscular fat contents, lower percent transmission values and less expressible juice are more tender and contain less perceptible connective tissue. They also indicate redder cuts which contain less yellow, contain less perceptible connective tissue. Taste panel juiciness ratings were negatively related to ribcage feathering ($r = -0.07$; $P < 0.01$), flank firmness ($r = -0.18$; $P < 0.001$) and flank streaking ($r = -0.09$; $P < 0.01$) scores; and positively related to ribcage light transmission ($r = 0.12$; $P < 0.001$) scores and percent transmission ($r = 0.06$; $P < 0.05$), indicating cuts with higher intramuscular fat contents were less juicy while cuts with higher percent transmission were more juicy. Lamb flavor intensity was positively related to ribcage feathering ($r = 0.11$; $P < 0.001$) and flank streaking ($r = 0.06$; $P < 0.01$) scores, Hunter "a" values ($r = 0.06$; $P < 0.01$), percent transmission ($r = 0.12$; $P < 0.001$) and percent expressible juice ($r = 0.05$, $P < 0.05$); and negatively related to marbling ($r =$

-0.08; P < 0.01) and ribcage light transmission (r = -0.10; P < 0.001) scores. These findings indicate redder cuts containing more intramuscular fat and expressible juice with higher percent transmissions were more intense in lamb flavor.

The consumer flavor acceptability of butt leg roasts was negatively related to marbling score (r = -0.07; P < 0.01); and positively related to flank firmness score (r = 0.05; P < 0.05); while the consumer flavor acceptability of shank leg roasts was negatively related to ribcage light transmission scores (r = -0.05; P < 0.05). These results indicate leg roasts with higher intramuscular fat contents have more acceptable flavor. The juiciness acceptability of butt leg roasts was positively related to ribcage feathering (r = 0.09; P < 0.001), flank firmness (r = 0.09; P < 0.001) and flank streaking (r = 0.07; P < 0.01) scores; and negatively related to ribcage light transmission scores (r = -0.11; P < 0.001); while the juiciness acceptability of shank leg roasts was positively related to ribcage feathering scores (r = 0.07; P < 0.01) and percent transmission (r = 0.10; P < 0.001). These results indicate juiciness acceptability to consumers was enhanced by greater intramuscular fat content, particularly in butt roasts and by higher percent transmission in shank roasts. The tenderness acceptability of butt leg roasts was positively related to ribcage feathering (r = 0.08; P < 0.01), flank firmness (r = 0.07; P < 0.01) and flank streaking (r = 0.06; P < 0.05) scores, Hunter "a" values (r = 0.06; P < 0.05) and percent expressible juice (r = 0.08; P < 0.01); and negatively related to ribcage light transmission scores (r = -0.10; P < 0.001), indicating redder cuts with more expressible juice and intramuscular fat are more acceptable to consumers for tenderness. The tenderness acceptability of shank leg roasts was positively related to ribcage feathering (r = 0.10; P < 0.001), flank firmness (r = 0.10; P < 0.001) and flank streaking (r = 0.10, P < 0.001) scores, Hunter "L" values (r = 0.05; P < 0.05), percent transmission (r = 0.06; P < 0.05) and percent expressible juice (r = 0.06, P < 0.05), indicating lighter colored cuts with a greater percent transmission and more expressible juice and intramuscular fat were more acceptable in tenderness to consumers. The overall palatability of butt leg roasts, as assessed by consumers, was positively related to ribcage feathering (r = 0.06; P < 0.05), flank firmness (r = 0.09; P < 0.001) and flank streaking (r = 0.06; P < 0.05) scores and Hunter "a" values (r = 0.05; P < 0.05), indicating redder butt leg roasts with more intramuscular fat were more acceptable to consumers in palatability.

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News & Notes

Call for Submissions

The American Sheep Industry has committed to the continued sponsorship of the *Sheep & Goat Research Journal* at least through Volume 14. Other parties have expressed an interest in assuming this role at a future date. Please forward your subscriptions ($30.00) to the ASI office along with any manuscripts to be considered for Volume 14.

Minutes of the Improvement of Wool Quality Meeting

A two-day meeting was held in Denver, CO, on September 29 to 30, 1997, to discuss the future direction of the American Sheep Industry (ASI) and wool quality improvement programs (WQIP). Represented at the meeting were the major U.S. wool processors, buyers, growers, warehouse managers, classers and research/extension personnel.

Out of all the discussion regarding U.S. wool quality, the processors made the strongest and most significant statement. For the first time all processors (Burlington Industries, Provost-LefeLvre, Wellman, Forte) were in agreement that the U.S. wool industry must do a better job of producing, preparing, packaging, and marketing wool in order to remain competitive with the rest of the world. These same individuals complimented efforts by growers on wool preparation, but also encouraged growers to improve preparation and packaging. Growers need to move to poly packs or warehouse bulk bales with a film wrap. Wool genetics need to be implemented. This does not mean that growers should focus only on wool, but there is a need to consider wool aspects in breeding and selection. Marketing considerations included strategies for a more efficient system, consolidated offerings, pricing on clean basis and utilization of objective measurement. They felt that warehouses are going to become more important in providing service to growers and buyers in the marketing process.

Wool quality is an ongoing problem worldwide. Australia, New Zealand, South Africa and South American wool-producing countries have quality programs in place. Even though some of the processors indicated U.S. wools are better than they perceived, U.S. wool has a high risk of contamination from poly, stain and other fibers. Proper shearing and preparation can reduce the problems of stain and second-cuts, but poly must be addressed in the total operation.

All present agreed the buyers/processors are key in driving the program through the manner they purchase wool and send signals back to the grower.

At the meetings end, the processors agreed to canvass their segment for a unified standard approach and to meet with a selected grower group to define basic standards for U.S. wools, which will be announced in January of 1998 and fully implemented by January 1, 1999.

–prepared by Ronald Pope; PMCI

Sheep & Goat Research Journal
Guidelines for Authors

Objective

The aim of the Sheep & Goat Research Journal is to provide a publication of sheep and goat research findings which can be used by scientists, educators, Extension agents and sheep and goat producers alike. The specific goal of the Journal is to gather and distribute current research information on all phases of sheep and goat production and to encourage producer use of research which has practical application. The Journal is published three times each year.

Editorial Policy

We are most interested in publishing articles of research relating to all aspects of sheep and goat production and marketing. Articles should relate and contribute to the advancement of the American sheep and goat industries and/or their products. All research manuscripts must represent unpublished original research. The submission of review articles is encouraged but will require review as well as those reporting original research. Articles which promote commercial products or services will not be approved for publication. Conclusions reached must be supported by research results. An orientation to practical applied research which may be useful to the sheep and goat industries is encouraged. At least one author of each manuscript must subscribe to the Journal.

Review Process

Manuscripts will be subject to critical review by an editorial board or others designated by the editor. Authors will be notified of acceptance or rejection of papers by mail. Manuscripts needing revision will be returned to authors and should be revised and returned by the deadline indicated. When papers are accepted for publication, the authors must send a floppy disk with the manuscript in the ASCII file format along with two hard copies. Papers not suitable for publication will be returned to the authors with a statement of reasons for rejection. Consult the Sheep & Goat Research Journal Editorial Policy and Procedures for details of the technical requirements for manuscripts submitted to the Journal.

Guidelines

Several sources were consulted, including the Journal of Animal Science and the Council of Biology Editors, Inc., when preparing these guidelines. Though the nature of the Journal is such that relatively few regulations are needed on style and form, we have attempted to standardize the manner in which the material is published as a service to Journal subscribers. Following are general guidelines for style and form.

Format

Manuscripts must be typed and double-spaced; five copies must be submitted. The lines on all pages including those pages for Literature Cited and Figure Legends must be numbered in the left margin beginning with the numeral one (1) at the top of the page. Tables should be as few and as simple as is feasible for presentation of the essential data; tables should be typed and double-spaced. Each table should be on a separate sheet. All figures used in the text must be camera-ready. The author will be billed at full cost if figure preparation is required.

Research manuscripts should follow the format of:

1st	**Summary** (250 words or less)
2nd	**Key Words** (up to 6)
3rd	**Introduction**
4th	**Materials and Methods**
5th	**Results and Discussion**
6th	**Conclusions**
7th	**Literature Cited**

In citing literature in the text, use both authors if there are only two. If there are more than two, use the first author and "et al." Authors are asked to provide "interpretive summaries" for use by the sheep and goat industries in other media.

Proofing

Primary authors will receive galley proofs of articles. Corrected proofs should be returned by the deadline indicated. Failure to do so will result in delay of article publication.

Reprints

Fifty reprints of each article will be provided at no cost to the primary author. When galley proofs are sent, the author will be requested to complete a reprint order form requesting free and any additional reprints and provide the name of the institution, agency or individual responsible for the reprint charges.

Charge

The publication charge for the Sheep & Goat Research Journal is $60.00 per page and position announcements are $30.00 per quarter-page or less. Contributors will be billed following publication. All manuscripts and correspondence should be addressed to: Sheep & Goat Research Journal, 6911 South Yosemite Street, Englewood, CO 80112-1414; unless noted otherwise on materials received from the editorial staff.