Sheep & Goat Research Journal
Volume 32, 2017 - June

Performance and Gastrointestinal Nematode Control When Meat-Goat Kids Grazed Chicory, Birdsfoot Trefoil, or Red Clover Pastures

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Acknowledgements

The authors thank Jeffrey B. Ellison, Sean Greene, Kenneth N. Harless, Edward C. Lester, Carol S. McClung, R. Brody Meadows, J. Mark Peele, and John P. Snuffer for their invaluable efforts in pasture management, livestock care and management, data collection, and laboratory analyses. Much appreciation and thanks is also extended to the staff and student workers in the Parasitology Laboratory, Virginia-Maryland Regional College of Veterinary Medicine, Virginia Tech, Blacksburg, Va. for conducting fecal egg count analyses over the two years of this study. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

Summary

In most pasture-based, meat-goat production systems, a major management challenge is control of gastrointestinal nematodes (GIN). Use of legumes and forbs that contain plant secondary compounds may reduce fecal egg count (FEC) expressed as eggs per g of fresh feces (epg) and/or improve overall protein nutrition to help animals better tolerate effects of GIN parasitism. This research monitored performance, FEC, FAMACHA© scores, and number of doses of dewormer administered to meat-goat kids grazing chicory (*Cichorium intybus* L.; CHIC), birdsfoot trefoil (*Lotus corniculatus* L.; BFT), or red clover (*Trifolium pretense* L.; RCL) pastures. Goat kids grazing RCL (68.9 g/d ± 5 g/d) had greater ($P < 0.03$) overall average daily gain compared to those grazing CHIC (35 g/d ± 5 g/d); BFT (53.2 g/d ± 5 g/d) was intermediate. When averaged over the season, there was a weak trend ($P = 0.19$) for goat kids grazing CHIC (2,034 epg) to have greater FEC compared to RCL (1,194 epg); BFT (1,718 epg) was intermediate. Typically goat kids grazing CHIC had greater ($P < 0.001$) monthly FAMACHA© scores than those grazing RCL with scores for goats grazing BFT similar to RCL. There was a weak trend for number of dewormer doses administered based on FAMACHA© scores to be less ($P = 0.13$) when goats grazed RCL (5.5 doses) compared to CHIC (6.3 doses); BFT (6.1 doses) was intermediate. Grazing red clover pasture, and to some extent birdsfoot trefoil, appeared to have a beneficial effect on meat-goat kid performance and on GIN-parasite infection (low FEC) in comparison to chicory pastures.

Key Words: Birdsfoot Trefoil, Chicory, Goats, Parasites, Performance, Red Clover

Introduction

Production of meat goats supplies both live animals and meat for many ethnic and health-product markets in the United States (Liu et al., 2013). In most pasture-based, small-ruminant production systems, a major management challenge is control of gastrointestinal nematodes (GIN). Overloads of GIN, especially the barberpole worm (*Haemonchus contortus* L.) can severely reduce goat-kid weight gain (Zajac and Moore, 1993). Many currently available anthelmintics are becoming ineffective in controlling GIN due to parasite resistance to these drugs (Terrill et al., 2001; Howell et al., 2008). If not controlled, *Haemonchus*, a blood feeder, can cause severe anemia resulting in poor weight gain and deteriorating health in goats.

The use of the FAMACHA© system by producers to determine the degree of anemia and need for administering dewormer to individual animals can help to slow the rate of resistance of GIN to anthelmintic drugs (Kaplan et al, 2004). Management options for grazing livestock can also help reduce effects of GIN infection. Use of legumes and forbs can improve overall protein nutrition to boost the immune system and improve animal resilience to *Haemonchus*. When finishing livestock on pasture, resilience is defined as an animal's ability to maintain body weight gain in spite of increasing GIN burdens (Albers et al., 1987). In addition, grazing management using rotational stocking (Burke et al., 2009) can break the worm life cycle and help maintain swards with high nutritive value (increased energy and protein) for increased GIN resilience in meat goats (Turner et al., 2014).

Some grasses, legumes, and forbs contain plant secondary compounds that may reduce GIN loads. Forage chicory (*Cichorium intybus* L.) is a perennial forb, which contains a group of secondary plant compounds (sequiterpene lactones; Foster et al., 2011) that can potentially reduce GIN-parasite infections (Marley et al., 2003). Birdsfoot trefoil (*Lotus corniculatus* L.) is a perennial legume that contains condensed tannins (CT) and can improve protein utilization in ruminants (Naumann et al., 2013) and reduce fecal egg count (FEC; Min et al., 1999; Terrill et al., 2009). Red clover (*Trifolium pretense* L.) is a legume containing the secondary plant compound, polyphenol oxidase, which increases rumen-undegradable protein for improved protein nutrition in ruminants (Broderick and Albrecht, 1997).

The objective of this research was to monitor FEC, FAMACHA© scores, selective blood parameters, and the number of doses of dewormer administered to meat-goat kids when finished on pastures of chicory (CHIC), birdsfoot trefoil (BFT), or red clover (RCL).

Materials and Methods

All experimental procedures were previously reviewed and approved by the Institutional Animal Care and Use Committee, Appalachian Farming Systems Research Center, Beaver, W.Va., United States. The experiment was conducted for two years during the 2009 and 2010 growing seasons in Beaver, W.Va. Details as to the establishment, seeding and agronomic management are reported by Cassida and Turner (2016). In summary, replicated 0.2-ha pastures of CHIC (cv. Oasis); BFT(cv. Pardee); or RCL (cv. Cinnamon) were established with prairie bromegrass (*Bromus catharticus* Bahl. cv. Lakota). Each of nine pasture strips was divided into 10 paddocks (14.6 m x 14.6 m). Pastures were managed with rotational stocking using 72 meat-goat kids (beginning mean BW 24.2 kg ± 0.6 kg). Beginning in late May through late September/early October, kids were moved approximately every 4 d resulting in about a 36-d rest period each year. Animal BW were determined every 14 d throughout the grazing season. Animals had access to water and trace-mineralized salt (Southern States Co-Op Inc., Beckley, W.Va.) at all times.

Prior to the start of grazing each year, all animals were orally dewormed with a combination of two classes of anthelmintics: benzimidazoleal [bendazole (Valbazen®; Zoetis, Florham Park, N.J.) at 15 mg per kg BW] and macrocyclic lactone [ivermectin (Ivomec®; Meriel LLC, Duluth, Ga.) at 400 μg per kg BW]. After initial deworming, which reduced FEC to approx. < 750 eggs per gram of fresh feces (epg) each year, a FAMACHA© score from each animal was evaluated and recorded every 14 d, and individual animals were administered a combination of the two dewormers listed above each time an animal's FAMACHA© score was 3 or greater. Also, every 14 d, feces were collected via grab samples from the rectum of each animal, placed in plastic bags, transported in chilled, insulated boxes, and refrigerated at 1°C until FEC were determined using a modified McMaster technique (Zajac and Conboy, 2006). The detection limit of the test was 50 epg. An overall FEC was calculated by summing counts of strongylid type + *Nematodirus* eggs. Periodically throughout the grazing season, subsamples of feces were combined by pasture type, cultured for 2 wk (Zajac and Conboy, 2006), and third-stage larvae were classified to determine percent *H. contortus* in the larval population.

At the end of each month (every 28 d), 10 ml of blood were collected via jugular venipuncture from each animal and packed cell volume (PCV) was determined via centrifugation to measure degree of anemia. The remainder of blood was allowed to clot, centrifuged to isolate serum, and serum stored at -20°C until analyzed for total protein and albumin using automated procedures on an Express Plus Chemistry Analyzer (PoleStar Labs, Escondido, Calif.). Blood globulin was determined by difference (total protein minus albumin) to assess activity of the immune system.

Statistics.

For this evaluation, a database was used that had the same time frame each year in order to evaluate the number of doses of dewormer administered to the animals during this critical time beginning in June through mid-September. In 2009, data collection began on 9 June, while in 2010 data collection was initiated on 8 June; then in each year, data were collected every 14 d and ended on 15 September and 14 September, respectively. In 2009, because of health concerns for the majority of the grazing animals, an extra FAMACHA© assessment was done the following week after the first-scheduled assessment in August. On that date, all animals grazing CHIC, BFT and RCL pastures were administered the two dewormers; this data was not included in the overall evaluation of the study because there was no similar concern during the same time frame in August 2010.

For the 120-d time frame in this evaluation, biweekly BW was used to calculate an overall average daily gain (ADG).

The BW and ADG during this time frame were analyzed using PROC MIXED of SAS (SAS Inst. Inc., Cary, N.C.).

The FEC and biweekly FAMACHA© were analyzed using PROC MIXED in SAS (SAS, Inst. Inc., Cary, N.C.). The FEC data were transformed via logarithm [as $\log_{10}$ (FEC + 1)] to accommodate a count of zero; transformed data statistics were used for statistical inferences, while untransformed least square means were presented. The FEC data and bi-weekly FAMACHA© score data were analyzed using day as a repeated measure with the following linear model: rep (random) tmt (fixed) rep*tmt (random) year (fixed) year*tmt (fixed) rep*year*tmt (random, pooled rep*year, rep*year*tmt) day (fixed), date*tmt (fixed), date*year (fixed), date*year*tmt (fixed), residual (random). Designations were as follows: rep is the replicate; tmt is the pasture (CHIC, BFT, RCL) treatment; year is the year of study; and date is the date when FAMACHA© and FEC was determined for an individual animal. Mean separations were done using t-statistics at $P < 0.05$, unless otherwise indicated with $P \leq 0.10$ considered a trend, $P \leq 0.15$ a weak trend, and $P > 0.15$ a numerical difference, and separated using PDIFF of SAS.

Doses of dewormer were calculated using biweekly FAMACHA© scores, where a score ≥ 3 resulted in an animal being administered a dose of anthelmintic. Deworming events were used to determine number of doses given per pasture treatment. This dosing information was subsequently divided by a theoretical deworming schedule of administering a dose of dewormer once every month (~28 d) to calculate a COUNTQ ratio for each animal using the same 120-d grazing period each year. The COUNTQ variable was transformed by square root conversion prior to statistical analyses. Since all animals were dewormed prior to 1 June each year (the start of each grazing season), FAMACHA© data were also used to determine days to first re-dose for each pasture group of goat kids. Deworming dose data were analyzed using mixed model least squares procedures (SAS Inst. Inc., Cary, N.C.) as a split-split plot with the main unit designed as a randomized complete block with the following linear model: rep (random) tmt (fixed) rep*tmt (random) rep*tmt (random, pooled, rep*tmt) year (fixed) year*tmt (fixed) residual (random). All differences were significant at $P < 0.05$, unless otherwise indicated with $P \leq 0.10$ considered a trend, $P \leq 0.15$ a weak trend, and $P > 0.15$ a numerical difference, and separated using PDIFF of SAS (SAS Inst. Inc., Cary, N.C.).

Monthly blood data and associated FAMACHA© scores were analyzed as a multi-year, randomized complete block design based on the field layout of pastures (pastures were not re-randomized each year) using PROC MIXED in SAS (SAS Inst. Inc., Cary, N.C.). Year and tmt were designated as fixed effects, while replication was random. Measurement periods within year were analyzed as a repeated measure. All differences were significant at $P < 0.05$, unless otherwise indicated with $P \leq 0.10$ considered a trend, $P \leq 0.15$ a weak trend, and $P > 0.15$ a numerical difference, and separated using PDIFF in SAS (SAS Inst. Inc., Cary, N.C.).

Results

Body Weight and 120-d ADG.

Overall there was a treatment by date interaction ($P < 0.01$) for changes in BW over this 120-d period (Figure 1). Meat goats grazing RCL had greater ($P < 0.05$) BW compared to CHIC on all weigh days (Figure 1); meat goats grazing BFT were typically intermediate, except early in the grazing season. Mid- to late-season (8 June to 15 September) pasture treatment influenced overall BW and followed a trend ($P < 0.01$) of RCL (28.5 kg ± 0.5 kg) > BFT (27 kg ± 0.5 kg) > CHIC (25.6 kg ± 0.5 kg). Goat kids grazing RCL (69 g/d ± 5 g/d) had greater ($P < 0.03$) 120-d ADG compared to those grazing CHIC (35 g/d ± 5 g/d); BFT (53 g/d ± 5 g/d) was intermediate (Table 1). The 120-d mean ADG across all pasture treatments in 2010 (58.3 g/d ± 3.9 g/d) was greater ($P < 0.05$) compared to 2009 (46.4 g/d ± 3.9 g/d).

FEC.

Overall, there was a year by date interaction ($P < 0.001$); in 2009, FEC were greater on 22 June, 6 July, 20 July, 1 September, and 15 September, but not different on other sampling dates compared to 2010 (Figure 2). When averaged over the 120-d period using both years, goat kids grazing CHIC (2034 epg

Figure 1. Mean change in body weight (BW) by date when meat-goat kids grazed chicory (CHIC), birdsfoot trefoil (BFT), or red clover (RCL) pastures. Vertical bars represent SEM of least squares means. Means within a date with unlike letters differ at the *P*-value listed.

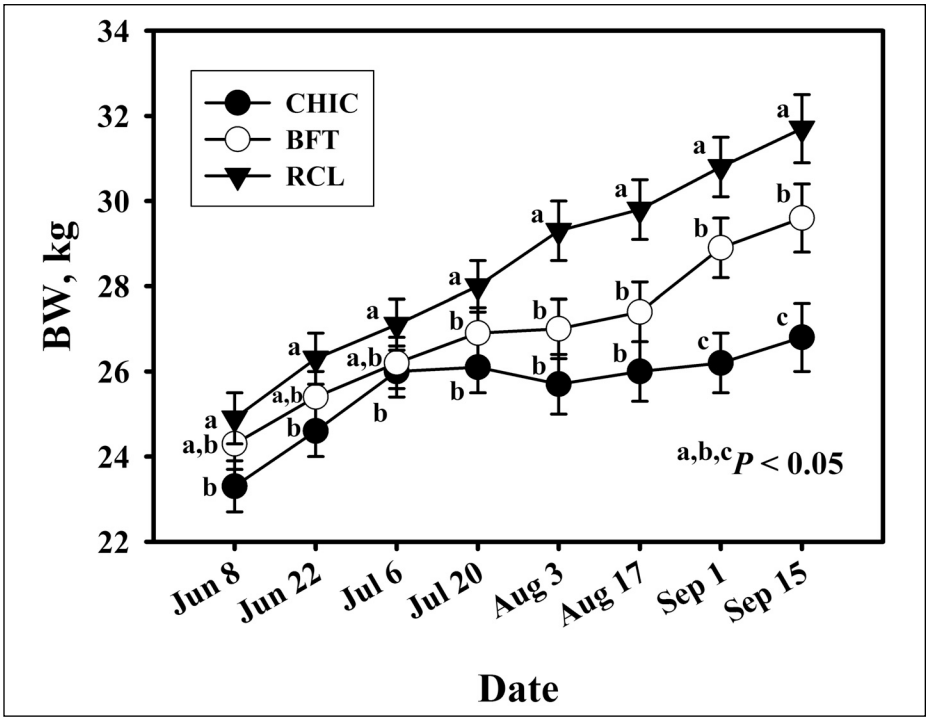


Table 1. Beginning (8 June) and ending (15 September) body weight (BW) and overall average daily gain (ADG) for 120-d period in 2009 and 2010 when meat-goat kids graze chicory (CHIC), birdsfoot trefoil (BFT), or red clover (RCL) pastures. Data are least square means ± standard error of the mean.

Item	CHIC	BFT	RCL	*P* level Tmt†	*P* level Date	*P* level Tmt x Date
8 June BW, kg	23.3 ± 0.6[b]	24.3 ± 0.6[a,b]	24.9 ± 0.6[a]	< 0.01	< 0.001	< 0.01
15 Sept BW, kg	26.8 ± 0.8[c]	29.6 ± 0.8[b]	31.7 ± 0.8[a]	< 0.01	< 0.001	< 0.01
Overall ADG, g/d	34.9 ± 5.1[b]	53.2 ± 5.1[a,b]	68.9 ± 5.0[a]	< 0.02	ND	ND

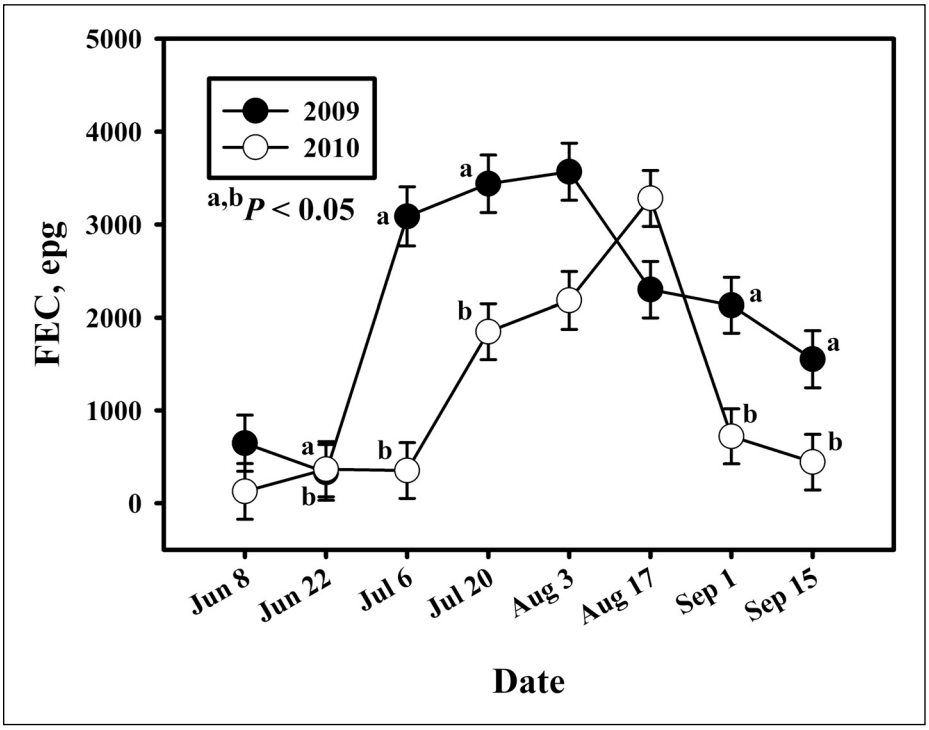
[a,b,c] Means in a row with unlike letters differ ($P < 0.05$).
† Treatment, Tmt; not determined, ND.

Table 2. Biweekly FAMACHA© score, mean doses of dewormer per animal, days to redosing after initial deworming (dose days), and ratio of doses given based on FAMACHA© to a theoretical monthly deworming schedule (COUNTQ ratio) when meat-goat kids grazed chicory (CHIC), birdsfoot trefoil (BFT), or red clover (RCL) pastures for 120 days in 2009 and 2010. Data are least squares means ± standard error of the mean.

Item	CHIC	BFT	RCL	*P* level Tmt†	*P* level Tmt x Year	*P* level Tmt x Date
FAMACHA© score	3.0 ± 0.1	2.9 ± 0.1	2.8 ± 0.1	= 0.19	NS	< 0.001
Dewormer doses/animal	6.3 ± 0.3	6.1 ± 0.3	5.5 ± 0.3	= 0.13	NS	ND
Dose days	30.6 ± 2	29.8 ± 2	28.9 ± 2	NS	< 0.01	ND
CountQ ratio	1.6 ± 0.1[a]	1.5 ± 0.1[a]	1.4 ± 0.1[b]	< 0.03	< 0.001	ND

[a, b] Means in row with unlike letters differ ($P < 0.05$).
† Treatment, Tmt; not significant, NS ($P > 0.20$); not determined, ND.

Figure 2. Mean fecal egg count (FEC) expressed as eggs per gram (epg) on different dates when goats grazed pastures in 2009 and 2010. Vertical bars represent SEM of least squares means. Means within a date with unlike letters differ at the *P*-value listed. First date is 14 days after initial administration of dewormers to all animals.

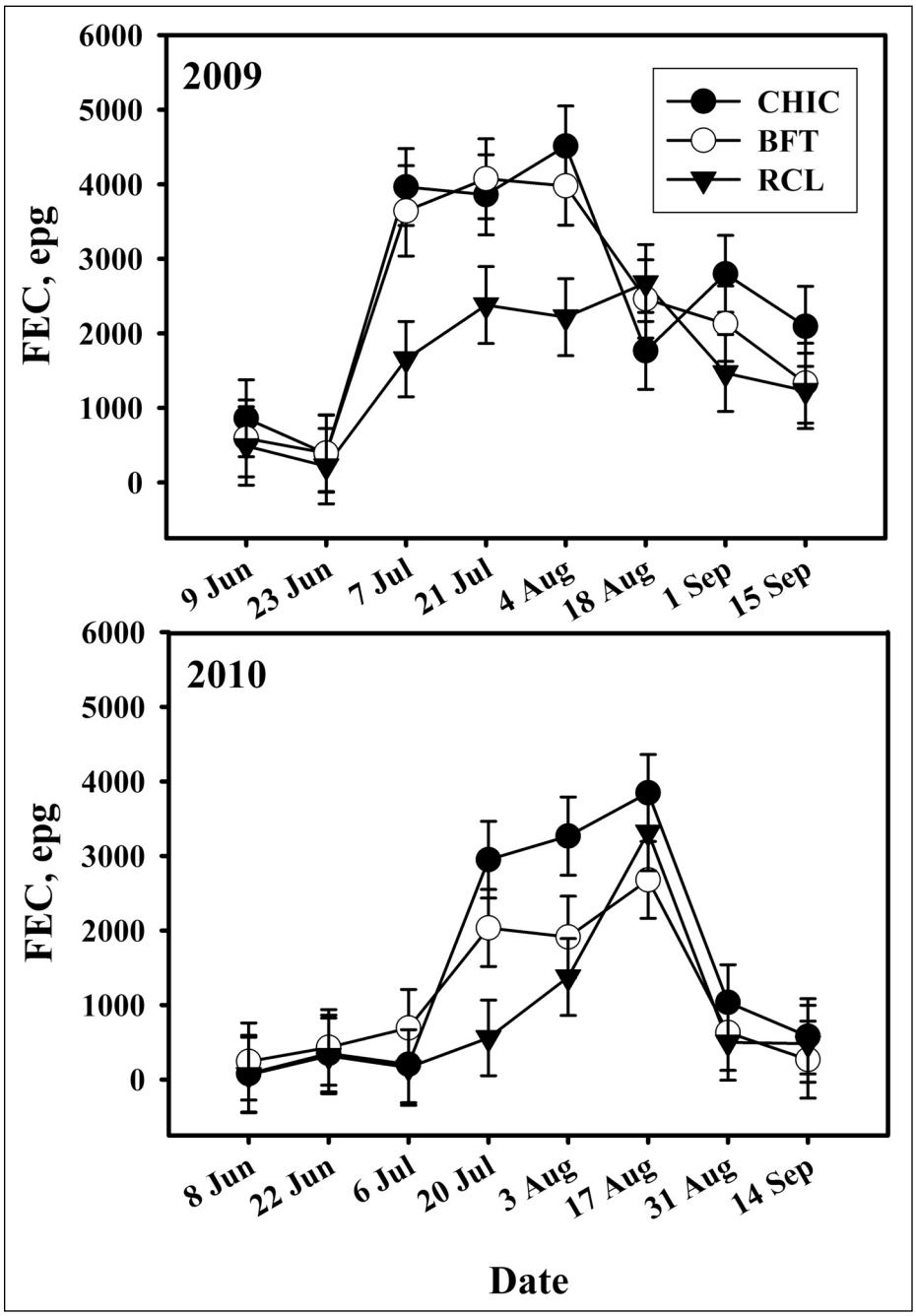


± 207 epg) tended ($P = 0.19$) to have numerically greater FEC compared to RCL (1194 epg ± 206 epg); BFT (1718 epg ± 210 epg) was intermediate. The FEC was variable over each 120-d period in 2009 and 2010 (Figure 3); there was no year by date by pasture treatment interaction ($P > 0.20$).

Monthly Blood PCV and FAMACHA© Score

In June and August, PCV were not different (month by treatment interaction, $P < 0.001$) among pasture treatments. In July goats grazing RCL had greater PCV than those grazing BFT or CHIC, while in September those grazing RCL had greater PCV than those grazing CHIC; BFT was intermediate (Figure 4). Corresponding monthly FAMACHA© scores showed a similar, but opposite trend to PCVs (month by treatment interaction, $P < 0.001$; Figure 4). When averaged over the 120-d grazing seasons, no difference among pasture treatments were observed for monthly PCV (mean 28 percent) or FAMACHA© scores (mean 2.9).

Figure 3. Fecal egg count (FEC) expressed as eggs per gram (epg) on different dates when meat goats grazed chicory (CHIC), birdsfoot trefoil (BFT), or red clover (RCL) pasture in 2009 and 2010. First date is 14 days after initial administration of dewormers to all animals each year.



Monthly Serum Total Protein, Albumin, and Globulin Concentrations.

All blood-serum concentrations are expressed as mg/dL. There was a trend for a month by treatment interaction ($P = 0.07$) for total protein (Figure 5). Goat kids grazing RCL had greater ($P < 0.05$) total protein in serum compared to those grazing CHIC in July, August, and September; those grazing BFT were similar ($P > 0.10$) to CHIC in July, and similar ($P > 0.10$) to RCL in August and September. Overall, total protein was greater ($P < 0.05$) for kids grazing RCL compared to CHIC, with BFT intermediate.

Serum albumin concentrations followed a similar numerical trend (month by treatment interaction; $P < 0.20$) as total protein for RCL and CHIC in June, and BFT was intermediate in August and September (Figure 5). Overall, goat kids grazing RCL showed a trend for greater ($P = 0.07$) blood albumin compared to those grazing CHIC, with BFT intermediate.

There was little evidence of month by treatment interaction ($P > 0.40$) or treatment ($P > 0.40$) effect for serum globulin concentrations (Figure 5). Overall, concentrations in June, August, and September were similar (mean 2.9 mg/dL ± 0.1 mg/dL); all were greater than concentrations in July (2.7 mg/dL ± 0.1 mg/dL).

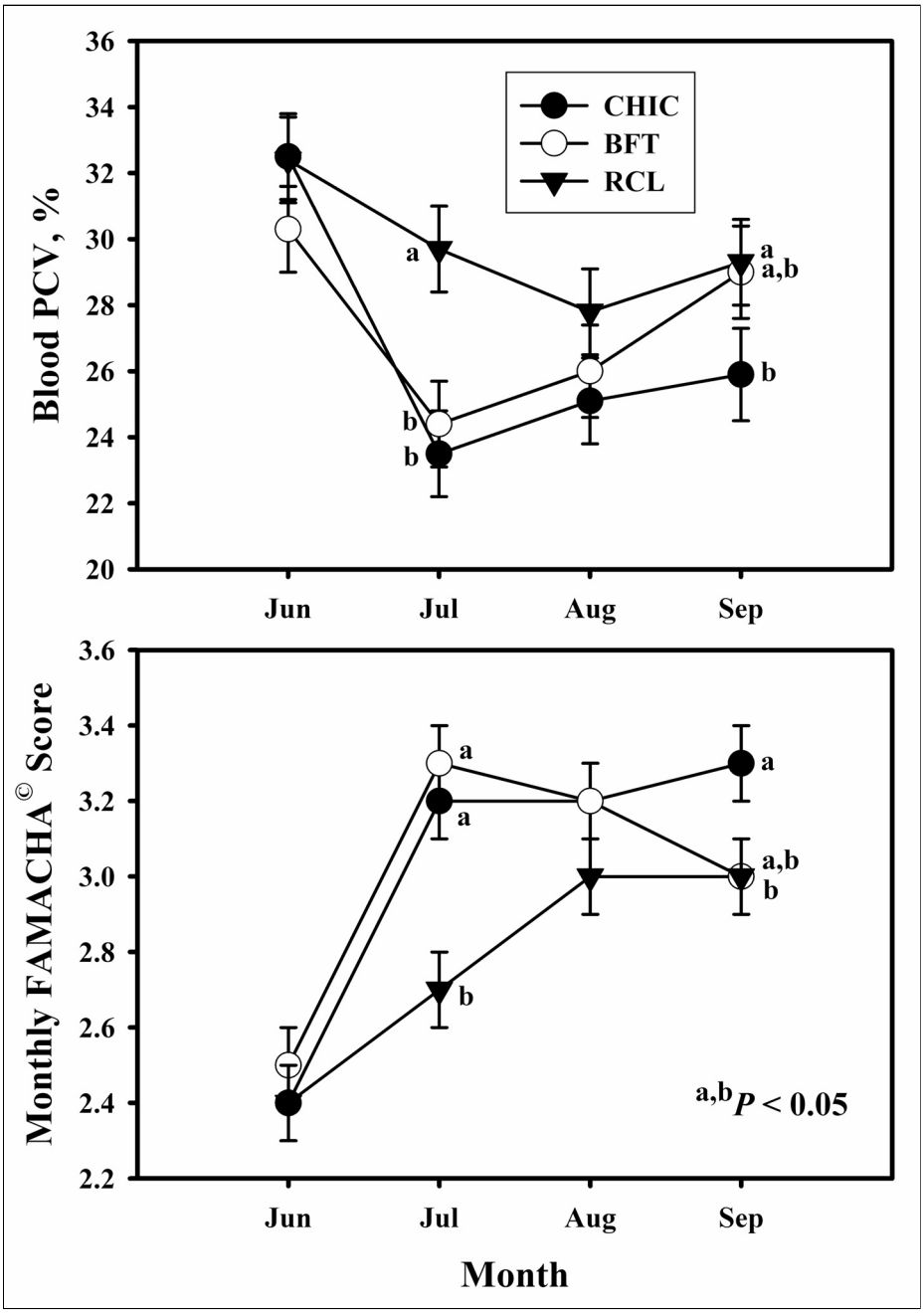
Bi-weekly FAMACHA© Score

There was a treatment by date interaction ($P < 0.001$) for bi-weekly FAMACHA© score (Figure 6). Overall, FAMACHA© scores were not different ($P > 0.10$; Figure 6) for 8 June, 22 June, 6 July, and 17 August; however, on 20 July, 3 August, and 1 September goat kids grazing CHIC had greater ($P < 0.05$) scores than those grazing RCL. On 15 September, scores when grazing CHIC were greater ($P < 0.05$) than when grazing BFT with scores from RCL intermediate. Typically, scores for goats grazing BFT were similar to RCL or intermediate. On the 15 September, FAMACHA© scores for goats grazing CHIC were greater ($P < 0.05$) than those grazing BFT with RCL intermediate (Figure 6). There was also a year by date effect ($P < 0.001$) in that scores in June, mid-August and mid-September were greater in 2010 compared to 2009 (data not shown). Bi-weekly FAMACHA© scores among pasture groups averaged 2.9 over the 120-d period (Table 2).

Doses of Dewormer

The number of dewormer doses administered based on FAMACHA© scores showed a weak trend ($P = 0.13$) to be less when goats grazed RCL (5.5 doses) compared to CHIC (6.3 doses); BFT (6.1 doses) was intermediate (Table 2). When comparing actual number of doses administered to a once monthly deworming regimen (COUNTQ ratio), goat kids grazing RCL (1.4 ratio) received less ($P < 0.03$) dewormer doses compared to goat kids grazing either BFT (1.5 ratio) or CHIC (1.6 ratio), but this was impacted by year (Figure 7). Overall

Figure 4. Mean packed cell volume (PCV) and monthly FAMACHA© score by month when meat-goat kids grazed chicory (CHIC), birdsfoot trefoil (BFT), or red clover (RCL) pastures. Vertical bars represent SEM of least squares means. Means within a month with unlike letters differ at the *P*-value listed.



mean-total doses of dewormer given per animal per year was less ($P < 0.001$) in 2009 (5.3) compared to 2010 (6.6). Overall mean days to first re-dosing was not different $P > 0.82$) among the pasture groups (mean 29.8 days; Table 2). However, since more doses were administered in 2010 compared to 2009, the days to first re-dosing were shorter (year-by-treatment interaction, $P < 0.001$) for CHIC, BFT and RCL in 2010 (22.8, 21.6, and 17.5, respectively) compared to 2009 (38.5, 36.2, and 42, respectively; Figure 8).

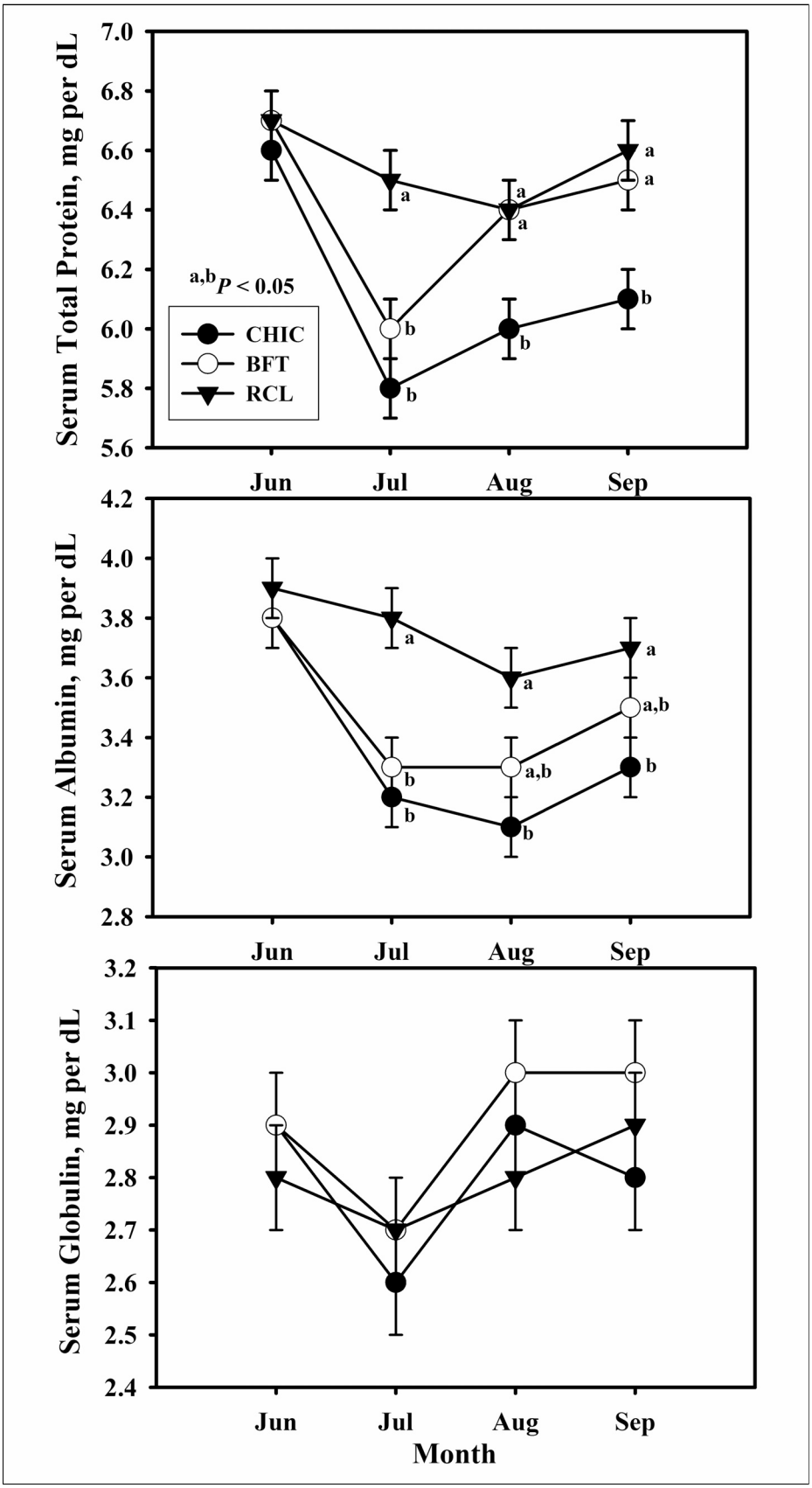
Discussion

Weight Gain

The 120-d weight gain by meat-goat kids grazing CHIC were less compared to those grazing RCL and BFT (Table 1). Comparative weight-gain data for meat goats grazing improved temperate pastures containing chicory, birdsfoot trefoil, or red clover is limited. Across all types of improved pasture, reported season-long weight gains by meat goats in the United States ranged from 27 g $d^{-1}$to 100 g d^{-1} (Goodwin et al., 2004; Animut et al., 2005; Muir, 2006; Lema et al., 2007; Lema et al., 2008; Turner et al., 2013; 2014). Meat-goat kids gained 90 g d^{-1} grazing pure chicory in Tennessee (Lema et al., 2008), which was better than grazing chicory/brassica mix or bermudagrass (*Cynodon dactylis* L.). No weight-gain comparisons were located for meat goats grazing birdsfoot. Turner et al. (2013) reported similar change in body weight trends and gains when meat-goat kids grazed red clover plus orchardgrass (*Dactylis glomerata* L.) pastures. The reason for less weight gain when meat-goat kids grazed CHIC compared to RCL or BFT in the present study is related to variations in forage mass and nutrient composition in CHIC paddocks compared to RCL or BFT in 2009 (Turner et al., 2010; Cassida and Turner, unpublished data), thus potentially reducing DMI and overall performance when compared to RCL or BFT. However, this contrasts with results from New Zealand, where lambs gained more weight when grazing chicory than birdsfoot trefoil (Marley et al., 2003; 2006). Lambs typically gain 50 percent to 150 percent more weight than meat-goat kids on the same pastures (Animut et al., 2005; Turner et al., 2014) and others have reported gains of 150 g d^{-1} to 300 g d^{-1} grazing pure stands of chicory (Kidane et al., 2010; Miller et al., 2011).

Performance (change in body weight and gain) by grazing livestock is impacted by a complex interaction of factors including: forage species, plant selectivity by the animal, dry matter intake, and forage digestibility; all of these factors in turn are influenced by livestock species, seasonal changes in proportion of forage species in the sward, forage mass, nutritive value, time on pasture, and secondary plant compounds (Villalba and Provenza, 2009). In a short, 21-d feeding study, Heckendorn et al. (2007) reported that lambs offered fresh chicory did not gain weight (zero g/d) compared to lambs offered fresh birdsfoot trefoil (80 g/d) or ryegrass-alfalfa (70 g/d) forages. In an 80-d graz-

Figure 5. Mean serum total protein, albumin, and globulin concentrations by month when meat-goat kids grazed chicory (CHIC), birdsfoot trefoil (BFT), or red clover (RCL) pastures. Vertical bars represent SEM of least squares means. Means within a date with unlike letters differ at the *P*-value listed.



ing study, Miller et al. (2011) reported greater ADG when lambs grazed chicory (280 g/d) compared to bermudagrass (20 g/d) pastures.

Overall performance (weight gain) in ruminants is related to DMI and forage digestibility. Heckerdorn et al. (2007) reported that the DMI by lambs offered freshly-harvested chicory was about half compared to lambs offered fresh ryegrass-alfalfa (*Medicago sativa* L.) forage during a short feeding trial and may have been related to initial animal adjustment to the diet. The overall digestibility of chicory alone can be similar to alfalfa (Turner et al., 1999). Although CHIC paddocks in the present study contained little if any bromegrass during the grazing season (K.A. Cassida, personal communication), successful establishment and maintenance of a cool-season grass in chicory pastures may improve rumen breakdown and use of organic matter and fiber for improved digestibility and overall nutritive value of chicory (Li and Kemp, 2005). Chicory is high in pectin (typically 80 g/kg to 90 g/kg DM; Ivarsson et al., 2011). Pectin is rapidly fermented in the rumen and needs a high rumen-degradable protein (RDP) present to insure efficient microbial protein synthesis for optimal nutrient-use efficiency during rumen microbial fermentation. Even though chicory was high in crude protein (CP) in the present study, the protein may not be rapidly degraded in the rumen (high RDP); this aspect was not evaluated in the current study. In a reverse scenario to the present study, addition of 10 percent sugar beet (*Beta vulgaris* L.) pulp (high pectin) to an Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot] hay diet (high in CP) resulted in optimal microbial protein synthesis in goats (Masuda et al., 1999).

The energy-to-protein ratio in grazed forages has an overall impact on nutrient utilization in the rumen and weight gain in growing animals. For growing goat kids, the desired total digestible nutrients (TDN) to CP ratio ranges from 5.8 to 6.1 (Turner et al., 2013). McCutcheon et al. (2012) reported that the season-long (9 July to 4 September) mean TDN:CP ratio for chicory grown in Ohio was 3.6. In beef cattle, TDN:CP ratios < 5 suggested the need for supplemental energy for

Figure 6. Mean bi-weekly FAMACHA© scores by date when meat-goat kids grazed chicory (CHIC), birdsfoot trefoil (BFT), or red clover (RCL) pastures. Vertical bars represent SEM of least squares means. Means within a date with unlike letters differ at the *P*-value listed.

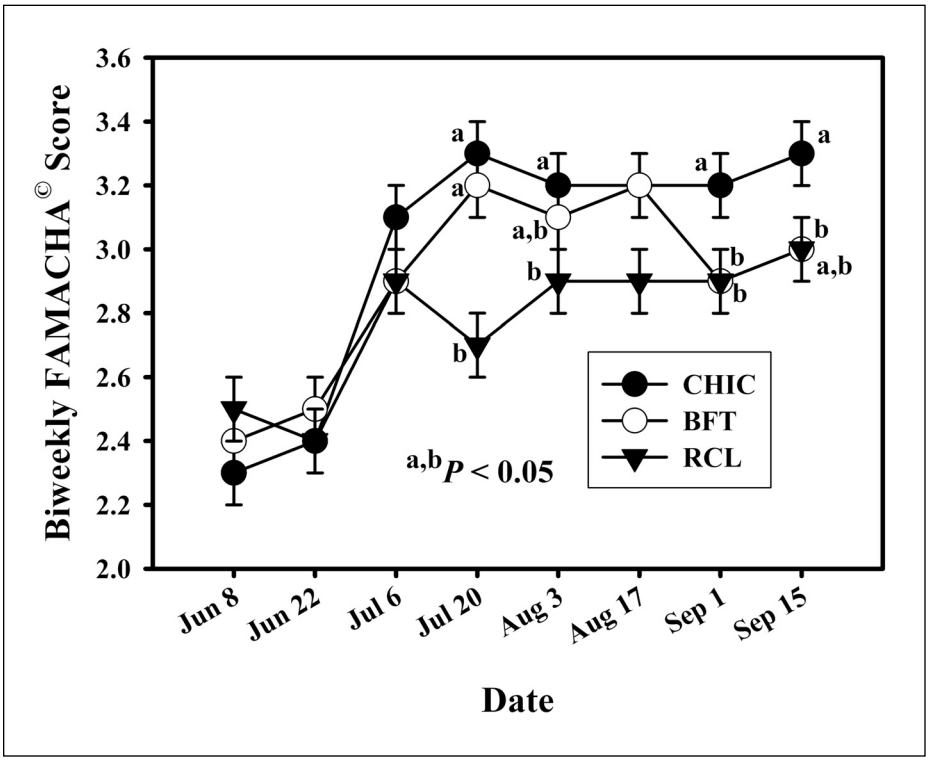
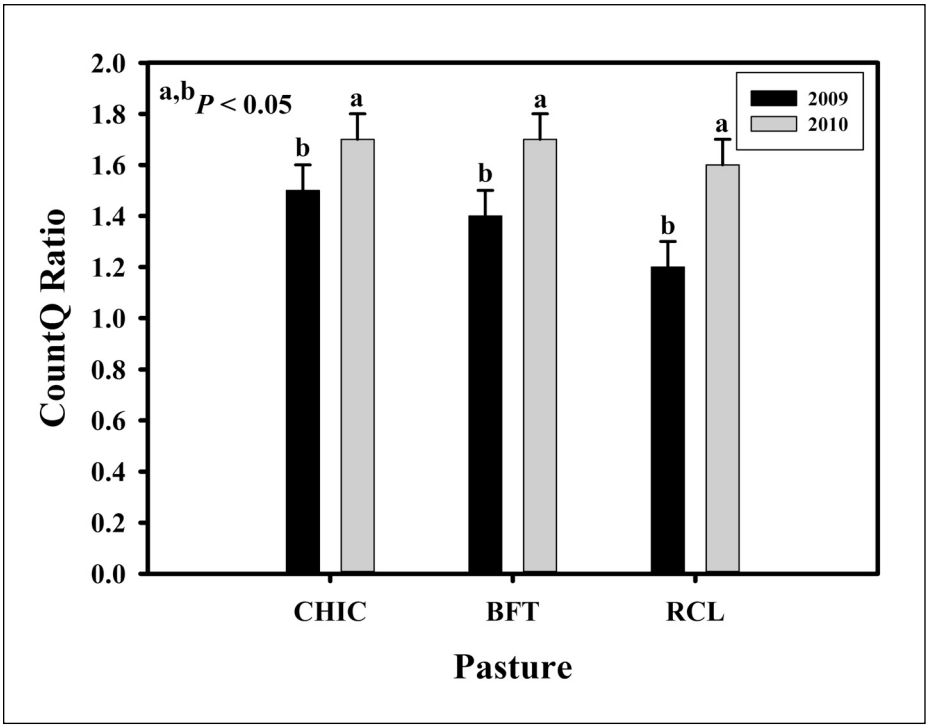


Figure 7. Mean ratio of actual dewormer doses to theoretical once monthly dewormer doses (CountQ) when meat-goat kids grazed chicory (CHIC), birdsfoot trefoil (BFT), or red clover (RCL) pastures in 2009 and 2010. Vertical bars represent SEM of least squares means. Means within a pasture with unlike letters differ at the *P*-value listed.



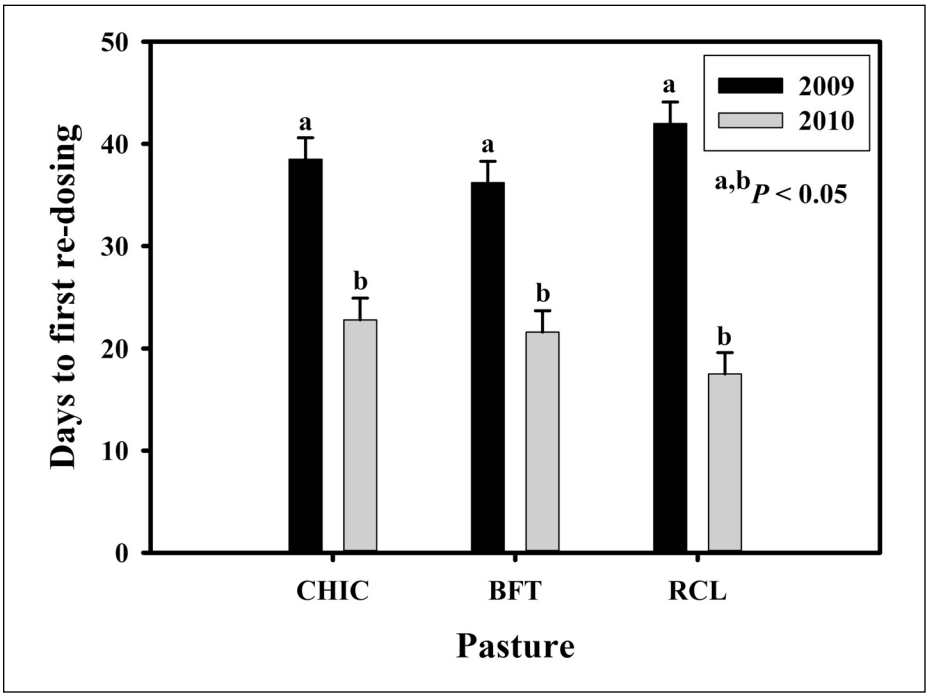
improved utilization of protein (Moore et al., 1999). In the present study, the ratio was approx. 4.5 for CHIC (high CP) and 3.5 for BFT and RCL (high CP; K.A. Cassida, personal communication); all indicated low available energy in relation to available protein in the rumen. Even with the need for supplemental energy, consideration then must be given to the type of energy supplement [corn grain (high starch) compared to soy hulls (low starch)]. More research is needed to address the type of supplemental energy and protein for different forage swards to aid in understanding improved performance and resilience to GIN infection in grazing meat-goat kids.

Although not evaluated in the present study, secondary plant compounds can also influence performance by ruminants. Phytoestrogens in red clover can improve overall weight gain in lambs (Moorby et al., 2004). Birdsfoot trefoil contains CT which can improve nutrient (protein) use and improve weight gain in lambs (Douglas et al., 1995). Overall impact of sesquiterpene lactones on weight gain of growing goats has not been reported.

FEC

Lack of differences among forage treatments in our study contrasts with previous reports. Niezen et al. (1994) reported that lambs grazing chicory had greater FEC compared to those grazing red clover. Marley et al. (2003) reported that lambs grazing chicory had greater FEC than lambs grazing birdsfoot trefoil on day 7 of a grazing study. Miller et al. (2011) reported lower FEC when lambs grazed chicory pastures compared to bermudagrass pastures for 80 d. In contrast, Heckendorn et al. (2007) reported that feeding fresh-harvested chicory or birdsfoot trefoil reduced total daily FEC (specific for *Haemonchus*) by 89 percent and 63 percent, respectively, when compared to a control group of lambs offered fresh-harvested ryegrass-alfalfa. Kidane et al. (2010) observed lower FEC when growing lambs (artificially dosed with the abomasal parasite, *Teladorsagia circumcincta*) grazed chicory compared to perennial ryegrass-white clover pastures. *T. circumcincta* is an internal strongylid parasite, which infects the lining of the abomasum, but unlike *Haemonchus* does not feed on blood to cause anemia (Roeber et al.,

Figure 8. Mean days to first re-dosing of dewormer when meat-goat kids grazed chicory (CHIC), birdsfoot trefoil (BFT), or red clover (RCL) pastures in 2009 and 2010. Vertical bars represent SEM of least squares means. Means within a pasture with unlike letters differ at the *P*-value listed.



2013). During the grazing season in the present study in a temperate environment in the eastern U.S pastures, the major GIN in cultured feces was *H. contortus* (data not shown). Even though *Haemonchus* was the dominant larval species in the present study, FEC was not reduced when meat-goat kids grazed CHIC compared to RCL or BFT. Marley et al. (2003) reported that lambs grazing chicory had greater FEC compared to those grazing birdsfoot trefoil and speculated that CT in birdsfoot trefoil reduced egg-laying abomasal adults and not stage-4 larvae, whereas with the secondary compounds in chicory, the reverse was true. Nadarajah et al. (2015) reported a 6-yr summary of meat-goat bucks of various breeds finished on pasture after an initial administration of dewormers representing two or three classes of anthelmintic. Any subsequent administration of dewormer was based on individual FAMACHA© score of 3 or greater. Bucks administered no additional dewormer were classified as resistant to GIN, while those administered subsequent dewormer were classified as susceptible to GIN. Resistant bucks had greater ADG and lower FAMACHA© scores than susceptible bucks; FEC was not different between the groups.

Interpretation of data from grazing studies using selective deworming of individual animals (used in the present study) is difficult (Burke et al., 2009). Wildeus and Zajac (2005) have reported seasonal trends in GIN in pastures grazed by meat goats. In the present study, greater FEC were observed in 2009 compared to 2010. This is, in part, related to a greater number of doses administered per animal and shorter number of days to re-dosing in 2010 compared to 2009. In addition, 2009 was the first year pastures were grazed since establishment of forages in the pastures. Grazing in 2009 probably loaded pastures with parasite eggs which could have survived the winter resulting in greater initial levels in 2010 pastures compared to 2009 and the greater need for control (administer dewormer) in 2010. Also, different groups of goat kids with different genetics were used each year. Young, growing meat-goat kids with high dietary nutrient requirements are typically more sensitive to GIN infections compared to older animals. The aim of selective deworming using FAMACHA© is to reduce FEC in animals shedding the most eggs based on development of anemia measured by the eye-lid score; therefore, a source of variation in FEC throughout the grazing season is a result of selective deworming practices. Our study also used grazing management based on rotational stocking of paddocks. Reentry time to a previously grazed paddock can affect FEC (Burke et al., 2009). In the present study, reentry time averaged approximately 24 d across the grazing season, which was likely not long enough to reduce infective larvae populations on grazed forage. During the summer with adequate moisture and high ambient temperatures, conditions are typically favorable for GIN (especially *Haemonchus*) egg hatch and subsequent larval development (Colvin et al, 2008) and probably influenced trends in FEC. Also, the main goal of grazing management using rotational stocking is to maintain vegetative swards with a high-nutritive value (high energy and protein). Grazing high-protein clovers reduced dependence on anthelmintics to control abomasal GIN in lambs (Marley et al., 2005); a similar result was seen in the present study when goats grazed red clover (high protein). However, goats have a delayed immune development to GIN and typically avoid ingestion of parasitic larvae by grazing the tops of canopies. By using rotational stocking for sward management, a low-profile, leafy sward is maintained, and when grazed by goats, more parasitic larvae are likely ingested (Burke et al., 2009).

Monthly Blood PCV and FAMACHA© Score

For goats, all blood PCV values were within normal (22 percent to 38 percent) range (Jain, 1993). The overall mean monthly FAMACHA© score (Table 2) was 2.9 (on a 5-point scale; 1 = no anemia and 5 = severe anemia associated with the burden level of *Haemonchus*; Kaplan et al., 2004). In general, a blood PCV of less than 21 percent or a FAMACHA© score of 3 or greater on the scale indicates anemia and the need to deworm meat goats to control *Haemonchus*. Turner et al. (2013) reported similar PCV values and FAMACHA© scores when goat kids grazed red-clover-grass pastures; however, meat-goat kids in that study were dewormed monthly and FAMACHA© scores were used as a supplemental evaluation in order to help monitor the deworming program.

Monthly Serum Total Protein, Albumin, and Globulin Concentrations

Meat goats grazing RCL in the present study had greater weight gains and serum-total protein and lesser FEC compared to CHIC; serum-globulin concentrations were not different among the animals grazing the three different forages. Goats grazing RCL and BFT probably had improved nutrients (especially CP; K.A. Cassida, personal communication) to support greater performance and any immune response to GIN. Greater serum-total protein and globulin have been suggested to be indicative of greater GIN and an active immune response in lambs grazing alfalfa compared to red clover (Marley et al., 2005). In comparison to sheep, goats have a delayed immune response to GIN, and immune responses are typically not fully expressed until 12 months (Hoste et al., 2008). Immune involvement or regulation in goats has been suggested to reduce larval growth/development once larvae are ingested, thus maturation to adult worms is reduced along with FEC (Hoste et al., 2010). The FEC was reduced in young goats grazing RCL compared to CHIC in the present study, but it is not clear if goats were mounting an immune response as calculated serum-globulin concentrations were not different among goats grazing the three forages, with BFT being intermediate.

Results of the present study represent a complex relationship among forage secondary compounds, forage CP, FEC, and blood parameters. Chicory contains sesquiterpene lactones, which are reported to have anthelmintic activity (Foster et al., 2011). Grazing plants with CT (Min and Hart, 2003), such as BFT, has been reported to reduce FEC possibly by CT damaging the cuticle on adult *Haemonchus* to reduce total female adults laying eggs, and thus overall FEC (Kommuru et al., 2015). In addition, interpretation of results is further complicated by selective deworming of individual animals in each pasture group, which probably impacted the number of adult female worms, FEC, and blood parameters.

Doses of Dewormer

Miller et al. (2011) reported reduced GIN infection and need for administration of dewormer when lambs grazed chicory compared to bermudagrass pastures. Turner et al. (2016) reported that a GIN-resistant sheep breed, Katahdin, needed less deworming (based on FAMACHA© score) compared to Suffolk lambs and meat-goat kids (Boer breeding) when finished on orchardgrass-red clover-white clover pastures. In the present study, doses of dewormer were based on FAMACHA© scores and varied with year (Figure 7 and Figure 8). The FEC and need to deworm based on FAMACHA© score were probably more influenced by seasonal rainfall patterns (Cassida and Turner, 2016) than by different goat groups used each year.

Conclusion

Grazing red clover, and to some extent birdsfoot trefoil, appeared to have a beneficial effect on meat-goat-kid performance (high ADG) and resilience to GI-parasite infection (low FEC and reduced administration of dewormer) in comparison to forage chicory.

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Sheep & Goat Research Journal
Volume 32, 2017 - August

Effects of Weight, Age and Breed Type on Loin Eye Area, Loin Depth and Backfat Thickness in Replacement Ewe Lambs

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Acknowledgements

We thank George and Lisa Wherry for the use of their flocks and assistance in scanning and weighing the animals. Dr. Marlon Knights, Dr. Quinn Baptiste, Noah Cummings, Adam Liller, Lakin Mouser and farm employees assisted in animal handling and Adam Redhead provided additional weight data. All procedures with animals were approved by the WVU Institutional Animal Care Committee, Protocols No. 10-0501 and 13-0508. Drs. Marlon Knights, Brett Kenney and David Notter provided valuable comments in review. This work was supported by a grant from the West Virginia State Legislature through the WV Department of Education (WV Sheep Improvement Project, State Project 140 of the West Virginia Agricultural and Forestry Experiment Station). It is published with the approval of the Director of the Station as Scientific Paper No. 3314.

Summary

Measurement of loin eye area (LEA) or depth (LD) and backfat thickness (BFT) by ultrasonography is a low cost, practical option for animal producers to estimate carcass merit for live animals. These highly heritable (~ 35 percent) traits can be used to select for meatier animals. Objectives of this study were to: (1) evaluate how LEA, LD and BFT vary with age, weight, and breed type of ewe lambs in a farm flock, (2) develop formulas to adjust LEA, LD and BFT to common bases for comparison, and (3) examine the effect of late pregnancy/early lactation on these traits. Ultrasonographic images of LEA, LD and BFT at the 11th and 12th rib were collected for 4 annual groups of replacement ewes in a farm flock. In Exp. 1, weight ($P < 0.001$) accounted for 44 percent of variation in LEA and 31 percent of variation in LD in groups 1 and 2 combined, and 56 percent of the variation in LEA and 52 percent of variation in LD in group 4. For BFT, weight accounted for 38 percent of variation in groups 1 and 2 combined and 45 percent of variation in group 4. Year, age and breed type had no effect ($P > 0.10$). Equations to adjust traits to mean group weight were:

Adj LEA [cm^2] = measured LEA [cm^2] + 0.24 (Individual Wt in kg - Group mean Wt in kg)

Adj LD [cm] = measured LD [cm] + 0.03 (Individual Wt in kg – Group mean Wt in kg)

Adj $\log_{10}$ BFT [mm] = $\log_{10}$ measured BFT [mm] + 0.019[a] or 0.014[b] (Individual Wt in kg – Group mean Wt in kg).

[a] *Coefficient for groups 1 and 2 combined;* [b] *Coefficient for group 4.*

Table 1. Means ± SEM for age, weight, loin eye area (LEA), loin eye depth (LD), and backfat thickness over the loin (BFT) in ewe lambs, by group scanned.

Group	N	Age (days)[a]	Weight (kg)[a]	LEA (cm^2)[b]	LD (cm)[b]	BFT (mm)[a]
Group 1	103	437 ± 1	36.4 ± 0.4	10.44 ± 0.18	2.24 ± 0.02	1.6 ± 0.6
Group 2	68	439 ± 1	44.9 ± 0.7	12.45 ± 0.22	2.47 ± 0.03	2.8 ± 0.1
Groups 1 and 2 combined	171	438 ± 7	39.8 ± 0.5	11.24 ± 0.16	2.33 ± 0.02	2.1 ± 0.1
Group 3	62	392 ± 4	42.9 ± 0.9	10.24 ± 0.24	2.22 ± 0.04	1.6 ± 0.1
Group 4	135	203 ± 5	36.5 ± 0.6	11.16 ± 0.21	2.37 ± 0.03	1.8 ± 0.1[c]
Total	368	344 ± 7	39.1 ± 0.4	11.01 ± 0.12	2.32 ± 0.01	1.9 ± 0.04[d]

[a] Values for age, weight and BFT are ordinary means from raw data.
[b] Values for LEA and LD are least squares mean from analyses.
[c] n = 132; [d] n = 365

In Exp. 2, late pregnant/recently lambed ewes had smaller LEA and less LD ($P < 0.0001$), but not reduced BFT, compared to open ewes. Both LEA and LD varied with weight ($P < 0.0001$); regression lines did not differ from parallel in late pregnant/recently lambed compared to open ewes. Physiological status, age, weight, breed type and interactions did not affect BFT. In conclusion, relationships of carcass traits to weight were consistent among groups of open, replacement-ewe lambs, and traits may be compared on an equivalent basis after adjustment for weight.

Key Words: Backfat Thickness, Ewe Lambs, Loin Depth, Loin Eye Area

Introduction

In the sheep industry, emphasis has been placed on lamb meat (Jones, 2004). Throughout the industry, lamb producers, packers, and consumers demand improvements to growth rate, carcass merit, feed efficiency, product yield, and quality (TAMRC, 1991; Ward et al., 1995). In the lamb-meat industry, there is considerable diversity in genetics, production systems, markets, and nutrition (Mousel et al., 2012). For the industry to remain competitive, producers must generate a carcass that meets or exceeds the buyer's needs (Beermann et al., 1995). However, adoption of performance testing for key production variables in this species has begun to grow only recently in the United States. Fewer than 125 flocks participated in the National Sheep Improvement Program in 2011, and that number had grown to only 344 in June 2017 (Burgett, 2017a, b).

To produce high yields of meat, carcass traits, such as loin eye (*Longissimus dorsi*) area or depth, fat thickness over the loin (backfat thickness), and other characteristics must be evaluated. Increasing loin eye area is considered to be the most influential goal of the lamb industry to improve carcass merit (Lupton, 2008), because a larger loin eye tends to increase the yield value of the carcass (Leeds et al., 2008; Notter et al., 2014). Yield grade also depends upon variation in backfat thickness (Boggs et al., 2006). In response to consumer demands for leaner cuts, research has been expanded in recent years to discover how to identify genetically leaner animals (Conington et al., 1995; Clelland et al., 2014).

Measuring loin eye and backfat through ultrasonography can provide breeders, producers, and researchers with an objective estimate of carcass composition and contribute to knowledge of relationships among genetics, management, and market value of the sheep (Leeds et al., 2008; Notter et al., 2012). Through this advancement in technology, producers are able to select in both sexes, thus enabling further genetic advancement on each farm due to the high heritability of muscle characteristics. For example, the genetic contribution to loin eye area has been estimated as 35 percent (*Sheep Production Handbook*, 2015). Furthermore, ultrasonography can be relatively low in cost, so it is a practical option for evaluation of live animals.

The objectives for this research were (1) to evaluate the effects of age, weight, and breed type on loin eye area (LEA), loin depth (LD), and backfat thickness (BFT) of replacement ewe lambs in a farm flock (Exp. 1), (2) to provide equations to adjust LEA, LD, and BFT for significant modifying factors, and (3) to determine if the physiological status of late pregnancy/early lactation affects LEA, LD, or BFT values (Exp. 2). The anticipated result was that each carcass trait would have a high relationship with weight and/or age. Furthermore, it was expected that breed type might influence the relationships of carcass traits to weight or age. The ultimate goal was to develop equations that can be used to adjust measured values to a common weight and/or age, for comparison in a selection program.

Materials and Methods

This work was performed over a 4-year period using 4 groups of replacement ewes on the Wherry Farm in Scenery Hill, Penn. (N 40° 4', W 80° 5'). Diet on the farm included a creep feed (14- to 16-percent protein) during the pre-weaning phase. Lambs were weaned to pasture, with a free-choice grain ration (6 parts corn, 6.25 parts distillers grain, 7 parts speltz, and 0.75 parts mineral mix) available in portable feeders on pasture. However, replacement ewes received that supplement for a limited period while on pasture, to avoid excessive deposition of fat in the udder that could reduce subsequent milk production (Villeneuve et al., 2010).

Each ewe lamb was prepared for ultrasonographic measurements by shearing a dorsal area over the 11th and 12th rib, which was then rubbed with vegetable oil to create a connection medium for the ultrasound. Two ultrasound images were

recorded using an Aloka 500 Console with a 3.5 MHz linear probe (Hitachi Aloka Medical America, Inc., 10 Fairfield Boulevard, Wallingford, Conn. 06492). The machine was set on 90 for overall gain, 25 for near gain, and 2.1 for far gain with F1 and F2 focal points. As each ewe lamb passed through the processing chute, two images were collected. These images were analyzed to determine LEA, LD (at the deepest part of the rib-eye image), and BFT (The Cup Lab, LLC 2610 Northridge Parkway, Ames, Iowa). In addition, the weight, age, and breed type were collected on all ewes to determine which of these variables required adjustment in order to allow the producer to compare animals within a group on an equivalent basis.

The first group of 103 ewes, born in 2012, consisted of Texel-sired, Dorset-sired, and mixed crossbreds, scanned on March 25, 2013 (designated group 1). The second group of 68 ewes was born in spring 2013 and included Texel-, Dorset-, or Suffolk-sired and a few Cheviot or crossbreds, scanned on May 5, 2014. Sixty-two ewes born in spring 2014 included the same breed types as before and were scanned on April 4, 2015 (group 3). However, this group differed from the other three groups because they were used in a nutritional trial that involved breeding in fall 2014, then were fed together throughout the winter. Some of them were in late pregnancy (n = 26) or had lambed (n = 17) just before the scanning date (range 29 days prepartum to 9 days postpartum; others were open (n = 19); therefore, late pregnancy/lambed or open status was recorded. The last group consisted of 135 ewes born in fall 2014 and spring 2015 that were Suffolk-, Texel- or Dorset-sired, and were scanned on September 9, 2015 (group 4). Basic data on weights, ages, and trait means are summarized in Table 1.

In Exp. 1, groups 1 and 2 were examined together, to test the null hypotheses that LEA, LD and BFT were independent of age, weight and breed type. Group 4, which included younger animals, was examined separately and used to test accuracy/applicability of the prediction equations developed from groups 1 and 2 combined. The additional hypothesis tested with group 3 (Exp. 2) was that late pregnancy and early lactation do not alter the relationship of carcass traits to age and weight from those seen in open ewes.

Statistical Analyses

Dependent variables were measurements of LEA (cm^2), LD (cm) and BFT (mm). Distributions of the variables were examined for normality using Shapiro-Wilk W test (Coin, 2008; Asar et al., 2017). In addition, residuals were examined and outlier observations that influenced normality were removed based on the Studentised residual and Cook's D distance. The BFT data had a severe right skewness (toward greater thickness with increasing weight), thus log10 transformation was applied. Data were analyzed using analyses of variance, regression and covariance (Kaps and Lamberson, 2004) with JMP and SAS software (JMP®, Version Pro 12.2, SAS Institute Inc., Cary, N.C., Copyright 2015; SAS®, Version 9.3, SAS Institute Inc., Cary, N.C., Copyright 2002-2010). Differences were considered significant at $P < 0.05$.

Initial statistical analyses included examining models that predicted LEA, LD and BFT from the array of all variables collected, such as fixed effect of age of ewe (days from birth to scanning), weight at scanning (kg), breed type and random effect of year (group 1 vs. group 2) and their interactions for ewes in group 1 combined with group 2, and in group 4 separately (Exp. 1). In Exp. 2, using group 3, status (late pregnant/lambed vs. open) was added to the model. After significant variables were identified, smaller models of analysis of variance or regression analyses were used to pinpoint the important variables and the final model was recorded.

In Exp. 1, the regression (linear and quadratic, if significant) equations of each trait on weight were determined, for the data of groups 1 and 2 combined together, and group 4 separately. Equations using the regression coefficients from these equations could then be developed and used to adjust each dependent variable for individual ewes to the average weight of ewes in the flock. To validate the equation for LEA from groups 1 and 2 combined, it was tested on animals of group 4. The ranking of ewes from highest to lowest adjusted LEA by that formula was then compared to the ranking by the formula derived from the model of group 4, using paired t-test and analysis of agreement (Stokes et al., 2012).

Results

The means and standard errors of the means for each continuous variable in each group tested are presented in Table 1.

Experiment 1

Loin Eye Area

Groups 1 and 2 Combined. The least squares mean for LEA for combined groups 1 and 2 was 11.24 cm^2 ± 0.16 cm^2. The model accounted for 44 percent of variation when both linear and quadratic effects of weight were included, compared to 41 percent with only the linear effect (Figure 1 A). The only variable with a significant effect on LEA was weight; age and breed type were not significant after fitting effects of weight. The best fitting equation to explain the relationship of LEA to weight (Wt) was the quadratic equation ($P < 0.0001$):

$$LEA\ [cm^2] = 1.77 + 0.24\ (Wt\ in\ kg) - 0.006\ (Wt\ in\ kg - 39.76)^2$$

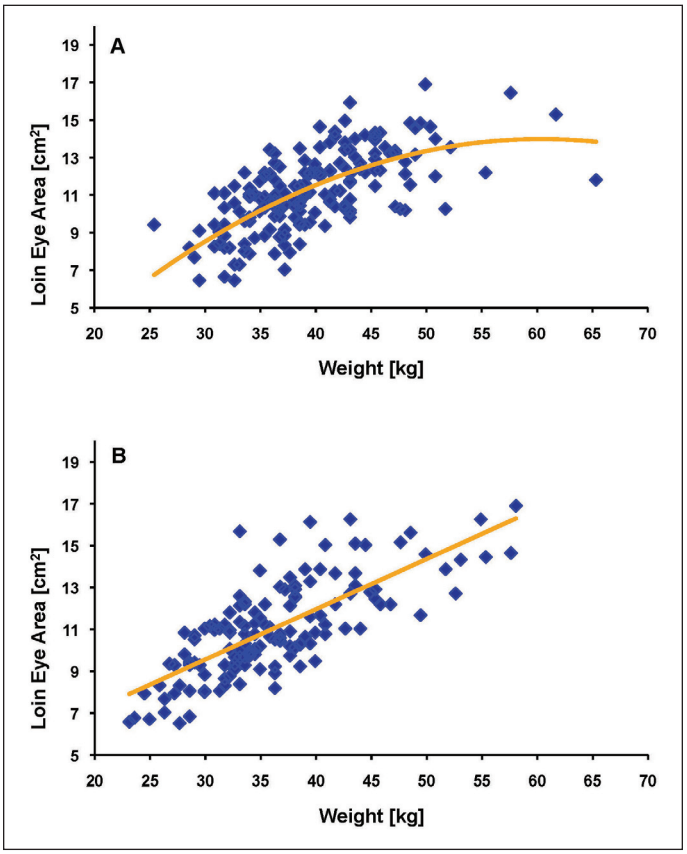
That formula provided the regression coefficients needed to adjust LEA for variation in individual weight from a group mean or from an arbitrary weight. Thus the formula to adjust measured values to be equivalent to the value at a group mean weight became:

Equation 1. $Adj\ LEA\ [cm^2] = measured\ LEA\ [cm^2] + 0.24\ (Individual\ Wt\ in\ kg - Group\ mean\ Wt\ in\ kg) - 0.006\ (Individual\ Wt\ in\ kg - Group\ mean\ Wt\ in\ kg)^2$,

in which *Adj LEA* is the calculated LEA, adjusted for the weight incorporated into the right side of the equation; *measured LEA* is the individual ewe's LEA, *Wt in kg* represents each ewe's individual weight and *Group mean Wt in kg* is the average weight of the flock at scanning. This equation should allow comparison of LEA in replacement ewes on an equal basis within the flock. It was subsequently tested for general applicability using the newer data from group 4.

Group 4. Again, LEA was related only to weight, and in this case, there was only a linear effect ($P < 0.001$; Figure 1 B), which accounted for 56 percent of the variation in LEA. The prediction equation for LEA from weight was:

Figure 1. Relationships of loin eye area to weight of ewe lambs in Exp. 1: A. Quadratic relationship in Groups 1 and 2 combined. B. Linear relationship in Group 4.



$LEA\ [cm^2] = 2.36 + 0.24\ (Wt\ in\ kg)$

Thus the equation for adjustment of measured LEA became:

Equation 2. *Adj LEA [cm²] = measured LEA [cm²] + 0.24 (Individual Wt in kg – Group mean Wt in kg)*

The slope of the linear regression term was identical in equation 1 and equation 2. To compare adjustment by equation 1 vs. equation 2, the values for individual ewes in group 4 were adjusted first by equation 1 from groups 1 and 2 combined, and second by equation 2 devised from group 4. Although adjusted values were larger when adjusted by equation 2 than by equation 1, the ranks of the replacement ewes in group 4 did not differ by paired student's t-test ($P > 0.10$) or by agreement analysis ($P < 0.0001$). Thus the simple linear equation (Equation 2) appeared to provide sufficient adjustment of LEA for weight of the animals in group 4. When one third of 129 potential replacements in group 4 were designated as culled based on their lowest rank (corresponding to smallest predicted LEA) by Equation 1 vs. Equation 2, only 3 of 43 (7 percent) culled ewes were classified differently.

Loin Depth

Groups 1 and 2 Combined. The least squares mean for LD was 2.33 cm ± 0.23 cm. The model including weight accounted for 31 percent of the variation in LD ($P < 0.0001$), and breed type and age were not significant. The quadratic equation (illustrated in Figure 2 A) that best fit the results for the relationship of LD to weight was:

$LD\ [cm] = 1.28 + 0.03\ (Wt\ in\ kg) - 0.0007\ (Wt\ in\ kg - 39.76)^2$.

Thus the adjustment formula became:

Equation 3. *Adj LD [cm] = measured LD [cm] + 0.03 (Individual Wt in kg – Group mean Wt in kg) – 0.0007 (Individual Wt in kg – Group mean Wt in kg)²*

Group 4. In the initial analysis of LD, only weight was significant ($P < 0.0001$), while breed type and age were not ($P > 0.10$). The model including only weight accounted for 52 percent of the variation in LD ($P < 0.0001$) by simple linear regression (Figure 2 B). The prediction equation became:

$LD\ [cm] = 1.35 + 0.03\ (Wt\ in\ kg)$

Again, the slope of linear regression in the equation for adjustment of LD was the same (0.03) for both groups 1 and 2 combined and group 4, and because the differences among breed types were not significant, it appeared practical to adjust LD for weight by the formula:

Equation 4. *Adj LD [cm] = measured LD [cm] + 0.03 (Individual Wt in kg – Group mean Wt in kg)*

Figure 2. Relationships of loin depth to weight of ewe lambs in Exp. 1: A. Quadratic relationship in Groups 1 and 2 combined. B. Linear relationship in Group 4.

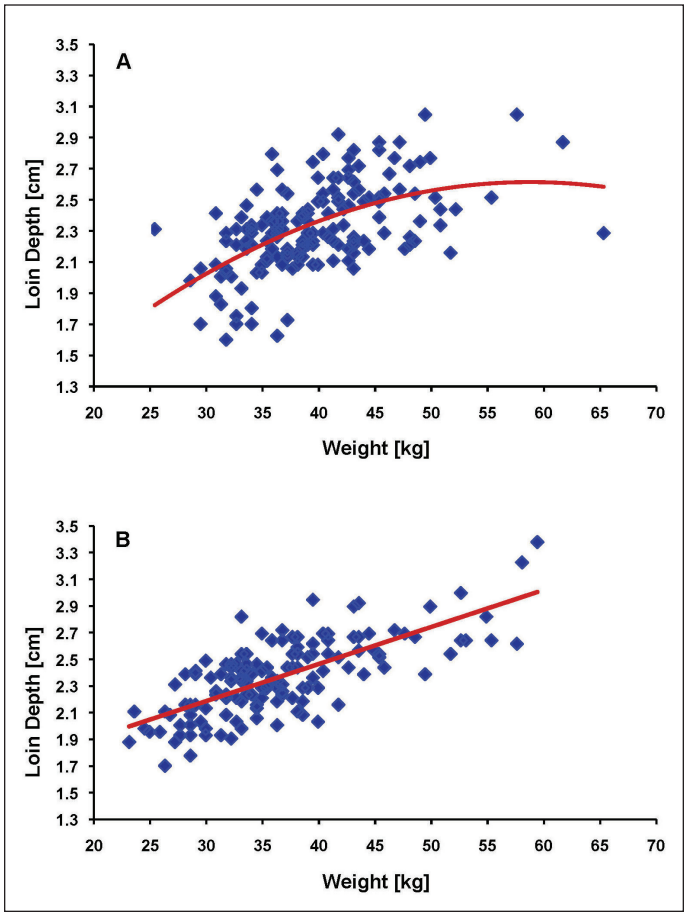
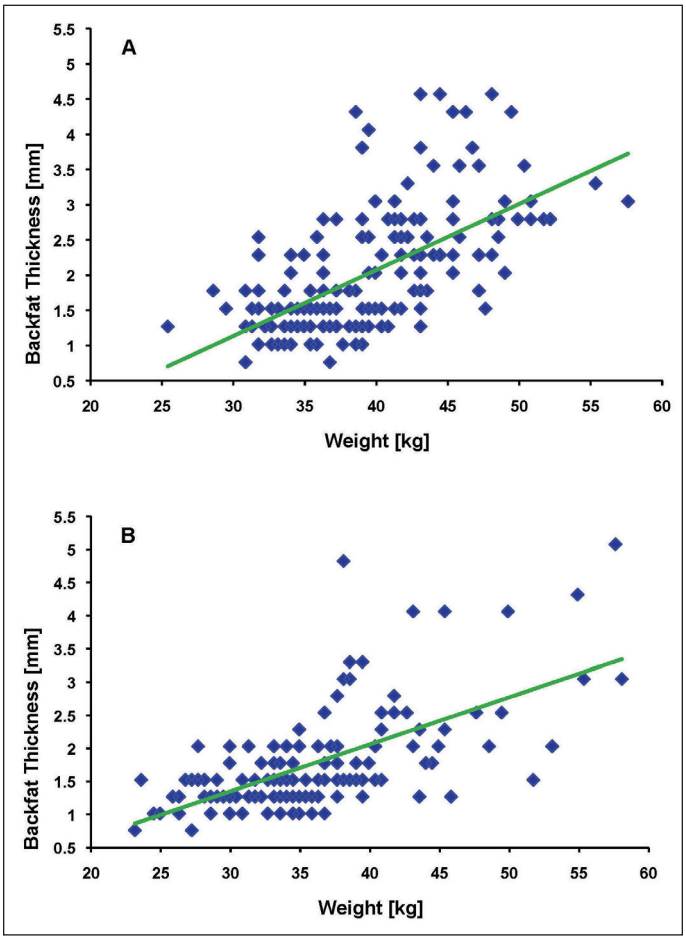


Figure 3. Linear relationships of backfat thickness to weight of ewe lambs in Exp. 1: A. Groups 1 and 2 combined. B. Group 4. These regressions were calculated from untransformed data.



Backfat Thickness

Backfat thickness was not distributed normally and was transformed to log_{10} (BFT) for all analyses. However, for convenient illustration of the relationship of BFT to weight, the regressions were calculated also on the initial (untransformed data) and presented in Figures 3A (Groups 1 and 2 combined) and 3 B (Group 4).

Groups 1 and 2 Combined. In an analysis of covariance model using sequential sums of squares, in which the effect of breed type was examined after BFT was adjusted for weight ($P < 0.001$), breed type also affected log_{10} BFT (mm; $P < 0.001$). Fat thickness increased with weight and the regression lines were close to parallel for all 3 breed types. Dorset breed type had the greatest fat thickness (2.77 mm ± 0.13 mm), with mixed breed type second (2.51 mm ± 0.25 mm) and Texel breed type third (1.73 mm ± 0.02 mm). When age or year was included in the model, they also affected log_{10} BFT ($P < 0.001$). Further analyses revealed that the Dorset and mixed types were older than the Texels, and thus heavier, especially in one year, and proportions of breed types varied with year. Therefore, in the final model, in which year was included as a random effect, age, breed type, and interactions were not significant; weight accounted for 38 percent of the variation in log_{10} BFT ($P < 0.001$). The formula to predict log10 BFT from weight was:

$$Log_{10}\ BFT\ [mm] = -0.50 + 0.019\ (Wt\ in\ kg)$$

Therefore, the adjustment equation became:

Equation 5: *Adj log_{10} BFT [mm] = log_{10} measured BFT [mm] + 0.019 (Individual Wt in kg – Group mean Wt in kg)*

Group 4. Weight was the only significant independent variable ($P < 0.0001$) in the model, accounting for 45 percent of the variation in log_{10} BFT, and there was no weight-by-breed-type interaction. The equation to estimate BFT from weight became:

$$Log_{10}\ BFT\ [mm] = -0.30 + 0.014\ (Wt\ in\ kg)$$

Thus the adjustment of measured BFT for weight was:

Equation 6 *Adj log_{10} BFT [mm] = measured log_{10} BFT [mm] + 0.014 (Individual Wt in kg – Group mean Wt in kg).*

Experiment 2

This experiment, using the data from group 3, examined if the response variables (LEA, LD and BFT; Table 2) depended on status of ewes (late pregnant/lambed or open), body weight, age, breed, and their possible interactions.

Loin Eye Area

Examination of the full model including age, weight, breed type, status, and their interactions revealed that weight

Figure 4. Linear relationships of loin eye area and loin depth to weights of late pregnant/lambed and open ewe lambs in Exp. 2: A. Loin eye area. B. Loin depth.

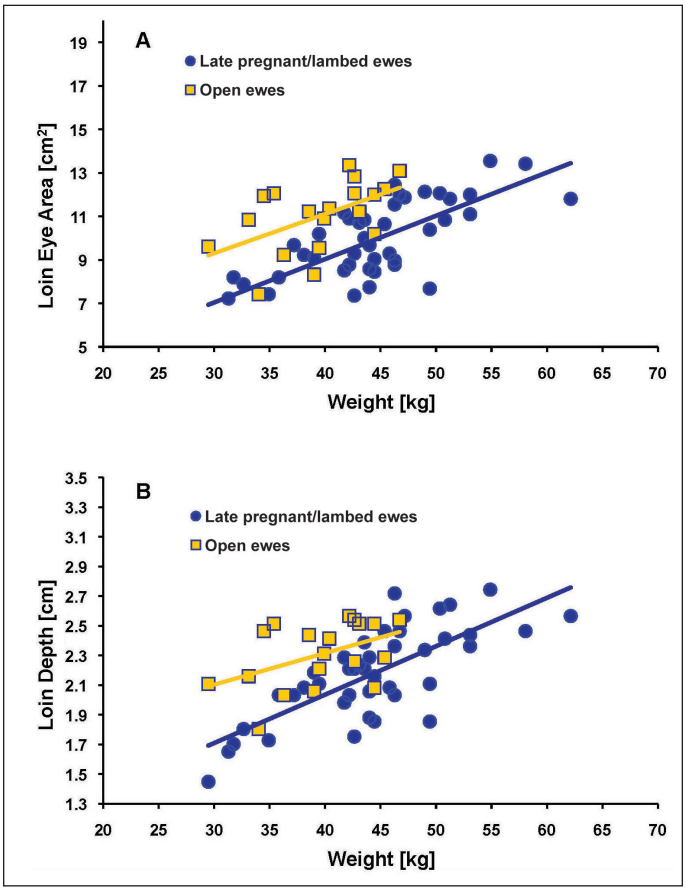


Table 2. Mean values ± SE for age, weight, loin eye area (LEA), loin depth (LD) and backfat thickness over the loin (BFT) in late pregnant/recently lambed and open ewe lambs in Exp. 2.

Status	N	Age	Weight (kg)	LEA (cm^2)	LD (cm)	BFT (mm)
Pregnant or Lambed	43	396.5 ± 4.4	44.3 ± 1.1	9.60 ± 0.21[a]	2.13 ± 0.20[a]	1.69 ± 0.11
Open	19	383.4 ± 6.5	39.6 ± 1.1	11.62 ± 0.37[b]	2.38 ± 0.41[b]	1.48 ± 0.08

[a, b] Least squares mean values within carcass trait with different superscripts differed ($P < 0.0001$).

explained most of the variation in LEA ($P < 0.0001$). When non-significant interaction terms were dropped from the model, significant linear dependencies of LEA on weight ($P < 0.0001$), specific to status ($P < 0.0001$) were found. The model including weight, status and their interaction accounted for 52 percent of the variation in LEA (Figure 4 A). Open ewes had an average LEA about 2 cm^2 larger (11.62 cm^2 ± 0.37 cm^2) than the LEA of ewes that were late pregnant or had lambed (9.60 cm^2 ± 0.21 cm^2). However, as shown in Figure 4 A, the slopes of the lines were similar, indicating parallelism and a lack of interaction of weight and status ($P = 0.79$). The linear regression equation for the late pregnant/recently lambed ewes (with respect to date of scanning) was:

LEA [cm^2] = 1.06 +0.20 (Wt in kg)

The comparable equation for the ewes that were open was:

LEA [cm^2] = 3.90 +0.18 (Wt in kg)

Loin Depth

In the complete model with age, weight, breed type, status and their interactions, the most influential variables detected were weight ($P < 0.0001$) and age at scanning ($P = 0.03$), followed by status ($P = 0.18$). After eliminating the non-significant breed type and interaction terms, weight ($P < 0.0001$), age ($P < 0.0006$), and status ($P < 0.0001$) were confirmed as significant predictors of LD. In a separate covariance model using sequential sums of squares in which LD was adjusted for the effect of weight ($P < 0.0001$), status still affected LD ($P < 0.0001$; Figure 4 B). The interaction of weight and status was not significant; as with LEA, the regression lines for LD on weight did not differ from parallel. The model accounted for 51 percent of variation in LD. The final equations reflected the linear relationship of LD to weight, specific to status. Late pregnant/lambed ewes had shallower (2.13 cm ± 0.20 cm) LDs than ewes that were open (2.38 cm ± 0.41 cm). The linear regression equation for late pregnant/lambed ewes was:

LD (cm) = 0.73 + 0.03 (Wt in kg)

The comparable equation for the ewes that were open was:

LD (cm) = 1.46 + 0.02 (Wt in kg)

Backfat

With either full or reduced models, physiological status, age, weight, breed type, and interactions did not affect BFT ($P > 0.05$). The BFT values for open vs. pregnant/lambed ewes (Table 2) varied in the same direction as body weights of the two groups; open ewes were on average 5 kg lighter and 13 days younger (Table 2) than the late pregnant/lambed ewes. Interestingly, the late pregnant/lambed ewes had been 5.4 kg heavier at breeding the previous fall (M. Knights and A. Redhead, unpublished data).

Discussion

Weight of the ewe had the most significant influence on loin muscle and backfat dimensions. This finding was consistent across 4 groups of replacement ewe lambs. There were significant increases in LEA, LD, and BFT as body weight increased among ewes in each group. When age, breed type, and/or status affected these traits, regression lines on weight remained parallel. Therefore, equations developed using these regression coefficients can be used to adjust traits to a common weight basis, at least within contemporary groups in the flock studied.

From early work by Hankins (1947), muscle made up 42 percent to 67 percent of carcass weight in lambs. The total muscle content of a lamb carcass was most closely related to the muscle content of the *Longissimus dorsi* from the 4th to the 12th rib (r = 0.656) in Hankins (1947) study. Similarly, Tatum et al. (1998) found that fat-free muscle tissue in slaughter lambs had a "moderately strong" correlation with visual appraisal of loin thickness by trained evaluators (muscle thickness score, r = 0.54). As pointed out by Notter et al. (2014), weight is the most important factor in carcass value, but LEA can be used to fine tune estimates of carcass value and product weight.

The approach used in this study was to adjust the trait to the mean weight of the group. When the measured LEAs in a group of ewe lambs were adjusted to mean weight of the group by a linear formula derived from the group, or by a linear and quadratic formula derived from another group, and one third of the group was culled, only 7 percent of animals culled differed. Thus the simpler linear adjustment appeared adequate to adjust LEA or LD to a common weight for use in selection. In fact, in reviewing this manuscript, D. R. Notter (personal communication) pointed out that the quadratic formulas derived in this study would predict a decline in LEA or LD as animals grew beyond about 60 kg. Given the repeatability from group to group, linear formulas derived from these data can be used to correctly rank animals according to each trait, therefore enabling genetic improvement in carcass merit (Leeds et al. 2008). The high heritability of LEA or LD (0.35; *Sheep Production Handbook*, 2015) means that selection for either trait can lead to rapid genetic gains in those traits.

For BFT, slightly different relationships may exist among groups of animals in relation to body condition score and

nutritional treatments. The coefficient derived from group 4 to adjust the $\log_{10}$ BFT values for weight was 0.014 compared to 0.019 derived from groups 1 and 2 combined or 0.021 from open ewes in Exp. 2. BFT has a relatively high heritability (0.30; *Sheep Production Handbook*, 2015), but when selecting for leaner animals on the basis of BFT, it is important to recognize that Lorentzen and Vangen (2012) found a positive genetic correlation of intramuscular fat (IMF) with dissected fat (r_g = 0.62 ± 0.34) in crossbred, meat-type lambs. Thus selection for less BFT may lead to less IMF and loss of flavor. Pannier et al. (2014) emphasized that continued selection for leanness should be closely monitored to be sure IMF remains above 4 percent to insure product quality and consumer satisfaction.

Ewes in Exp. 2 that were late pregnant or had lambed had significantly smaller LEA and LD, but did not have reduced BFT, compared to open ewes. This striking result would have to be due to either loss of muscle tissue or loss of IMF as a result of the high demands of the third trimester and milk production. In a recent study of Texel lambs that ranged from 20 kg to 49 kg body weight (mean 35) at ages of 91 days to 202 days (mean 132), Clelland et al. (2014) found that IMF in the loin ranged from 0.3 percent to 3.9 percent (mean 1.5 ± 0.7). Pannier et al. (2014) found an average of 4.2 percent IMF in a large sample of Australian female lambs. Thus the observed reduction of 2 cm^2 in LEA or 0.25 cm in LD for late pregnant/lambed ewes compared to open ewes has to be due mainly to reduction in muscle fiber size in response to protein demands of late pregnancy and early lactation. Much of this atrophy can be credited to mobilization of protein from peripheral tissues, primarily skeletal muscle (Kuhla et al., 2011). Such an effect has been shown in lactating sheep (e. g., Vernon et al., 1987 and citations therein), as well as dairy cows (e.g., Kuhla et al., 2011) and sows (e.g., Clowes et al., 2005). However, in lactating dairy cows as an example, Bruckmaier et al. (1998) saw decreases in both BFT and *Longissimus dorsi* diameter as measured by ultrasound. Lack of change in BFT in association with decreasing LEA or LD in ewe lambs in the current study may have related to the very small amount of fat cover in most animals, even in the open group. Thus it appears that the protein nutritional level in the flock studied was less than optimal during the late pregnant period.

Conclusion

In summary, equations to adjust carcass traits measured by ultrasonography in the live animal for body weight at scanning were developed for replacement ewe lambs in a farm flock. Appropriate emphasis on carcass traits in selection programs can increase muscular growth capacity and thus pounds harvested by the producer as well. At heavier weights, increased muscle mass will be accompanied by deposition of subcutaneous and intramuscular fat at a faster rate, decreasing cutability, but greater IMF will increase palatability. Use of adjusted values for these traits in the selection process can improve the overall productivity and meat quality of offspring in farm flocks; creating a more acceptable product, while increasing profitability in the long run.

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Sheep & Goat Research Journal
Volume 32, 2017 - August

The Use of Chambourcin Grape Extract as a Natural Anthelmintic in Goat Kids

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Lincoln University Cooperative Research Manuscript # 20170005

Acknowledgements

This research was supported by the NCR-SARE as a graduate student grant project. Fermented Chambourcin grape extract was provided by Le Bourgeois Winery in Rochport, Missouri

Summary

Gastrointestinal parasitism is one of the greatest economic threats to goat production in the United States. Further, with increased frequencies of anthelmintic resistance, there is compelling interest in natural dewormers, such as alternatives containing condensed tannins. Therefore, the objective of this study was to evaluate effects of fermented Chambourcin grape extract (CG) on parasite level and performance in meat-type goat kids. On October 14, 2014, mixed-breed male and female meat-type goat kids (n = 45; 17.17 kg ± 0.79 BW) were stratified by fecal egg count, weight, sex, and were allocated randomly to 1 of 3 treatments: 1. an oral dose (10-mL per 4.5 kg of BW) of CG at 7 d (D7) intervals (n = 15), 2. the same dose of CG at 14 d (D14) intervals (n = 15), or 3. control (C; 30-mL oral dose of water at 14 d intervals; n = 15). Condensed tannins were extracted, purified, and standardized from CG and were found to have a concentration of 0.33 mg/mL. Kids were maintained on tall fescue [*Lolium arundinaceaum* (Schreb.) Darbysh] and mixed-browse pasture with 14-percent crude-protein, corn-soybean-meal-based creep feed for the duration of the 63-d study. Data were analyzed using PROC MIXED of SAS. Two contrast statements were used to compare the mean of C compared with D7 and D14 and the mean of D7 compared with D14. Start BW, end BW, ADG, and gain did not differ ($P \geq 0.42$) across treatments. Start, end, and change from start to end body condition scores, fecal egg counts, and packed cell volumes did not differ ($P \geq 0.12$) across treatments. End FAMACHA© scores were higher ($P = 0.02$) from D7 and D14 compared with C. White blood cell (WBC) concentrations at the end of the study were lower ($P = 0.04$) from C compared with D7 and D14; whereas, D14 tended ($P = 0.08$) to be greater compared with D7. Start neutrophil concentrations tended ($P = 0.08$) to be higher from C compared with D7 and D14 and a change ($P = 0.05$) was found in neutrophil concentrations from start to end of study from C compared with D7 and D14. End of study basophil concentrations were greater ($P = 0.04$) from D14 compared with D7. End of study hemoglobin concentration and mean-corpuscular hemoglobin concentration percent tended to be lower ($P = 0.07$ and $P = 0.06$, respectively) from C compared with D7 and D14. End of study mean-corpuscular hemoglobin concentrations were lower ($P = 0.04$) from C compared with D7 and D14 and a change ($P = 0.04$) was found in mean-corpuscular hemoglobin concentrations from start to end of study from C compared with D7 and D14. Change from start to end of study platelet concentrations differed ($P = 0.04$ and $P = 0.02$, respectively) from C compared with D7 and D14. Other blood parameter counts were similar ($P > 0.10$) across treatments. Therefore, fermented Chambourcin grape extract may not be an effective natural anthelmintic for controlling nematodes in creep-fed goat kids.

Key Words: Anthelmintic, Condensed Tannin, Goats, Grape Extract

Introduction

Gastrointestinal nematodes (GIN) are the largest constraint to profitable goat production worldwide (Shaik et al., 2006). Since their introduction in the 1960s, broad-spectrum synthetic anthelmintics have been the primary defense against GIN infection in small ruminants (Hoste, 2011). However, due to widespread prevalence of anthelmintic resistance in goat GIN and in response to increased consumer awareness of chemical use in agricultural production, alternative, natural control methodologies are needed to increase profitability in the small ruminant industry (Shaik et al., 2006; Terrill et al., 2009).

A compilation of research by Muir (2011) suggested that phytotherapy or use of plants containing flavonoids, as a natural anthelmintic, should be evaluated. The most abundant flavonoids are polyphenols (Githiori, 2006). Polyphenols are tannins, which manifest as plant secondary metabolites, and are linked to plant defense mechanisms against insects (Githiori, 2006; Oksana et al., 2012). Tannins are comprised of two groups: condensed tannins (CT) and hydrolysable tannins (Anthanasiadou, 2001). Condensed tannins are compounds that may demonstrate biological activities in ruminants, such as binding to proteins and suppression of GIN infection (Naumann et al., 2013).

Elevated levels of CT have been quantified in dark red, blue, or black pigmented fruits, such as grapes; many dark orange or red-skinned vegetables; some legume cereals and beans; tree nuts, such as almonds, pecans and hazelnuts; cocoa beans; wine; and spices, such as cinnamon (King and Young, 1999; Gu et al., 2004; Mattivi et al., 2008). King and Young (1999) indicated that pH, level of astringency, and bitterness are linked to CT concentration (King and Young, 1999). Condensed tannins are compounds that possess high molecular weights, 500 to 3,000, that demonstrate biological activities causing them to react and precipitate most proteins (Muir, 2011). An increase in concentration of CT is also observed when comparing red grape juice to red wine (King and Young, 1999), indicating that fermentation may positively influence CT levels (Githiori, 2006).

In a companion paper, Cash et al. (2016) reported that organic fermented Pinot Noir grape extract may be an effective strategy for controlling GIN and increasing performance in Katahdin lambs. Therefore, the objective in the current study was to evaluate effects of fermented Chambourcin grape extract on performance and parasite level in goat kids.

Materials and Methods

Animals and experimental design

This project was conducted at the Lincoln University Allen T. Busby Farm in Jefferson City, Mo. and was approved by the Animal Care and Use Committee (14-4). Pastures at the Allen T. Busby Farm have been historically utilized for small ruminant grazing. Mixed-breed, male and female meat-type goat kids (n = 45; 17.17 kg ± 0.79 kg BW) were maintained on endophyte-infected tall fescue [*Lolium arundinaceaum* (Schreb.) Darbysh] and mixed-browse pasture with 14-percent crude-protein (CP), corn-soybean-meal based creep feed for 81 d post-weaning and were allowed to acquire a natural GIN infection. Starting October 14, 2014, kids were stratified by FEC, weight, and sex, and allocated randomly to 1 of 3 treatments: 1. drenched with Chambourcin grape extract (CG) every 7 d (D7) at a rate of 10-mL per 4.5 kg of BW (n = 15); 2. drenched with CG every 14 d (D14) at a rate of 10-mL per 4.5 kg of BW (n = 15); and 3. drenched with 30-mL of water every 14 d (C; n = 15). In accordance with established farm procedures, animals were removed from the study if they met three out of the following four criteria: 1. FEC of > 4,000 eggs/g; 2. FAMACHA© score of > 4; 3. packed cell volume (PCV) of < 21 percent; or 4. a BCS < 2. For the duration of the 63-d trial, kids grazed fescue and mixed-browse pasture and had *ad libitum* access to water, mineral (Redmond Naturals, Redmond, Utah), and creep feed. Throughout the study, kids were maintained in a single group with ear tag numbers as the primary identification method.

Condensed tannin and feedstuff analysis

Condensed tannins were extracted, purified, and the concentration of protein bound CT and the procyanidins:prodelphinidin ratio of CT from CG were determined according to Cash et al. (2016).

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

Parasitological procedure and measures

During the 63-d trial, individual fecal samples were taken from the rectum of each animal every 7 d. Fecal egg count was determined within 24 h by the modified McMaster procedure (Whitlock, 1948; Mines, 1977) and quantified by using 2-g subsamples of fresh feces from each kid. Every 7 d, individual blood samples were taken by jugular venipuncture into hematocrit tubes and PCV was determined using a HemataSTAT II Centrifuge (Separation Technology, Inc., Sanford, Fla.) within 6 h of blood collection. Additionally, weights, FAMACHA© scores (Hepworth et al., 2006) and BCS (Russell, 1991) were taken every 7 d by the same experienced evaluator throughout the entire study.

Analysis of complete blood cell counts

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

Statistical analyses

Data were analyzed using PROC MIXED of SAS 9.3 (SAS Inst. Inc., Cary, N.C.). Animal was considered the experimental unit. Treatment means are reported as least squares means with the contrast statements of the mean of control compared with D7 and D14 and the mean of D7 compared with D14. For all statistical analyses, differences were considered significant at $P < 0.05$ and were considered tendencies at P values of less than 0.10 but greater than 0.05.

Results

Pasture averages for all sample dates included: CP = 11.9 percent; NDF = 65.6 percent; ADF = 35.3 percent; DM = 95 percent. Corn-soybean-meal-based creep feed analysis was: CP = 14 percent; NDF = 38.4 percent; ADF = 23.4 percent; DM = 98 percent. Chambourcin-grape extract was found to have a concentration of 0.33 mg/mL of CT. Crude protein was 1.7 mg/mL by sample. The concentration of protein bound CT was determined and found to bind 3.5 mg/mL of protein with a 7.01 percent binding capability. The level of combined procyanidins and prodelphinidin was 0.0007 mg/mL with 12.5 percent Galloylated tannin.

As shown in Table 1, start BW, end BW, ADG, and gain did not differ ($P \geq 0.42$) across treatments. Start, end, and change from start to end of the study BCS also did not differ ($P \geq 0.12$) across treatments.

Natural GIN infection was perceptible in all kids with an average FEC of 12.6 eggs ± 6.47 eggs per g of feces. Three kids were removed from D7, three kids were removed from D14, and one kid was removed from C, because they met three of four health threshold criteria. As displayed in Table 2, end FAMACHA© scores were higher ($P = 0.02$) from D7 and D14 compared with C; however, start, end, and change from start to end FEC and PCV did not differ ($P \geq 0.12$) across treatments.

White blood cell (WBC) concentrations at the end of the study were lower ($P = 0.04$) from C compared with D7 and D14; whereas, D14 tended ($P = 0.08$) to be greater compared with D7. Start neutrophil concentrations tended ($P = 0.08$) to be higher from C compared with D7 and D14 and a change ($P = 0.05$) was found in neutrophil concentrations from start to end of study from C compared with D7 and D14. End of study basophil concentrations were greater ($P = 0.04$) from D7 compared with D14. End of study hemoglobin concentration and mean-corpuscular-hemoglobin concentration percent tended to be lower ($P = 0.07$ and $P = 0.06$, respectively) from C compared with D7 and D14. End-of-study mean-corpuscular-hemoglobin concentrations were lower ($P = 0.04$) from C compared with D7 and D14 and a change ($P = 0.04$) was found in mean- corpuscular-hemoglobin concentrations from start to end of study from C compared with D7 and D14. Change from start to end of study platelet concentrations differed ($P = 0.04$ and $P = 0.02$, respectively) from C compared with D7 and D14. Other blood parameter concentrations were similar ($P > 0.10$) across treatments (Table 3).

Discussion

Evidence has suggested that differences in ruminant species and a lack of direct information about goats have led to dramatic errors in efficacy of GIN control (Hoste et al., 2010). It has been shown that goats metabolize anthelmintics faster than other ruminants (Hoste et al., 2010). Consequently, treating goats at the recommended sheep-dosage rate has resulted in anthelmintic under-dosing, thus causing a reduced efficacy (Hoste et al., 2010). This could help explain the prevalence of anthelmintic resistance and increased resistant GIN in goats (Hoste et al., 2010). Subsequently, the purpose of natural anthelmintics involves a different approach towards the control of GIN in ruminants. Natural-control methods do not always have a direct effect on the parasite, but instead use the animal's own ability to recover and assist in maintaining parasite infections below the economic threshold of the physical capabilities of the animal (Ketzis, 2006). This not only relates to the effectiveness of the control method used, but also to the epidemiology of parasites, animal-management program, ease of integration as a sustainable program, and climate in which pro-

Table 1. Effect of Chambourcin grape extract on performance in goat kids.

	Treatment[a]				
Item	C	D7	D14	SEM[b]	Contrast[c]
Start BW, kg	17.3	17.1	17.1	0.79	ns
End BW, kg	23.1	22.4	23.4	1.27	ns
ADG, kg	0.09	0.08	0.10	0.010	ns
Gain, kg	5.4	5.2	5.9	0.66	ns
Start BCS[d]	2.9	3.0	3.0	0.13	ns
End BCS[d]	2.8	2.9	2.8	0.13	ns
BCS[d] change[e]	-0.25	-0.17	-0.21	0.140	ns

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

Table 2. Effect of Chambourcin grape extract on parasite parameters in goat kids.

Item	Treatment[a] C	D7	D14	SEM[b]	Contrast[c]
Start FEC, eggs/g[d]	8.5	7.1	22.1	6.50	ns
End FEC, eggs/g[d]	21.7	19.7	19.9	5.57	ns
FEC[d] change, eggs/g[e]	12.9	11.9	-1.0	10.82	ns
Start FAMACHA©[f]	3.3	3.5	3.7	0.20	ns
End FAMACHA©[f]	2.4	3.0	2.7	0.13	W
FAMACHA©[f] change[g]	-0.7	-0.5	-0.9	0.24	ns
Start PCV, %[h]	27.4	28.8	28.6	1.42	ns
End PCV, %[h]	33.0	32.8	34.4	1.00	ns
PCV[h] change, %[i]	3.9	2.7	5.0	1.50	ns

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

duction occurs (Ketzis, 2006). In the least, the precise mechanism by which CT acts as a natural anthelmintic needs to be better understood and a concerted effort on isolation, development, and validation of the effects needs to be undertaken before they are more widely accepted (Githiori, 2006).

In the current study, no change in performance in treated kids was apparent, which suggests there were no added benefits of CT in kids creep-fed a 14-percent CP supplement. In contrast, in a companion study, Cash et al. (2016) reported that fermented, organic Pinot Noir-grape extract improved ADG and total weight gain in lambs not provided any additional supplementation. The widely accepted explanation for positive effects of CT on protein digestion and metabolism is that CT-protein complexes escape ruminal degradation resulting in greater protein availability in the abomasum (Reed, 1995). In kids on a higher plane of nutrition, additional protein-bound CT may not result in improved production and parasite control, because protein needs are already being met (Waghorn, 2008). Madibela and Jansen (2003) fed a diet containing Mistletoe, *Viscum verrucosum*, which supplied 8.9 g/d of CT. Similar to the current study, Mistletoe did not affect ADG in control goats compared with treatment goats (Madibela and Jansen, 2003).

High-CT content (Mattivi et al., 2008; Yang et al., 2009) and world-wide availability make red-grape products a potential source of natural anthelmintics (Kammerer et al., 2004). *In vitro* research conducted by LeShure (2014), revealed grape-pomace extract resulted in 100-percent inhibition of egg hatching into third-stage larvae. It was suggested that grape pomace had efficacy in decreasing hatchability of GIN eggs, as well as decreasing parasite viability in an *in vitro* setting (LeShure, 2014). However, CG extract used in this study had a CT concentration of 0.33 mg/mL, but did not demonstrate a natural bioactive anthelmintic effect in pasture-grazed, creep-fed goat kids. Three experiments conducted by Whitley et al. (2009) to determine the influence of high-CT grain sorghum on parasites suggested there was no influence of diet on PCV or FEC. The authors concluded that high-CT grain sorghum did not suppress GIN in goats (Whitley et al., 2009). Research by Paolini et al. (2005) used Quebracho, *Schinopsis* spp., extract and sainfoin, *Onobrychis*, hay, at a rate of 50-percent CT at 5 percent of DM diet and 3.2-percent CT, respectively. When compared with control animals, worm counts decreased, but differences were not significant. Furthermore, no differences were found in physiological measurements between the three groups (Paolini et al., 2005). In agreement with previously mentioned research, results from the current study exhibited similar response in FEC or PCV and end FAMACHA© scores. In contrast, our lab (Cash et al., 2016) demonstrated that fermented Pinot Noir, with a CT concentration of 0.20 mg/mL, dosed at the same amount and interval as the current study, was an effective strategy for controlling GIN in pasture-grazed Katahdin lambs. Further, Shaik et al. (2006) examined effects of sericea lespedeza, *Lespedeza cuneata*, hay on FEC, PCV, morbidity of adult *Haemonchus contortus* (HC) worms, and larvae. On a diet with a total-CT concentration of 22.4 percent on a DM basis, they found that FEC decreased starting at wk one and continued to decrease for the duration of the study. Also, PCV, number of larvae recovered, and HC recovered from fecal cultures were improved (Shaik et al., 2006). In a study by Mueller-Harvey (2006), grazing of sericea lespedeza forage (50 g CT/kg) achieved high reductions

Table 2. Effect of Chambourcin grape extract on parasite parameters in goat kids.

Item[b]	Treatment[a] C	D7	D14	SEM[c]	Contrast[d]
Start WBC, K/µL	13.93	12.97	14.66	1.894	ns
End WBC, K/ µL	13.20	14.00	17.72	1.491	W; x
WBC change, K/ µL[e]	0.70	-0.90	-2.58	1.774	ns
Start NEU, K/µL	5.57	4.11	5.02	0.558	w
End NEU, K/µL	5.88	5.75	8.07	1.018	ns
NEU change, K/µL[e]	0.22	-1.60	-2.96	1.098	W
Start LYM, K/µL	5.09	5.59	5.19	0.772	ns
End LYM, K/µL	3.35	3.97	3.99	0.594	ns
LYM change, K/µL[e]	1.28	1.92	1.51	0.927	ns
Start MONO, K/µL	2.67	2.32	2.82	0.216	ns
End MONO, K/µL	2.20	1.97	2.42	0.242	ns
MONO change, K/µL[e]	0.63	0.48	0.48	0.233	ns
Start EOS, K/µL	0.61	0.89	0.70	0.196	ns
End EOS, K/µL	1.53	1.26	1.76	0.383	ns
EOS change, K/µL[e]	-0.67	-0.32	-1.10	0.408	ns
Start BASO, K/µL	0.84	0.88	0.93	0.111	ns
End BASO, K/µL	1.19	1.06	1.46	0.135	X
BASO change, K/µL[e]	-0.18	-0.24	-0.50	0.182	ns
Start RBC, K/µL	10.40	10.07	10.83	0.587	ns
End RBC, K/µL	11.06	11.85	12.01	0.548	ns
RBC change, K/µL[e]	-0.38	-1.70	-1.02	0.900	ns
Start HGB, g/dL	8.27	7.83	8.64	0.526	ns
End HGB, g/dL	8.65	9.40	9.99	0.510	w
HGB change, g/dL[e]	-0.15	-1.34	-1.10	0.809	ns
Start HCT, %	19.78	19.23	20.27	1.256	ns
End HCT, %	21.40	22.78	22.88	1.187	ns
HCT change, %[e]	-0.70	-3.48	-2.29	1.779	ns
Start MCV, fL	18.87	18.87	18.67	0.459	ns
End MCV, fL	19.25	19.15	19.00	0.522	ns
MCV change, fL[e]	-0.01	-0.43	-0.32	0.329	ns
Start MCH, pg	8.09	7.71	7.95	0.325	ns
End MCH, pg	7.76	7.93	8.31	0.261	W
MCH change, pge	0.39	-0.03	-0.23	0.291	W
Start MCHC%, g/dL	43.17	41.09	42.63	1.534	ns
End MCHC%, g/dL	40.42	41.73	43.94	1.257	w
MCHC% change, g/dL[e]	2.33	0.67	-0.52	1.410	ns
Start RDW, %	31.17	31.10	31.68	1.129	ns
End RDW, %	31.40	30.11	30.32	1.436	ns
RDW change, %[e]	0.52	0.19	0.93	1.383	ns
Start PLT, K/µL	612.36	547.39	579.53	99.662	ns
End PLT, K/µL	785.25	807.75	960.85	128.975	ns
PLT change, K/µL[e]	22.91	-194.91	-334.62	105.225	W

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

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

[c] SEM = Pooled standard error of means.

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

[e] Change = Change of start CBC parameters compared with end CBC parameters.

(57 to 100 percent) in FEC, total fecal egg output, and numbers of parasitic nematodes HC, *Teladorsagia* spp., and *Trichostrongylus* in goats. Further exploration is needed to determine anthelmintic properties and biological processes by which CT influences response of host to nematodes.

Most ruminants are grazers; in contrast, goats are browsers, which in theory limits contact with infective stages of GIN (Hoste et al., 2010). Goat feeding behavior has evolved to browse on a high diversity of plants. This behavior might be involved in the regulation of parasite populations by a combination of self-medication with plant secondary metabolites and avoidance of GIN (Hoste et al., 2010). Goats have developed physiological adaptations to, and dependencies on plant CT, which have carved a browse niche that seeks out CT-containing plants (Muir, 2011).

Goats have a higher tolerance than most ruminants to high levels of CT, which are astringent or bitter and reduce palatability (Lamy et al., 2009). This difference could be the result of existence of tannin-binding proteins in goat saliva (Lamy et al., 2009). For the majority of forage plants with moderate levels of CT, palatability to goats appears to be independent of CT presence and concentration, due to excretion of proline-rich proteins in goat saliva (Lamy et al., 2009). Proline-rich proteins have been the most studied salivary proteins with defense functions against the potential harmful effects of tannins. Saliva of species which ingest high levels of tannins in their regular diet have been reported to have higher levels of proline-rich proteins (Lamy et al., 2009). These salivary proteins are very reactive with CT and bind them as goats ingest forage CT. This may improve palatability of plants with moderate concentrations of soluble CT, but may also negatively affect ability of CT to bind with proteins in the ruminant environment (Muir, 2011). Additionally, some forage CT may interfere with intestinal absorption of amino acids, even in a low pH environment, where CT-protein bonds should be broken (Waghorn, 2008). This phenomenon may be specific to goats only and could further explain the absence of a by-pass protein effect in this study.

Another consideration for the lack of an anthelmintic effect in the current study could be in part due to the increased metabolism rates of goats compared to other ruminants. Pharmacological studies (Sprenger et al., 2013; Gokbulut et al., 2014) indicate that goats metabolize drugs much faster than sheep or cattle, resulting in decreased bioavailability of anthelmintics. Although not as practical, perhaps a shorter dosage interval would have impacted results seen in the current study.

Laboratory examination of the ruminant CBC can be an important addition to physical examinations (Jones and Allison, 2007). Consulting a CBC can often show an immune response to infection or virus before symptoms are presented in the animal. Research conducted by Hoste et al. (2008) illustrated that acquisition and expression of immune responses against GIN species are less efficient in goats and a fully expressed immune response appears delayed in goats compared with other ruminants (Hoste et al., 2008). In this research, some changes were found in CBC results, including significantly lower white blood cell concentrations at the end of the study from C compared with D7 and D14; whereas, D14 tended to be greater compared with D7. Increases in NEU can indicate stress-related health responses (Jones and Allison, 2007). In the current study, start NEU tended to be higher, and a significant change was found in NEU from start to end of study from C compared with D7 and D14. Increases were found in end of study BASO concentrations from D14 compared with D7, which could indicate an allergic response or inflammation (Jones and Allison, 2007). A decrease was found for HGB and MCHC percent from C compared with D7 and D14, which could indicate presence of anemia (Jones and Allison, 2007). A decrease was found in end of study MCH and a greater change from start to end of study in C compared with D7 and D14, again demonstrating anemia (Jones and Allison, 2007). Positive changes in blood parameters involving HGB, MCH, and MCHC percent, could be related to increased antioxidant properties of CT constituents (King and Young, 1999). A significant increase from start to end of study was found in PLT from D7 and D14 compared with C. An increase in PLT may indicate infection or anemia (Jones and Allison, 2007).

Conclusion

Fermented Chambourcin-grape extract may not be a beneficial natural anthelmintic for controlling nematodes in creep-fed goat kids at the dosage rate and interval used in the current study. Continued research is needed to understand why grape extract may be an effective natural anthelmintic in some ruminant animals, but not in goat kids in the current study.

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Sheep & Goat Research Journal
Volume 32, 2017 - November

Consumer Preference for Goat Meat in a Blind Sensory Analysis

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Funding and Acknowledgement:

This work was supported by the USDA National Institute of Food and Agriculture, Hatch grant number OKLO 2851, and by the Oklahoma Agricultural Experiment Station. Support does not constitute an endorsement of the views expressed in the paper by the USDA.

Summary

Though consumed only rarely by Americans, goat meat is commonly eaten around the world, but it is unclear whether this is due to its taste or some other reason. A blind sensory analysis was performed to study U.S. consumer preferences for goat meat compared to beef and pork. Goat shoulder, beef brisket, and pork shoulder were all slow cooked and shredded, and a group of consumers in the State of Oklahoma rated each meat using a 9-point hedonic scale in four categories. Although goat received favorable ratings for tenderness, juiciness, and flavor, ratings for pork and beef were slightly higher. These results help demonstrate why Americans consume more beef and pork than goat, but does not explain why goat is consumed so seldom.

Keywords: Sensory Analysis, Goat Meat, Flavor, Juiciness, Taste, Goat

Introduction

Goat is among the most widely consumed livestock in the world, with much of the population eating goat meat as part of their regular diet (Biswas et al. 2007). This may come as a surprise to Americans because goat meat is rarely included in their diet. When Americans consume meat it usually consists of beef, pork, or poultry. While goat is not favored in western countries, it is popular among developing countries, making up 90 percent of the goat inventory worldwide (Webb et al., 2005). Even in developing countries, however, goat is sometimes seen as a poor person's food, and raising or eating goat signifies a lack of success (Dubeuf et al, 2004; Morand-Fehr et al. 2004). Nonetheless, more people are consuming goats than ever before (FAO, 2015), and as goat production continues to rise and Americans seek to diversify their agricultural production, goat may deserve a second look.

In 2012 meat-goat production was said to be the most rapidly expanding animal enterprise in the country (Jones, et. al., 2015). Slaughter of goats in federally inspected facilities has risen from just over 200,000 head in 1988 to 589,100 in 2011. Although those numbers fell to 448,800 head in 2016, they are still considerably higher than their 1988 level (NASS, 2017). The rise in goat production was exceeded by consumption increases, as the United States became a net importer of goat in 1991 (Sande, et. al., 2005). The number of imports since then has risen from 1,749 metric tons to 15,752 metric tons in 2011 (Stanton, 2012). This rise in demand has been attributed to 1. a more ethnically diverse America, 2. a keener interest in health foods, and 3. interest in goat from a culinary perspective (Sande, et. al., 2005).

Although the rise in goat demand is good for the goat industry, it could rise much further if the average American began eating goat. The Center for Disease Control and Prevention interviewed 65,536 individuals regarding their food consumption, asking them to keep a food journal for two days out of the year, but only seven out of the 65,356 people ate any goat during those two days. Not only is goat seldom consumed, it does not have a good reputation among Americans. Knight et al. (2005) found in a telephone survey that over 50 percent of individuals were unwilling to even try goat meat, and that people perceive the meat as inexpensive but inconvenient.

It is unclear why goat meat is absent from most kitchen tables and restaurants: is it a supply or demand issue, or both? There is some evidence it is the taste of goat meat that keeps demand low, but much of the evidence is decades old, whereas consumers now seem more adventurous in their food consumption, and few recent evaluations have been conducted. Moreover, limited evidence exists on the likeability of different attributes of goat meat. To further investigate the role of taste in goat meat's minor role in American food consumption, this study conducts a sensory analysis of shredded goat shoulder meat to 1. determine individuals' overall satisfaction of goat meat compared to pork and beef, 2. evaluate the distinctness of goat meat compared to pork and beef, and 3. study how the flavor, juiciness, and tenderness of goat meat contributes to its overall likeability.

Materials and Methods

To determine how people rate their eating experiences between goat, pork, and beef, a blind sensory analysis was conducted. The goats were acquired by the Sheep and Goat Center at Oklahoma State University, butchered at a live weight of around 100 lbs, and processed and prepared by a federally inspected facility. All were Boer meat-goat breeds, and although meat from the entire carcass was cooked only shredded meat from the goat shoulder was used in the sensory analysis.

To compare the sensory attributes of goat relative to two other common meats, pork shoulders and beef briskets were acquired from a nearby supplier. Beef brisket instead of beef shoulder was used because, while pork and goat shoulder are a frequently used cut for making shredded barbeque meat, barbeque beef is typically acquired from the brisket. Rather than focusing on identical components of the carcass across the three animal types, we focused on the components that would most likely be used to make shredded, barbeque meat. It is possible that the results would differ had beef shoulder meat had been used.

The pork and beef were seasoned, cooked, and shredded identically to the goat, and each were cooked intact and only shredded after cooking. All three meats were seasoned liberally with Legg's Old Plantation Seasoning Prime Rib Rub. The meats were then cooked in the same cooker/ smoker as follows: cooked 160°F (dry bulb temperature) for one hour, smoked at 170 °F for two hours, and

Figure 1. Steps 1 & 2 of sensory experiment.

Table 1. Summary of subjects.

Variable	Student (N=57)	Adult (N=31)
Male	51.9%	80.6%
Age (average)	22	35
Consumes the meat occasionally or frequently:		
Goat	2%	3%
Beef	100%	97%
Pork	89.9%	87%
Chicken	98%	100%
Wildlife	33%	36%
Percent who agree that meat is:		
Humanely Raised	82%	84%
Easy Food Poison Carrier	54%	61%
Tasty	96%	100%
Environmentally Friendly	91%	74%
Reasonably Priced	63%	19%
Healthy	98%	90%

then cooked at 190 °F for four hours. As can be seen in Figure 1, the three meats seem to be similar in their final texture and appearance.

A sensory analysis was designed to measure the tenderness, juiciness, flavor, and overall eating experience of the three meats by non-trained panels of Midwestern consumers. The analysis was conducted at two locations to acquire an adult and student sample. The first location was at a local precision agriculture software business in Stillwater, Okla. and the other was a student social gathering on the Oklahoma State University campus. Both experiments provided the participants with a free meal in exchange for partaking in the survey. Respondents from the two locations will be referred to as adults and students, respectively.

Table 1 shows the overall demographics of the participants. The student set contains 57 observations, with both genders represented equally, and an average age of 22. The adult sample is heavily dominated by males, making up over 75 percent of the observations, and is about thirteen years older than the students. Although the samples differed in many ways, both groups consume goat only rarely but pork and beef frequently.

Hedonics

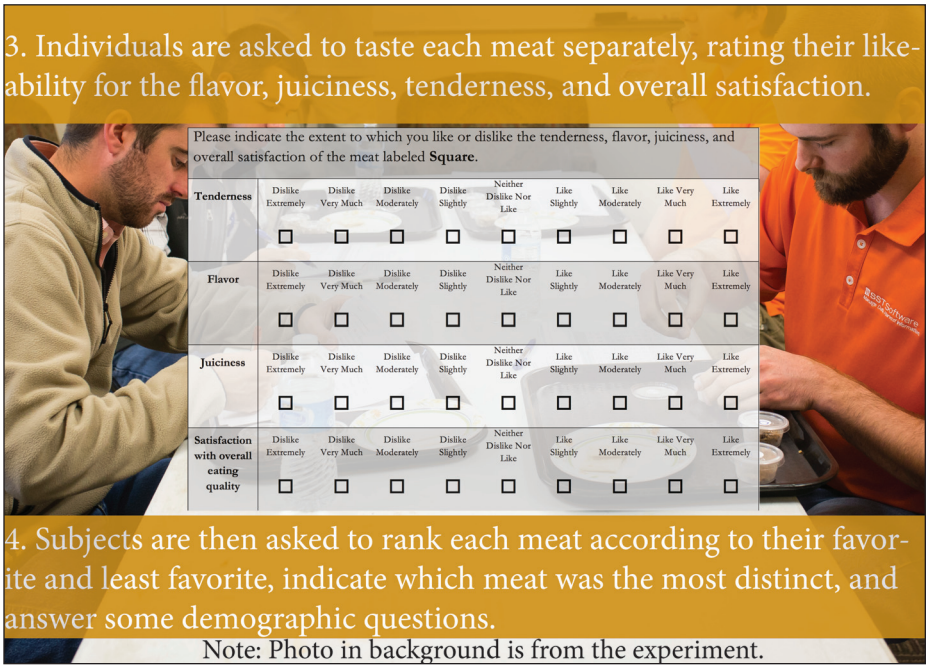
The objective of this study is to determine how people rate their satisfaction of goat meat compared to pork and beef. Asking consumers directly about their preferences for goat is problematic because only a minority of people have consumed goat, and it may have an unwarranted reputation that influences the meat flavor. Participants must be allowed to taste the three different meats without knowing the identities to allow their responses to measure goat meat's true experience attributes. This was accomplished by placing each meat into individual cups labeled only as square, circle, or triangle, as shown in Figure 1. The meat associated with each shape was randomized across respondents. Additionally, participants were provided water and unsalted crackers to cleanse their palate before tasting each meat.

The questionnaire asked subjects to indicate the extent to which they liked the tenderness, flavor, juiciness, and overall satisfaction of each meat. The standard 9-point hedonic scale shown in Figure 2 was used (Stone, et. al., 2012), and the questionnaire reminded the subject to bite a cracker and take a sip of water between each meat.

After ranking each meat according to these four attributes participants were asked to rank the three meats (identified only by shapes) corresponding to which was their favorite, where 1 = most favorite. This forces individuals to indicate a preferred meat even if they gave two, or even all three, meats identical ratings on the hedonic scale. The order in which the three shapes were listed was randomized across each questionnaire. The survey asked a number of demographic questions in addition to how often the participant consumed a variety of different meats.

In order to determine which meats were preferred in terms of the four attributes (tenderness, flavor, juiciness, and overall satisfaction) we conducted a simple sign test. The sign test is non-parametric, meaning that it has few assumptions about the nature of the distribution of the test. We paired goat to pork, goat to beef, and finally, beef to pork. Consider a pairing of meat x and y. The comparison has three possible outcomes, x>y, x=y, or x<y. The hypothesis tests defines *P* =

Figure 2. Steps 3 & 4 of sensory experiment.



Note: Photo in background is from the experiment.

$Pr(x>y \mid x \neq y)$ and then evaluates the null hypothesis that P=0.50. Simply put, the null hypothesis says that given a random set of values (x, y) it is equally possible for x and y to be larger than the other.

Ranking

The average ranking of the student and adult populations were found by taking the average ranking of each meat: goat, beef, and pork. When asked to rank the meats each respondent was to assign a unique ranking of 1 to their favorite meat and a 3 to their least favorite meat. However, we reversed the rankings so that 1 is the least favorite meat and 3 is the favorite meat, so hereafter a higher number refers to a higher, more desirable ranking.

To test whether the beef and pork rankings are statistically different from the goat ranking, the ranking data are also analyzed using the rank-ordered logit regression in the program STATA. This model assumes that the overall utility or satisfaction from any one meat can be described by the random utility model in (1), where each respondent, i, has a certain utility, U_{ij}, for every choice, j, where j =1, 2, 3 and V_{ij} represents the systematic component. The random component, ε_{ij}, is assumed to follow a Type II Extreme Value Distribution.

$$(1) U_{ij} = V_{ij} + \varepsilon_{ij} = \beta 0\ (GOAT_{ij}) + \beta 1\ (BEEF_{ij}) + \beta_2\ (PORK_{ij}) + \varepsilon_{ij}$$

The variable *BEEF* = 1 if the meat being evaluated is beef; otherwise it equals zero. Likewise, *PORK* = 1 if it is pork and if it is not then *PORK* = 0. Although the variable *GOAT* goes by a similar definition, the coefficient β_0 must be normalized to equal zero (or else the model is not identified), so the equation could be written without the term β_0 ($GOAT_{ij}$). Thus, if the meat being considered is goat then *BEEF* = *PORK* = 0 and the systematic utility is normalized to equal zero. The coefficients β_1 and β_2 are coefficients to be estimated using maximum likelihood. The sign and statistical significance of the coefficients β_1 and β_2 describe the ranking of beef and pork, respectively, relative to goat. For example, if β_1 is positive and statistically significant, then beef tends to be ranked higher (meaning better) than goat, on average.

Another advantage of the rank-ordered logit model is that it provides an intuitive way of expressing the rankings in terms of consumer choice. Due to the assumption of the error term in (1), the probability that an individual will rank goat over beef is given by the equation $\exp(\beta_0) \div [\exp(\beta_0) + \exp(\beta_1)]$, allowing us to calculate the percentage of subjects who, when given the choice (based on taste alone) between goat or beef, would choose goat.

Results and Discussion

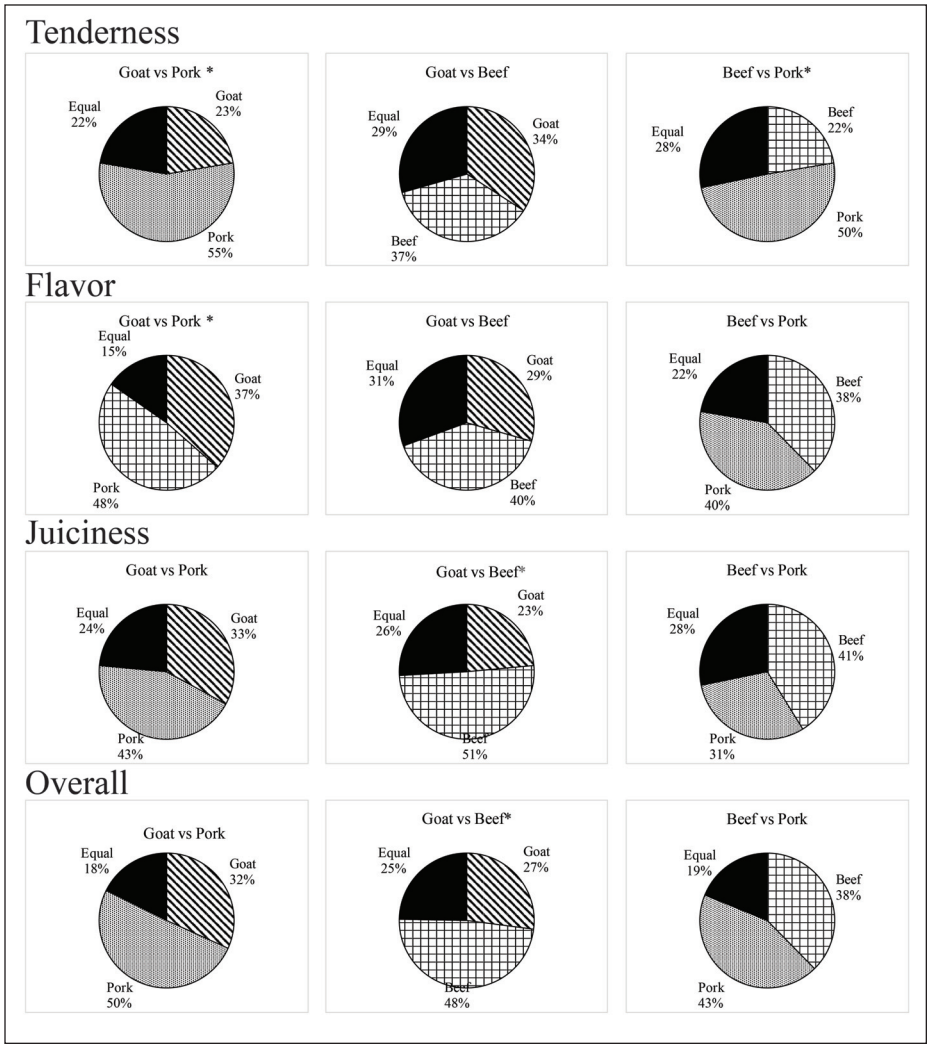
A total of 88 individuals participated in the sensory analysis, however some of these observations were excluded. Eight respondents who answered in an incorrect format, such as ranking only one of the three meats and leaving the other two blank, were omitted from the final analysis.

Hedonic Results

First, the percent of times each meat was assigned a higher sensory rating than another for all four attributes (tenderness, juiciness, flavor, and overall satisfaction) was calculated and is shown in Figure 3. A meat is considered superior in any one attribute if the probability of an individual assigning it a higher rating is greater than 50 percent, and a non-parametric sign test is used to statistically test whether this is the case. For example, Figure 2 shows that in regards to juiciness, people assign pork a higher rating 43 percent of the time and goat a higher rating 33 percent of the time, with 24 percent of people assigning them an equal rating.

Is the 43 percent sufficiently higher than 33 percent to conclude that pork

Figure 3. Percent of subjects who rate each meat higher than the other according to tenderness, flavor, juiciness, and overall satisfaction (* denotes statistically significance in a one-tail test at the 95% confidence level).



has a better juiciness profile? The sign test evaluates this by first distributing the 24 percent of equal ratings equally between pork and goat, making the percentage for pork and goat 55 percent and 45 percent, respectively, and then testing the hypothesis that the 55 percent is not statistically different from 50 percent (Dixon and Mood, 1946). If it is not, then we cannot really say that pork has a better juiciness quality than goat. Indeed, Figure 3 shows that it is not statistically different (using a one-tail test at the 95 percent level), and so we conclude that people like the juiciness of pork and goat about the same.

Consider the first pie chart in the top-left of Figure 3. This shows that 55 percent of the time the tenderness of pork was preferred to the tenderness of goat, 23 percent percent of the time the opposite occurred, and 22 percent of the time both received equal hedonic scores for tenderness. As indicated in the figure, the sign test shows that for those cases where one meat was rated higher, more than 50 percent of the time pork received the higher rating. This doesn't prove that pork is tenderer than goat, but it does suggest that consumers like the tenderness attribute of pork above that of goat. Move one pie chart to the right, and it shows that 37 percent of people preferred the tenderness of beef to that of goat, with 29 percent rating them equal. These numbers suggest that consumers like the tenderness of goat and beef the same, and the sign test confirms this.

The tenderness, flavor, juiciness, and overall satisfaction of pork was consistently favored over goat; and with the exception of juiciness, pork was also preferred to beef. However, in only a few instances were the differences statistically significant. Taking into account the sign-test we can only say that a. pork has a higher tenderness and flavor rating than goat, b. beef has a higher juiciness and overall satisfaction rating than goat, and c. pork has a higher tenderness rating than beef.

Roughly one-third of individuals rated goat higher than pork and beef overall, so goat does appeal to a considerable number of people. Nonetheless, in every comparison and every attribute beef and pork were rated higher than goat. Still, while goat does not out-perform beef and pork in taste tests, it competes well and is received favorably among many.

The histograms in Figure 4 testify to this result. Most of the respondents indicated they do like the tenderness, flavor, juiciness, and overall satisfaction of goat meat. However, as in the sign test it appears that pork is preferred over goat and beef. Nevertheless, there is little variation between the attributes, in that roughly the same number of people liked its tenderness, flavor, and juiciness, so goat performs well on all three measures—as does pork and beef. This suggests similarities among the meats, as one was not considered much more tough, distasteful, or dry than the others.

The similarities in the ratings between the three meats begs the question of whether the meats were distinct from one another. To test this we asked participants to select which two meats were the most similar and which one meat was most distinct. Given that the majority of the participants reported they never eat goat (Table 1), we suspected that goat meat would be the most distinct out of the three meats, but this suspicion was wrong. Figure 5, next page, shows that the majority, 50 percent, of participants found that pork was the most distinct followed by beef (29 percent) then goat (21 percent). This is surprising. Goat, which would be considered a novelty food to most Americans, was actually more similar to beef than pork. However novel the idea of eating goat may be, the actual eating experience is rather ordinary.

Ranking Results

Finally, we analyzed the average rankings of each meat. Participants were asked to rank each meat giving their most favorite a '1', next favorite a '2', and least favorite a '3', but these were recoded so that '3' denotes their favorite and '1' their least favorite. In Figure 6 we see the average rankings of the adult and students surveyed. While adults prefer beef, we see that students prefer pork. Although neither group prefers goat, it does have a ranking higher than 1, meaning that it is not consistently the least favorite meat.

It is difficult to tell from Figure 6 whether the rankings for beef and pork are higher than goat for the entire sample. Beef and goat are ranked about the same for students, and pork and goat are ranked similarly for adults. This test is

Figure 4. Histogram of hedonic scores for each meat and attribute.

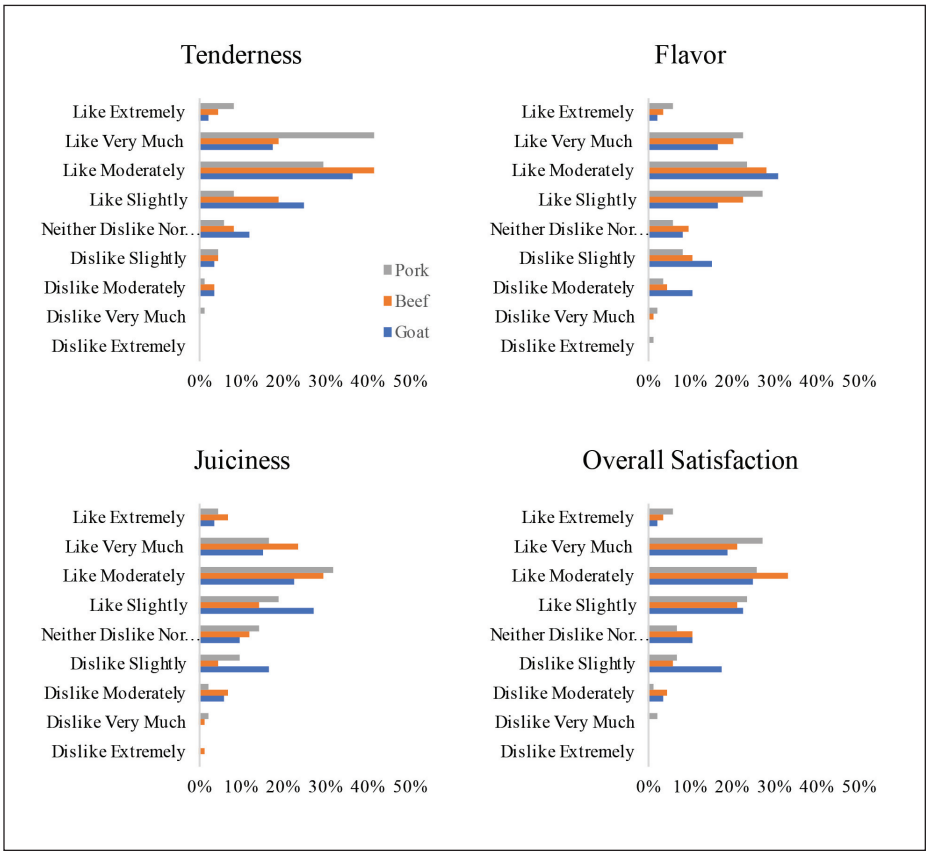


Figure 5. Percent of subjects who identified goat, beef, or pork as being the most distinct of the three meats.

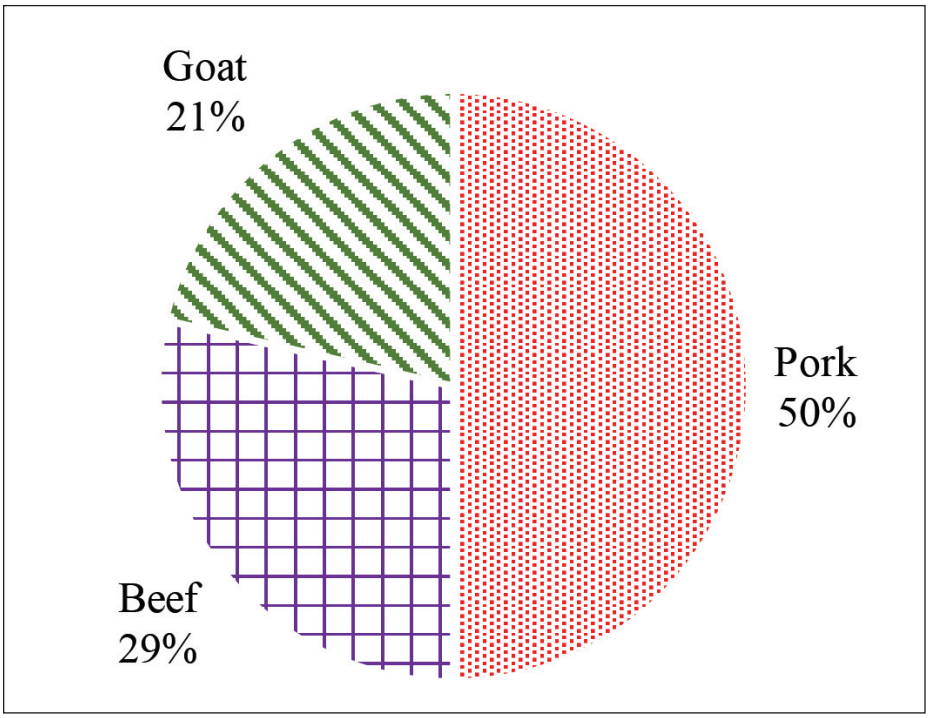
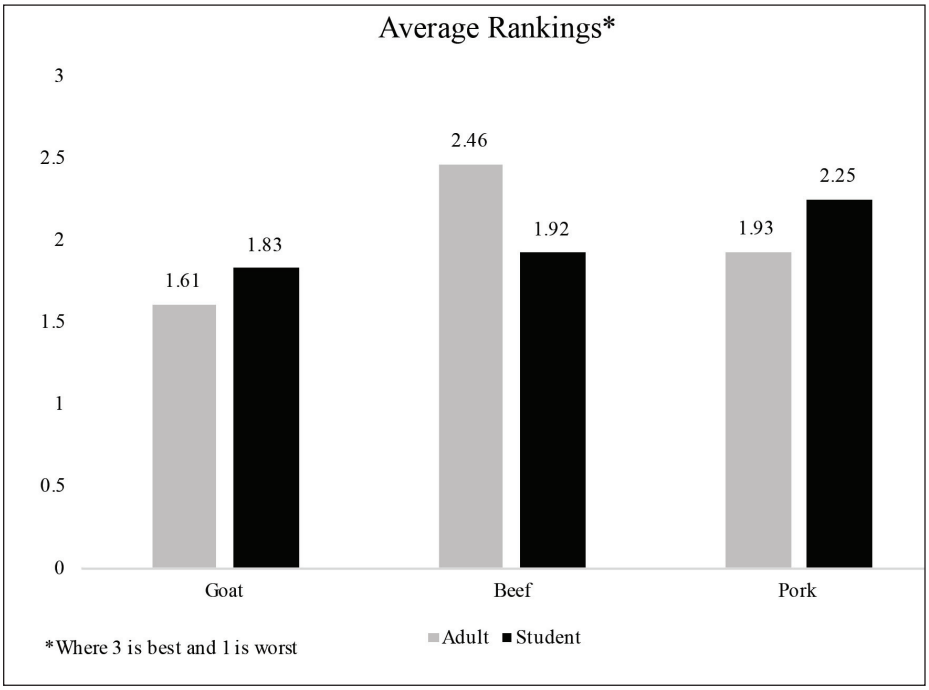


Figure 6. Average ranking of goat, beef, and pork for adult and student subjects.



made using the estimates of the rank-ordered logit model below. Notice that both beef and pork have positive coefficients (the coefficient for goat meat is zero by definition), and since the p-values are less than 0.05 we can conclude they are statistically significant as well. These estimates suggest an equation detailing the utility/satisfaction subjects receive from each meat goes by the equation: utility = 0.000(*Goat*) + 0.429(*Beef*) + 0.448(*Pork*). When eating goat the utility is 0.000, when eating beef the utility is 0.429, and when eating pork utility is 0.448. Another way of interpreting this equation is to note that, if given the choice between goat or beef, and the person made their choice based solely on blind taste, there is only a $e^0 \div [e^0 + e^{0.429}] = 39$ percent chance they would choose goat but a $e^{0.429} \div [e^0 + e^{0.429}] = 61$ percent chance they would choose beef. If given the choice between pork and goat, the percentages (after rounding) are the same. So although beef and pork are definitely ranked higher than goat for the sample as a whole, when given the choice between beef and goat or pork and goat, about a third of the subjects would still choose the goat.

Discussion

We evaluated Midwestern-consumer preferences for shredded, slow-cooked goat meat in comparison to two commonly consumed red meats: pork and beef. Although consumers preferred the pork and beef to goat, they still viewed goat meat favorably. A meat type does not have to be the highest ranked meat to find a permanent place at Americans' dinner tables, so long as people possess different tastes and desire variety. Whatever the reason goat is seldom eaten in the United States, its taste is not the obvious one.

This study was conducted on the basis that goat's rare dinner table appearance is a curious fact and that only a few studies have compared its taste to other popular meats. Two notable exceptions are Rhee, Myers, & Waldron (2003) and Degner and Lin (1988), who also used untrained subjects in a blind taste test, but their experiments differed in a number of ways. The Rhee study compared unseasoned ground beef and goat, both made from various cuts of the animal carcass, whereas our study focused on shredded shoulder and chest meat and provided identical seasoning to both. Using unseasoned meat, it is not surprising that the Rhee study found lower overall hedonic scores (they used the same 9-point scale) than those in our study. What is surprising is that the Rhee study found that their subjects tended to prefer whatever meat they ate first. Goat was preferred to beef, so long as goat was tasted first (and vice-versa). However, this preference effect was not present in our data, as goat's overall score for satisfaction was lowest when it was tasted first.

The Degner study better resembled

Table 2. Estimate of rank ordered logit model (N = 80).

Variable	Coefficient (*P*-value)
Goat	0.000
	—
Beef	0.429
	(0.04)
Pork	0.448
	(0.03)

our experimental design in that the beef and goat were slow-cooked and presented in a blind taste test, but differed in that their meat was cut into 0.5 inch cubes (instead of shredded) and no seasonings were used (we used seasonings). They did, however, allow their subjects access to salt shakers. They used only the bottom rounds of the beef carcass and most of the whole goat carcass, so our study differs in this respect as well. Subjects in the Degner study were on average indifferent between the two meats, rating both about the same in regards to tenderness, flavor, and overall appeal. Goat was appraised as too dry, as opposed to beef's 'just right' juicy rating, but still the authors conclude that, "In terms of the meats' smell, overall taste and overall appeal, the ratings suggest that participants did not have strong preferences toward either of the meats," (Degner and Lin, 1988, page 7.)

In all studies considered, including the present one, when goat is compared to other familiar meats in a taste test, it performs well. This does not imply that many consumers will purchase goat meat, though. If individuals knew the identities of the meats they might penalize or reward goat based on perceptions independent of its actual taste. Preconceived notions not only affect demand for products but the actual perception of taste. This is why people claim to prefer the taste of regular meat falsely labeled as humanely raised (Anderson and Barrett, 2016), and prefer the taste of regular tomatoes falsely labeled as organic (Johansson, et. al., 1999).

A bias against goat meat might arise if it is perceived as undesirable. Some might assume it is not good simply because so few stores or restaurants serve it. A recent internet survey found that most Americans perceive the taste of goat meat to be "neither tasty nor untasty" suggesting that for the average person they are neither biased against or for it. However, this rating was considerably lower than that for beef, so most people do expect beef to taste better than goat meat (Lusk, 2016). Moreover, a telephone study by Knight et. al. (2006) found that 57 percent of respondents in southeastern states were unwilling to consume goat meat, so there does seem an aversion to the meat from a considerable number of people. These considerations might cause goat meat to be rated higher in a blind taste test compared to a setting where they knew the identity of the meat.

On the other hand, those displaying a social desirability bias might rate the goat meat higher than it would in a blind taste test. If a researcher is advertising free samples of goat meat, then subjects might perceive the researchers are interested in promoting the product, and in appreciation for the sample may tell the researcher they like it more than they really do.

The fact that preconceived notions and social desirability bias impacts taste perceptions makes the study by Nelson et. al. (2004) less relevant to the present study, as they asked people to taste barbequed goat meat in a context where people knew what they were eating. Nevertheless, the Nelson study does provide insights into the acceptability of goat meat, so it is worth noting that although after tasting the goat most people indicated it was as good as beef or pork barbeque. Although they only tasted goat barbeque, they were asked to first rate it compared to beef barbeque and then compare it to pork barbeque. When the subjects did not rate it "about the same" as beef or pork barbeque, they tended to rate goat better than beef barbeque but not as good as pork barbeque. This preference for pork relative to beef and goat is probably related to the location of the experiment. Barbeque in the southeast is dominated by pork, and so by holding the experiment in Georgia, it was natural that pork would be rated highest. Regardless, the Nelson study concurs with our findings that even if goat is not considered the superior tasting meat, it is certainly acceptable and provides a pleasurable eating experience to many.

Conclusion

Although it appears pork and beef producers do not need to fret about the potential of goat meat taking a large portion of their consumers, it is evident that people find goat meat to be palatable. The present study, which compared pork and beef directly to goat, found goat to be the least favored meat of the three but nevertheless receiving favorable ratings. While we are located in a college town with a variety of people, our study was skewed with a majority of the participants being Caucasians. Considering previous studies suggested that Hispanics and African Americans were more likely to be consumers of goat meat, this may have had an effect on our results. Another drawback to our study is the blind taste test. Since the participants were not aware of what they were eating, their shopping preferences were not evident. While this is desirable for evaluating the experience attributes of meats, it cannot be used to predict actual store purchases. Finally, we chose to season all three meats which may have masked the flavor of the three meats giving them all a similar taste resulting in most of the hedonic scores falling in a small, close range. Having established that goat meat is enjoyable to most of the participants leads us to believe that there is a need for future research in this area to discover why goat meat is seldom eaten in the United States.

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Sheep & Goat Research Journal
Volume 32, 2017 - December

Passive Transfer in Domestic and Bighorn Lambs

Total IgG in ewe sera and colostrum and serum IgG kinetics in lambs following colostrum ingestion are similar in domestic sheep and bighorn sheep (Ovis aries and Ovis canadensis)

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[5] *Funding for this project was provided by a fellowship training grant from Zoetis (previously Pfizer) Animal Health-Morris Animal Foundation (145-02-13K-2540-0992) and ADRU-ARS-USDA CRIS Project funding (2090-32000-036-00D).*

Acknowledgements:

The authors thank past veterinary medical students, Drs. Alicia Ewing, Andrew Heitman, and Kristen Tjerandsen, for assisting with lamb rearing; Jan Luft, Emma Karel-Ward, Ralph Horn, and James Allison for all the hard work put forth to ensure safe and healthy environments for the sheep and lambs described in this study; and Drs. Hong Li and Subramaniam Srikumaran for providing the ewes described in this study.

The authors declare to have no conflicts of interest.

Summary

Pneumonia is a population-limiting disease of bighorn sheep (BHS; *Ovis canadensis*) and a recognized disease entity in domestic sheep (DS; *Ovis aries*) worldwide. Respiratory disease in BHS lambs can persist for years after all-age outbreaks, resulting in suppressed lamb recruitment. It has been suggested that inadequate passive transfer (PT) of maternal antibodies may play a role in BHS lamb pneumonia, although inadequate PT is often associated with illness prior to 4 weeks of age in DS, while BHS mortality predominantly occurs >4 weeks of age. The purpose of this study was to analyze PT of total colostral IgG in BHS lambs and DS lambs born and hand-raised under similar conditions. Total IgG concentrations were quantified for ewe serum, colostrum, and lamb sera collected at multiple time points following ingestion of a known quantity of colostrum. No significant interspecies differences were observed for total IgG concentrations in ewe sera or colostrum, or in the calculated apparent efficiency of IgG absorption. Waning kinetics of IgG in DS and BHS lamb sera was similar post-colostrum ingestion. BHS lambs produced IgG sooner than DS following waning of maternal IgG and had significantly higher serum IgG at 16 weeks, 20 weeks, and 24 weeks. Significant differences were observed in birth weight (DS > BHS) and amount of time to ingest colostrum (BHS > DS). Findings of this study, as well as consideration of the age of mortality in wild BHS lambs, do not support inadequate PT of total IgG as a primary contributor in BHS lamb pneumonia.

Key words: Passive Transfer; Colostrum; Bighorn Sheep; Domestic Sheep

Introduction

The bighorn sheep (*Ovis canadensis*, BHS) population in North America has declined from a broad estimate of five hundred thousand to two million at the beginning of 19th century to an estimated 15,000 to 18,000 in 1960, with an increase to an estimated 72,000 reported in 2007 (Buechner, 1960; Rominger, 2008). More recent population numbers are seemingly elusive in the literature, with unofficial numbers reported in the media as "nearly 200,000", as per a recent New York Times article entitled "The Ultimate Hunt: Sheep" (Branch, 2017){Boeskorov, 2011 #682}. The most pronounced population decline of BHS occurred in the second half of the 19th century and early 20th century and is proposed to be due to a combination of factors, including unregulated hunting, loss of habitat, competition for forage with domestic livestock, and diseases, particularly pneumonia (Grinnell, 1928; Marsh, 1938; Besser et al., 2013b). All age epizootic pneumonia outbreaks continue to sporadically afflict wild BHS herds. Poor lamb recruitment, due to bacterial respiratory disease afflicting primarily lambs in years subsequent to all-age pneumonia epizootics, is reported to be the biggest impediment to BHS population recovery (Ryder et al., 1992; Cassirer et al., 2013). Bacterial pneumonia has also long been a health burden to the domestic sheep (*Ovis aries*, DS) industry worldwide, predominantly afflicting lambs, and is often caused by similar etiological agents found associated with BHS pneumonia, including *Mycoplasma ovipneumoniae* and members of the Pasteurellaceae family (Ayling and Nicholas, 2007; Donachie, 2007; Besser et al., 2012; Besser et al., 2013a). While both species are affected by similar bacterial agents of pneumonia, comparative experimental data and field observations indicate that BHS are more susceptible to bacterial pneumonia than are DS (Dassanayake et al., 2009; Besser et al., 2014). Factors associated with bacterial pneumonia in DS lambs are known to include inadequate passive transfer (PT) of maternal antibodies and environmental stressors (housing density, air quality, shipping) (Brogden et al., 1998). Investigations to determine the impact of similar factors, including environmental stressors and PT, on respiratory disease in BHS are scarce to absent in the literature.

A previous publication indicated that one factor in the reportedly heightened susceptibility to pneumonia in bighorn lambs is due to lower PT of maternal antibodies against *Mannheimia haemolytica*, a member of the Pasteurellaceae family, in BHS as compared to DS (Herndon et al., 2011). The design of that study had limitations in comparatively examining PT in DS and BHS lambs, including examination of colostrum that was collected up to 24 hours postpartum (presumably after suckling had occurred in at least some of the ewes) rather than immediately following parturition. That study also lacked data regarding amount of colostrum ingested and therefore apparent efficiency of absorption (AEA) could not be calculated. Additionally, the authors focused only on the transfer of antibodies to just 2 microbes (*M. haemolytica* and parainfluenza virus-3) rather than including total PT in the analyses. The present study provided testing to determine if there is a significant difference between PT of total IgG in BHS and DS and to examine serum IgG concentrations over time (kinetics) in lambs. To our knowledge, this is the first study designed to measure total PT and kinetics or waning of IgG in BHS over time and comparatively assess PT with that of DS cohorts born and raised under similar environmental conditions.

Materials and Methods

Experimental sheep and care

Animals described in this report were housed and maintained at Washington State University (Pullman, Wash., USA) and experiments were carried out according to the guidelines of the Institutional Animal Care and Use Committee and Association for Assessment and Accreditation of Laboratory Animal Care. All lambs were born at Washington State University; domestic lambs described in this study were born in April and bighorn lambs were born May through June.

Two male and two female Suffolk DS lambs and four male and one female Rocky Mountain BHS lambs were gently removed from the birth canal of four DS ewes and five BHS ewes during late parturition; two additional female BHS lambs were delivered by Caesarian section from a sixth BHS ewe. Each lamb was cleaned and dried with a towel and had no further contact with the ewe. Lambs were separated by species and housed in an indoor vivarium. Immediately following parturition, colostrum was collected from each ewe using a handheld vacuum pump (Udderly EZ; Lexington, Ky., USA). Immediately following, and for up to 18 hours post parturition, each lamb was fed colostrum from their dam, therefore the volume of colostrum ingested by each lamb was dependent on the amount that could be collected from each dam. Following consumption of the collected colostrum, DS lambs were switched to Land O'Lakes Ultra Fresh® milk replacer and BHS were switched to Purina ProNurse®, a more readily soluble, multispecies milk replacer. Each lamb was weighed and received a subcutaneous injection of vitamin E/Selenium (BO-SE®, Schering-Plough, Merck Animal Health; Madison, N.J., USA) and an intramuscular injection of vitamin A/D (Agri Laboratories LTD; St. Joseph, Mo., USA) between 20 and 30 hours after birth. At 3 days of age, each lamb was subcutaneously vaccinated with CD-T (*Clostridium perfringens* Types C & D – tetanus toxoid (Boehringer Ingelheim Vetmedica, Inc., Bar Vac®; St. Joseph, Mo., USA), tail docking was performed on each DS lamb, and the 2 male DS lambs were castrated. Volume of colostrum and milk replacer consumed was recorded for each lamb through weaning. DS lambs were fed 3 to 5 times, and BHS lambs were fed 4 to 6 times, per 24-hour period (feedings/day decreased with age). Each lamb was weighed weekly until weaned at 6 weeks of age for the DS lambs and 12 weeks of age for the BHS lambs. Water and alfalfa hay were provided ad libitum throughout this study.

Sample collection and sheep IgG ELISA

Blood was collected from each ewe within 4 weeks prior to parturition and colostrum was collected immediately following parturition. Blood from each lamb was collected at 1 day (20 to 32 hours post-parturition) and at 3weeks, 6 weeks, 9 weeks, 12 weeks, 16 weeks, 20

weeks and 24 weeks of age. All blood was collected by jugular venipuncture. Serum was separated by centrifugation (800 x g for 20 minutes) and stored along with colostrum samples at -80 C. Duplicate samples of ewe serum, colostrum, and lamb sera, from each time point, were diluted and total IgG (mg/mL = g/L) measured using a commercially available ELISA, following manufacturer's recommendations and protocol (Sheep IgG ELISA kit, Alpha Diagnostic International, San Antonio, Texas, USA). Colostrum and sera samples were diluted 1:1000 and 1:500, respectively, with diluent provided in the kit prior to performing the ELISA. Each sample was tested in duplicate in three independent assays, and the mean value was used for each sample for further statistical analyses. The IgG ELISA kit was confirmed for use in DS and tested for cross reactivity in BHS using purified serum IgG. Purified IgG was obtained from pooled sera collected from lambs at 24 weeks of age using the NAb™ Protein G Spin Kit following the manufacturer's recommended protocol (Thermo Scientific; Rockford, Ill., USA). The solution containing IgG was dialyzed against phosphate-buffered saline containing 0.02 percent sodium azide using a 3.5 kD Slide-A-Lyzer cassette (Thermo Scientific; Rockford, Ill., USA). Isolation of purified IgG was confirmed by gel electrophoresis (Invitrogen NuPAGE 3 to 8 percent Tris-Acetate pre-cast gel; Grand Island, N.Y., USA) and stained with coomassie blue for visualization (Bio-Rad Bio-Safe Coomassie Blue G250; Hercules, Calif., USA) (Fig. 1, panel A). A NanoDrop 200C (Thermo Scientific; Rockford, Ill., USA) was used to spectrophotometrically quantify isolated IgG in order to test the accuracy (validity) of the ELISA kit for use in both species.

Statistical analysis

Intra- and inter-assay coefficients of variability were calculated for all test sample results to determine assay precision for the Sheep IgG ELISA kit (108 samples total: 10 ewe sera, 10 colostrum samples, and sera from 11 lambs at 8 time points). Mean values and standard deviations were calculated for each species for ewe sera, colostrum, and lamb sera IgG concentrations, and for lamb birth weight (kg), volume of colostrum ingested (mL), and time to ingest colostrum (hours). Apparent efficiency of absorption (AEA) for each lamb was calculated as follows: AEA = [(g IgG / L serum) (0.06 x kg body weight) (100 percent)] / [(g IgG / L colostrum) (L colostrum ingested)] (Husband et al., 1973). This calculation makes the assumption that both DS and BHS lambs have a plasma or sera volume that is 6 percent of body weight, as previously described for DS lambs (Gratama et al., 1992). A two-tailed t-test was performed, with Welch's correction for data sets having unequal variance, for each interspecies analysis, except for repeated sampling over time of the lamb sera, for which a two-way repeated measures ANOVA was performed and statistical significance was determined using the Holm-Sidak method with alpha = 0.05. Statistical analyses were performed using GraphPad Prism 6 (GraphPad Software, Inc., La Jolla, Calif, United States) and results were considered significant for all analyses at $P \leq 0.05$.lif.

Results

Validation of commercial sheep IgG ELISA for use in BHS

Analysis of purified IgG from sera, pooled by species from lambs at 24 weeks of age, showed similar interspecies results (Fig. 1, panel B) that were consistent with the standards provided with the kit (Fig. 1, panel C). The intra- and inter-assay coefficients of variability for the ELISA for the 108 test samples (10 ewe sera and colostrum

Figure 1. IgG purification from pooled domestic (DS, left lane) and bighorn (BHS, right lane) lamb sera and Sheep IgG ELISA validation. Coomassie blue stained gel (sodium dodecyl sulfate polyacrylamide gel electrophoresis) containing IgG purified from domestic lambs (DS) and bighorn lambs (BHS). Molecular markers, in the first and last lanes, are labelled in kilodaltons (A). Comparative analysis of serially diluted purified IgG from DS and BHS lamb sera by Sheep IgG ELISA; absorbance at 450 nm wavelength (OD450) (B). Serial dilutions of purified sera IgG from DS and BHS lambs, of known concentrations (Expected) versus concentrations calculated from Sheep IgG ELISA standard curve (Observed) (C).

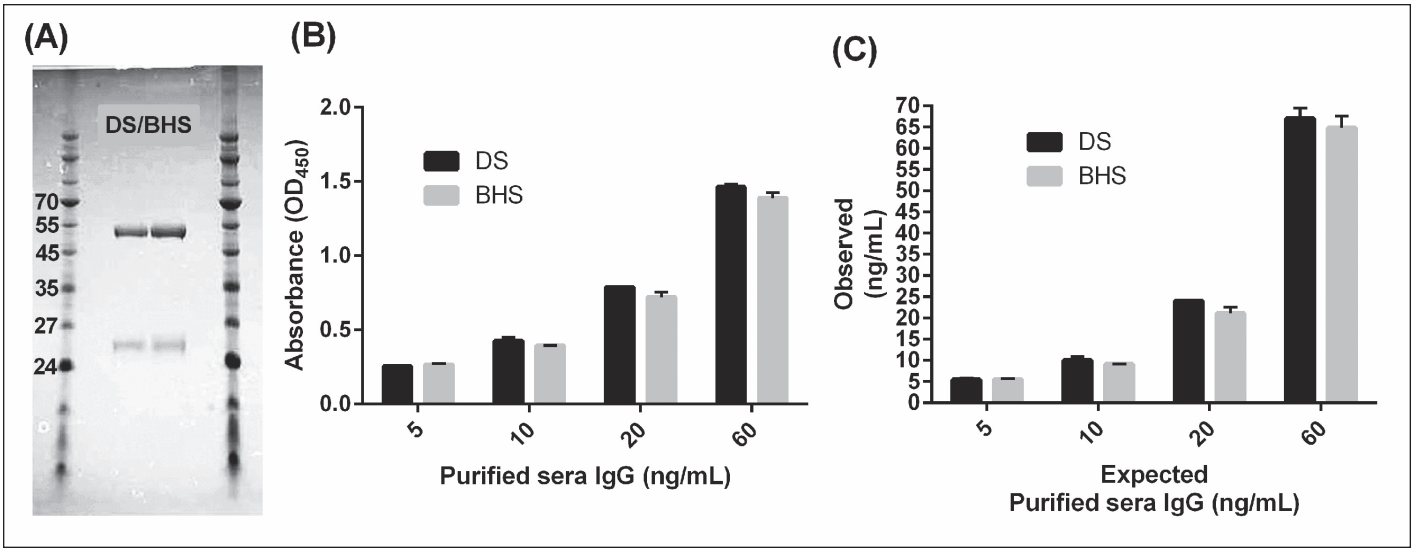


Table 1. Interspecies comparative analyses of maternally derived, passively transferred total IgG in domestic sheep (*Ovis aries*) and bighorn sheep (*Ovis canadensis*)

	DS	BHS	
	Median ± SD	Median ± SD	*P* value
Ewe			
Serum IgG (mg/mL)	14.7 ±1.2	19.0 ±6.6	0.3583
Colostrum IgG (mg/mL)	57.2 ±14.6	69.9 ±16.3	0.1209
Colostrum/Sera IgG ratio (mg/mL)	4.5 ±2.0	4.6 ±2.1	0.9443
Lamb			
Birth weight (BW, kg)	6.1 ±0.5	4.1 ±0.2 (4.1 ±0.2)	<0.0001* (<0.0001)*
Volume colostrum ingested (mL)	384.4 ±59.1	232.3 ±98.7 (266.1 ±95.8)	0.0217* (0.0690)
Time to ingest colostrum (hours)	4.2 ±0.38	10.1 ±3.89 (10.6 ±4.7)	0.0065* (0.0369)*
Colostrum ingested/BW (mL/kg)	63.0 ±4.5	56.9 ±25.5 (65.7 ±24.9)	0.5559 (0.8242)
IgG ingested (g)	21.5 ±4.0	16.8 ±8.7 (20.7 ±6.9)	0.3390 (0.8317)
IgG ingested/BW (g/kg)	3.6 ±0.8	4.12 ±2.2 (5.1 ±1.8)	0.6491 (0.1537)
24 hour sera IgG (mg/mL)	11.5 ±4.6	8.23 ±4.6 (10.6 ±2.5)	0.2781 (0.7117)
AEA (%)	20.8 ±11.4	11.7 ±3.7 (13.1 ±3.4)	0.2082 (0.2747)

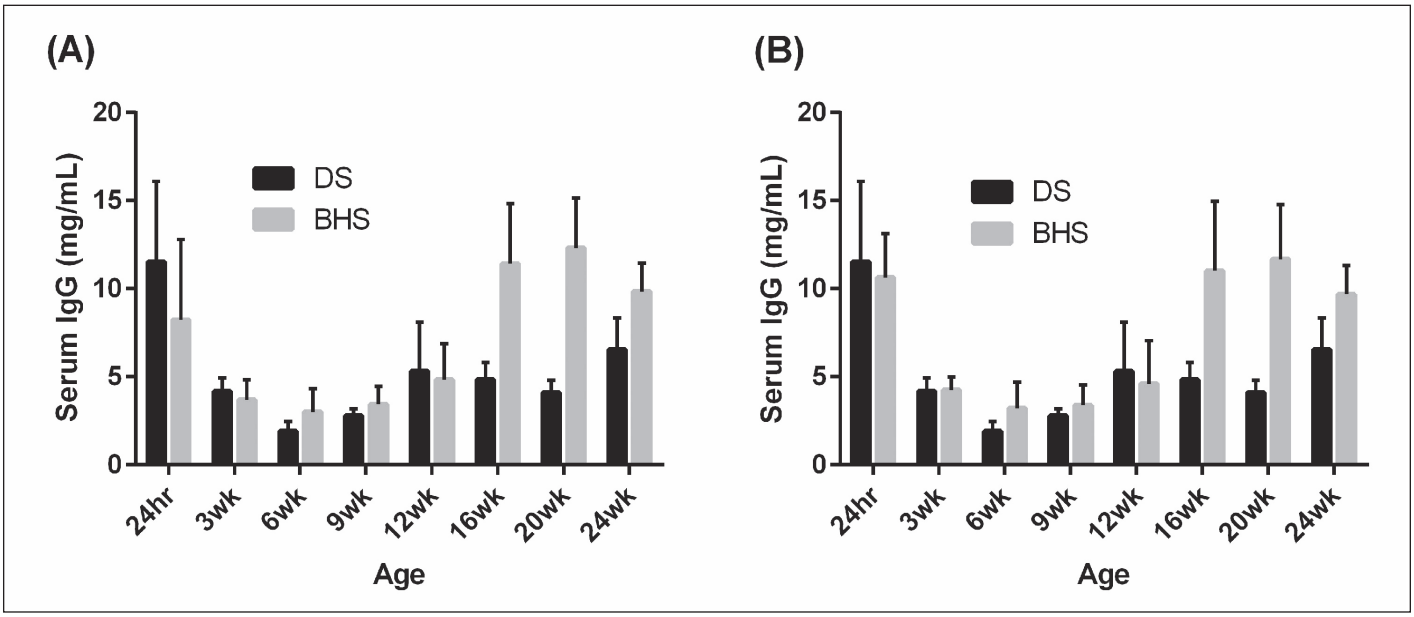
AEA = apparent efficiency of absorption; DS=domestic sheep (ewes: n=4, lambs: n=4); BHS = bighorn sheep (ewes: n=6, lambs: n=7); parenthetical BHS lamb data excludes data from twin ewe lambs

and sera from 11 lambs collected at 8 time points) were 6.2 percent and 10.6 percent, respectively.

Interspecies analysis

Table 1 summarizes the results of interspecies comparative analyses for PT, including IgG concentrations in samples (ewe sera, colostrum, 24 hour lamb sera), volume of colostrum ingested by the lambs, lamb birth weights (BW), and amount of time to ingest colostrum, as well as calculations based on these data (volume ingested/BW, IgG ingested/BW, and AEA). Data analysis was performed both including and excluding the twin BHS lambs, as these 2 lambs were considered to have insufficient IgG at 24 hours of age (2.6 mg/mL and 1.9 mg/mL). All other lambs had >6 mg IgG per mL serum, a value considered to be sufficient PT, with serum concentration ranging from 7.1 mg/mL to 17.9 mg/mL in DS lambs and 6.4 mg/mL to 11.6 mg/mL in BHS lambs (McGuire et al., 1983). No significant difference was identified for total IgG (mg/mL) in the ewes' sera, colostrum, or lamb sera at 24 hours of age. No significant difference in lamb sera was identified until 16 weeks of age, at which time the BHS lambs had significantly higher concentration of

Figure 2. Comparative analyses over time of domestic (DS) and bighorn (BHS) lamb sera IgG concentrations (mg/mL). Analysis performed by ELISA. Graph (A) includes all lambs (DS n=4; BHS n=7). Graph (B) excludes the twin female BHS lambs as they had 24 hour (hr) serum IgG concentrations considered inadequate passive transfer of IgG (1.9 and 2.6 mg/mL). The only notable difference between the two graphs is at the 24 hour age in which error bars are wider for BHS. Two-way repeated measures ANOVA, statistical significance was determined using the Holm-Sidak method with alpha = 0.05 and denoted by an asterisk (*) at 16, 20, and 24 weeks (wk) of age (P = 0.0050, 0.0004, and 0.0115, respectively).



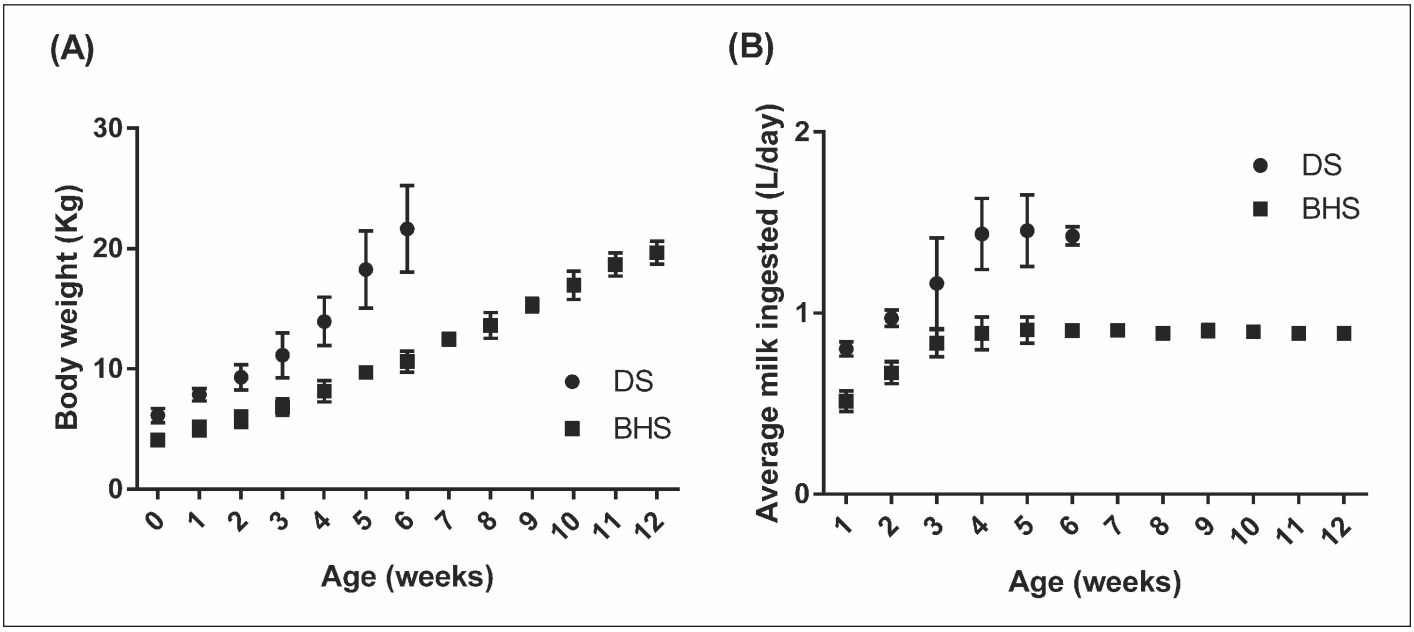
total serum IgG (P = 0.0050; Table 1 and Fig. 2). This higher concentration of total serum IgG in BHS persisted at the final two time points, weeks 20 and 24 (P = 0.0004 and 0.0115, respectively; Fig. 2). Comparative evaluation of serum IgG concentrations over time from repeated serum sampling indicates that DS and BHS lambs have a similar waning kinetics of IgG following consumption of colostrum, with the nadir identified in serum samples collected at 6 weeks and 9 weeks of age (Fig. 2). DS lambs weighed significantly more at birth and at each of the following weekly weight measurements, collected for both species through 6 weeks of age ($P \leq$ 0.0122). The average weekly weight gain and volume of milk replacer ingested was significantly greater for DS lambs as compared to BHS lambs ($P \leq$ 0.0202 and $P \leq$ 0.00003, respectively; Fig. 3). No significant intraspecies gender differences in weight or weekly weight gain were observed ($P \geq$ 0.2031). All lambs were observed drinking water and eating hay at will within the first week of age.

Discussion

This study was performed to assess total maternal IgG (serum and colostrum) and to compare kinetics of total IgG in lamb sera following consumption of colostrum in DS and BHS lambs hand-raised under the same controlled environmental conditions (indoor isolation facility). While the sample size for both BHS (6 ewes, 7 lambs) and DS (4 ewes and 4 lambs) hold statistical limitations, a larger study under such controlled parameters would be difficult to achieve, particularly for a wildlife species with limited availability. Previous studies investigating PT in DS have reported a great deal of variability between individual DS and between different breeds; our findings are within reasonable limits in comparison (McGuire et al., 1983; Vatankhah, 2013). The twin female BHS lambs in this study had serum IgG concentrations indicative of inadequate PT (<6 mg/mL), at 2.6 mg/mL and 1.9 mg/mL at 24 hours, and also had the two lowest calculated %AEA values (8.3 percent and 8.2 percent) (McGuire et al., 1983). Dystocia, delivery by caesarian section with delay in colostrum ingestion, hypoxia, and hypothermia in the 1.9 mg/mL lamb, and having to divide the ewe's colostrum, which had a lower IgG concentration compared to the other BHS ewes (48.1 mg/mL versus ≥68.1 mg/mL for the other BHS ewes), may have all contributed to the inadequate 24-hour serum IgG in these lambs. Considering the inadequate transfer in these two lambs, interspecies comparisons and statistical analyses were performed with and without their values, as described.

While the AEA between the DS and BHS lambs in this study were not significantly different, the lower mean %AEA for BHS lambs (calculated with and without the twins' values) as compared to DS lambs may have been at least in part attributable to the significantly longer time it took for the BHS to ingest the colostral IgG under the condition of being handfed. This is supported by research that has shown a linear decrease in immunoglobulin absorption by neonatal ruminants from birth to 24 hours of age, with optimal absorption reported to occur within 4 hours of parturition (Besser et al., 1985; Weaver et al., 2000; Nowak and Poindron, 2006). As the neonate's ability to absorb maternal antibodies decreases over time, so does the concentration of IgG in colostrum as it is diluted with new mammary secretion, gradually becoming milk. The concentration of IgG that is concentrated in colostrum prior to parturition is reported to decrease rapidly,

Figure 3. Weekly body weights (A) and average volume of milk ingested per day (B); week 1 includes ingested colostrum volume. DS = domestic lambs (n=4), weighed through weaning at 6 weeks of age; BHS = bighorn lambs (n=7), weighed through weaning at 12 weeks of age. Interspecies comparative analysis for each time point through week 6 were significantly different for both body weight and ounces of milk replacer ingested ($P \leq$0.0202 and $P \leq$0.00003, respectively). Two-way repeated measures ANOVA, statistical significance was determined using the Holm-Sidak method with alpha = 0.05.



with a decrease to 50 percent at 6 hours and to less than 10 percent by 24 hours following parturition when DS lambs are allowed to suckle (Shubber and Doxey, 1979). It is therefore important to evaluate the mammary content before or at the lamb's first feeding in order to accurately investigate the colostral component of PT. This rapid decrease in colostral IgG concentration explains results reported by Herndon, *et al*. (2011), in which ewe serum samples from all DS and BHS were reported to have similar or greater mean titer values to specific pathogens/antigens, (*M. haemolytica*, leukotoxin (a primary virulence factor of *M. haemolytica*), and parainfluenza 3 virus) than did the colostrum collected up to 24 hours postpartum, likely after the lambs suckled, as the authors acknowledge may have occurred. Herndon *et al*. also reported 24 hour DS and BHS lamb sera to have higher titers than did the colostrum, which would indicate an impossible %AEA of greater than 100 percent, as neonatal ruminants have negligible serum IgG prior to colostrum ingestion due to the epitheliochorial cotyledonary placentation, which limits transfer of immunoglobulin from the dam to the fetus (Hunter et al., 1977).

Findings in this study indicate that following ingestion of colostrum, total serum IgG in BHS and DS at 1 day of age are similar, as are the waning kinetics of IgG with the nadir or "immunity gap" observed at 6 weeks to 9 weeks of age followed by an increase in IgG after 9 weeks of age, interpreted to be endogenous production (Fig. 2). Mortalities due to pneumonia typically occur in wild BHS lambs greater than 4 weeks of age, peaking between 6 weeks and 11 weeks, while inadequate PT is typically associated with mortality in the first weeks of life, when maternally derived antibodies should be at the highest concentration with adequate PT (Sawyer et al., 1977; Cassirer et al., 2001; Cassirer *et al.*, 2013). Supporting our findings and conclusions is a 2001 publication by Cassirer, et al. that reported "free-ranging lambs appeared especially vulnerable to pasteurellosis from 6 weeks to 11 weeks of age, near the time that passively-acquired agglutinating and leukotoxin neutralizing antibody levels wane" (Cassirer *et al.*, 2001). Additionally, the 2001 publication by Cassirer, et al. reported that 36 BHS ewes, sampled from three Hells Canyon herds, had high-serum agglutinating and neutralizing titers to *M. haemolytica* and leukotoxin, respectively, and high titers did not correlate with increased lamb survival. Herndon, *et al*. contradict this 2001 publication by concluding that BHS ewes, both wild (from Hells Canyon) and captive, are "deficient in Ab production" against *M. haemolytica* and leukotoxin. Herndon *et al*. go on to make the conclusion that the lower titers observed from 12 captive and 12 wild BHS ewes in their study is "representative of BHS in general", which seems an unreasonable conclusion based not only on the 2001 Cassirer *et al*. publication, but also when considering the overall population of BHS, located in western Canada, western United States, and northern Mexico, is estimated to be greater than 72,000. While the present study has limitations due to group size, our findings indicate a similar transfer of maternal total IgG in DS and BHS and similar serum IgG concentration kinetics in both species following colostrum ingestion. Our finding of similar PT in DS and BHS is supported by the findings of Herndon, *et al*. describing similar interspecies PT of antibodies directed at a specific-pathogen to which both BHS and DS ewes had serum titers.

Conclusions

This study provides a controlled interspecies comparative analysis of maternal total IgG in DS and BHS ewe serum and colostrum and kinetics of total serum IgG concentrations in DS and BHS lambs following colostrum ingestion. Not evaluated in the present study and vastly absent from the literature overall are factors that may impede BHS lambs from mounting an effective endogenous protective immune response against ovine respiratory pathogens. This seems a valid consideration in light of documentation that peak BHS lamb mortality coincides with the timing of the immunity gap identified in this study.

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