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

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Summary

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

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

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

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

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

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

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

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

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

Materials and Methods

Details of pasture establishment, forage management, and animal management were reported by Turner et al. (2015). In summary, the three-year (2006 through 2008) experiment was conducted during the grazing season each year using a mixed sward of orchardgrass, red clover, and white clover pastures established on a Gilpin silt loam (fine-loamy, mixed, mesic Typic Hapludults) in Raleigh County, W.Va. (37°45' N, 80°58' W, 875 m elevation), United States. All experimental procedures using animals were previously approved by the Institutional Animal Care and Use Committee, Appalachian Farming Systems Research Center, Beaver, W.Va., United States. Wether Suffolk (with Hampshire influence) lambs (n = 36), wether Katahdin lambs (n = 36), and wether Boer (with Kiko influence) crossbred meat-goat kids (n = 36) were used in 2006 and 2007 while Boer x Kiko (F1) meat-goat kids were used in 2008. In 2006, the lambs and kids were born March 15 through March 31, while in 2007 and 2008, all lambs and kids were born March 1 through March 15; in all years animals were procured from the same three flock vendors, and all animals were weaned June 28 (Turner et al., 2015). Mean body weights (kg ± SEM) at the start of the grazing study in 2006, 2007, and 2008 for Suffolk lambs were 25 ± 0.6, 26 ± 0.5, and 31 ± 0.6; for Katahdin lambs were 18 ± 0.6, 25 ± 0.7, and 26 ± 0.6; and for meat-goat kids were 14 ± 0.4, 15 ± 0.5, and 19 ± 0.8, respectively (Turner et al., 2015). Each year, the six grazing groups contained 18 animals each (lambs and kids) — 6 Suffolk, 6 Katahdin, and 6...
goat wethers and grazed a pasture together. Three groups of animals were not supplemented, while the other three groups received whole cottonseed (WCS) at 0.5 percent BW. Every 14 d, animals were weighed and supplement amount adjusted. Animals had access to water and minerals containing salt at all times.

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

FAMACHA® and Anthelmintic Dosing

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

FAMACHA® and Fecal Egg Count (FEC)

After the initial deworming, FAMACHA® score from individual animals was determined and recorded every 14 days. In addition, feces were collected every 14 days from the rectum of individual animals. Plastic bags with feces were placed into chilled, insulated boxes, and transported to the lab, and refrigerated at 1°C until FEC was determined (Zajac and Conboy, 2006) for identification and determination of the percentage of H. contortus.

Statistical analyses

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

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

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

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

Monthly blood data and FAMACHA® scores associated with this monthly blood collection date were analyzed as a multi-year, Randomized Complete Block Design based on the field layout of pastures (pastures were not re-randomized each year) using
PROC MIXED in SAS (SAS Institute, 2001; Cary, N.C.). Year and tmt were designated as fixed effects, while replication was random. Measurement periods within year were analyzed as a repeated measure. All differences were significant at $P < 0.05$, unless otherwise indicated, and separated using PDIF in SAS.

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

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

**Results**

**BW and ADG**

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

**FEC**

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

**Blood Parameters**

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

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

<table>
<thead>
<tr>
<th>Item</th>
<th>No Supplement</th>
<th>Supplement</th>
<th>$P$ level* Tmt x Breed</th>
<th>$P$ level† Breed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Begin BW, kg</td>
<td>Suffolk 31 ± 0.5</td>
<td>Katahdin 25 ± 0.5</td>
<td>Goat 15.9 ± 0.5</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>End BW, kg</td>
<td>Suffolk 40.1 ± 0.5</td>
<td>Katahdin 32.7 ± 0.5</td>
<td>Goat 19.1 ± 0.5</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Overall ADG, g/d</td>
<td>151.4 ± 5.1b</td>
<td>117 ± 5.1a</td>
<td>38.5 ± 5.1d</td>
<td>NS</td>
</tr>
</tbody>
</table>

* Tmt = Supplement Treatment; NS = Not Significant ($P > 0.10$).
† Breed Group, Breed.

a,b Means with unlike letters differ ($P < 0.003$).

c,d Means with unlike letters differ ($P < 0.10$).

e,f Means with unlike letters differ ($P < 0.17$).

Table 1. Beginning and ending body weight (BW) and overall ADG for 90-d periods in 2006-2008 when Suffolk lambs, Katahdin lambs, and meat-goat kids were finished on orchardgrass-legumes pasture without or with supplemental whole cottonseed supplement. Data are lsmeans ± standard error of the mean.
Albumin. Blood albumin concentrations (Fig. 3) each month did not trend the same among the three breed groups (Month × Breed group interaction, \( P < 0.001 \)). Serum albumin concentrations in June, July, and September were similar and were greater (\( P < 0.001 \)) than those obtained in August samplings. Blood-albumin concentrations were similar for Suffolk lambs and goat kids (mean 3.7 ± 0.04); concentrations were less (\( P < 0.01 \)) than those of Katahdin lambs (3.9 ± 0.04).

Globulin. Blood-globulin concentrations each month (Fig. 4) did not trend the same among the breed groups (\( P < 0.001 \)). Overall, concentrations were higher in July (2.8 ± 0.03) compared to the other months, while concentrations in June (2.8 ± 0.03) were higher than August (2.4 ± 0.03) with September (2.5 ± 0.03) being intermediate. Blood-globulin concentrations in goat kids and Suffolk lambs were similar.
(mean 2.6 ± 0.03); both were greater than Katahdin lambs (2.5 ± 0.03).

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

Monthly FAMACHA© Scores Associated with Blood Parameters

Trends in monthly FAMACHA© scores for the breed groups were similar, but the goat kids had higher ($P < 0.01$) monthly FAMACHA© scores compared to Suffolk and Katahdin lambs (Table 2). Overall, monthly FAMACHA© scores were higher ($P < 0.001$) in August compared to the other months, while scores in July and September were similar but greater ($P < 0.05$) than scores in June. The trend ($P < 0.001$) for monthly
Table 2. Monthly blood packed cell volume (PCV) and FAMACHA© scores when Suffolk lambs, Katahdin lamb, and goat kids were finished on orchardgrass-legume pastures 2006-2008. Data are lsmean ± standard error of the mean.

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

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

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

<table>
<thead>
<tr>
<th>Item</th>
<th>Year</th>
<th>Suffolk</th>
<th>Katahdin</th>
<th>Goat</th>
<th>P level Year</th>
<th>P level Breed*</th>
<th>P level Year × Breed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dewormer Doses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>0.08 ± 0.2b,B</td>
<td>0.03 ± 0.2b,B</td>
<td>2.1 ± 0.2a,B</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>1.4 ± 0.2b,A</td>
<td>0.9 ± 0.2c,A</td>
<td>3.2 ± 0.2a-A</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>1.5 ± 0.2b,A</td>
<td>0.8 ± 0.2c-A</td>
<td>1.9 ± 0.2a-B</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td></td>
</tr>
</tbody>
</table>

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

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

**Bi-weekly FAMACHA© Scores and Doses of Dewormer**

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

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

The mean number of deworming doses for supplemented (1.4 ± 0.1) and unsupplemented (1.2 ± 0.1) groups was not different (P > 0.10). However, there was a Treatment × Breed group effect (P < 0.001) in that WCS supplementation of goat kids (2.2 ± 0.02) tended to reduce (P < 0.10) the number of deworming events compared to the unsupplemented goat kids (2.7 ± 0.02); the average deworming events for supplemented and unsupplemented Suffolk...
lambs (1.0 ± 0.1 and 1.0 ± .01, respectively) and Katahdin lambs (0.5 ± 0.1 and 0.6 ± 0.1, respectively) were not different (P > 0.10).

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

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

**Discussion**

**BW and ADG**

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

**FEC**

Different groups of sheep and goats were used each year, yet these animals were from the same producer sources each year. The GIN levels on pasture herbage each year were probably influenced more by weather, forage growth patterns, and proportion of grass/legumes than by animal source.
Variation in FEC during the grazing season is, in part, related to the administration of dewormer to individual animals based on subjective anemia scores using the FAMACHA© scoring system. In the present study, Katahdin lambs received the fewest number of anthelmintic treatments and typically had higher FEC than goat kids that received a higher number of anthelmintic doses while Suffolk lambs were intermediate. Thus, deworming individual animals reduced and confounded FEC trends throughout the grazing season. Burke et al. (2009) suggested that interpretation of FEC data is difficult in studies where individual animals are treated based on FAMACHA© scoring and that data are related to the number of animals dewormed. Although there was a trend in the present study for higher FEC later in the grazing season compared to earlier sampling times, this was most likely a result of more goat kids being treated (based on FAMACHA© scores) at the beginning of the grazing season compared to Suffolk and Katahdin lambs, with relatively few Katahdin lambs requiring anthelmintic at the end of the grazing season.

Seasonal trends in GIN in pastures have been reported (González-Garduño, 2013; Wildes and Zajac, 2005). Rinaldi et al. (2009) noted that FEC in dairy goats was greatest from April through June compared to later in the year with no effect associated with the time-of-day collection of the samples. There was also a positive relationship between FEC and H. contortus worm burden in these animals. In our study, worm burdens were not determined, but H. contortus was the dominant L3 (57 percent to 72 percent of L3) recovered from composite larval cultures determined periodically throughout the grazing season each year.

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

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

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

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

Supplemental protein can suppress FEC in sheep and goats probably through an enhancement of the immune system, which could result in a decreased frequency of dewormer administration. Immune system development is slower in young animals. Manipulation of dietary nutrients may improve tolerance, resilience, and/or resistance to GIN parasites (Hoste et al., 2008). In goats, Nnadi et al. (2007) reported that West African Dwarf adult doe goats on a low-protein diet had higher FEC compared to adult does on a high-protein diet. In addition, the high-protein diet limited H. contortus establishment. Marley et al. (2005) suggested that grazing clovers (high protein) can reduce dependence on anthelmintics for control of abomasal GIN in lambs.

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ingestion of more larval parasites by grazing animals (Burke et al., 2009) if animals are returned to graze these paddocks too soon (short frequency of rotation), but most probably is dependent on the ambient temperature for GIN egg hatch and larval development (esp. H. contortus) and to the days of return to initial paddocks (Colvin et al., 2008). We had about 42 d of return in a temperate environment during summer.

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

## Blood Parameters

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

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

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

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

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

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

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

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

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

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

Summary

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

Literature Cited


