



Original Research Article

Influence of tannin-rich pine bark supplementation in the grain mixes for meat goats: Growth performance, blood metabolites, and carcass characteristics[☆]

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ABSTRACT

The objective was to evaluate the use of condensed tannin (CT)-rich ground pine bark (PB) in grain mixed diets on meat goat growth performance, blood metabolites, and carcass characteristics. Twenty four Kiko crossbred (*Capra aegagrus hircus*) growing male kids (BW = 36.9 ± 2.5 kg) at approximately 8 months of age were assigned randomly to 2 treatments with 3 replicates per treatment and 4 goats per replicate. The goats were fed grain mixed diets composed of either 30% bermudagrass hay (BGH) plus concentrate (control) or 30% PB plus concentrate. Diets were fed at 1.2% of BW. In addition, all goats grazed a crabgrass/bermudagrass (CB)-based pasture. The feeding trial lasted for 55 d. Using ground PB as a supplement did not negatively affect BW, average daily gain (ADG), carcass characteristics, meat pH, and meat color compared to the control diet. Plasma gamma-glutamyl transferase ($P = 0.03$), glucose ($P < 0.01$) and Ca concentrations ($P = 0.04$) were higher for PB than for BGH, respectively. The 30% PB supplementation does not negatively affect animal performance, blood metabolites, and carcass parameters.

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1. Introduction

More than 13 million hectares of Southern USA are planted with pine trees, with a projected increase of 67% (to approximately 22 million hectares) by 2,040 (United States Forest Service [USFS, 2008]). Lumber industries produce more than 2 million tons of

pine bark (PB) annually (USFS, 2008). Much of this is used for mulching while the rest of them are disposed of as wastes due to lack of other use. Although plant tannins were assumed to be a negative feed ingredient for ruminants for a long time, their effect may be beneficial for animal performances depending on the type of tannins consumed and the amount of ingested (Barry and Manley, 1984; Barry and Forss, 1983). Recent research results indicated that condensed tannins (CT)-rich PB (*Pinus* spp.) is an excellent feed ingredient for meat goats (Min et al., 2012, 2015a) as either a natural growth promoter or an alternative parasites control strategy (Min and Hart, 2003; Shaik et al., 2006). However, it has been suggested that excessive concentrations of CT (>5% CT DM) in the rumen can react with certain proteins to inhibit rumen carbohydrate fermentation (Barry and Forss, 1983; Barry and Manley, 1986). High CT concentrations such as those found in *Lotus pedunculatus* (6.3 to 10.6% CT DM) substantially depressed feed intake, digestibility, average daily gain (ADG), and some blood metabolites (Barry and Duncan, 1984; Waghorn et al., 1994). It has been reported that blood basophils, alanine transaminase,

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aspartate aminotransferase, albumin, Na⁺, and Cl⁻ concentrations decreased as PB supplementation increased (Min et al., 2012). However, recent study has shown that goats received diet containing up to 30% PB inclusion with elevated dietary crude protein (CP; 14.9% vs. 16.6%) had no change in those blood parameters (Min et al., 2015b). Therefore, not all feed ingredients high in CT have negative effects on small ruminant production. *Onobrychis viciifolia* (Sainfoin; 5.0% to 8.0% CT DM), *Hedysarium cornarium* (Sulla), *Lotus cuneata* (5.2% CT DM), peanut skin (6.1% CT DM), and PB (10% CT DM) when fed to sheep and goats, had a higher nutritive value and ADG than similar forages without CT (Ulyatt et al., 1976; Niezen et al., 1995; Min et al., 2005; Shipp et al., 2017).

Use of ground PB or wood chips as roughages in livestock feed is not a new concept (Carter, 1958; Coultrap et al., 2008). More recently, CT-rich diets (e.g., CT-rich legume forages, PB and *Juniperus* woody plants) have been effectively used in lambs (Whitney et al., 2014, 2017) and meat goats (Min et al., 2012) to enhance meat characteristics (Whitney and Smith, 2015; Lee et al., 2017) and reduce internal parasites infection (Shaik et al., 2006; Min and Hart, 2003). In addition, moderate levels of CT-containing diets (<4% CT DM) can reduce protein breakdown in the rumen and improve protected protein flow to the small intestine (Min and Hart, 2003), thus accelerating more dietary amino acids in the lower gut (Barry and McNabb, 1999). This is similar to the results obtained by Solaiman (2010) and Shipp et al. (2017), who found diets of 2.0% to 3.2% CT of DM had a significant effect on dry matter intake (DMI) and ADG as well as carcass characteristics in meat goats (Min et al., 2012). The enhancement in ADG can be elucidated by the improvement in the feed efficiency (e.g., gain to feed [G:F] ratio [Min and Hart, 2003; Shipp et al., 2017]) and superiorly protected protein flow to the lower gut in the tannin-rich diets compared to the control (Barry and McNabb, 1999). Therefore, incorporating ground PB into meat goat diets may help ruminal microbial growth while synergistically improving animal health. The objective of this study was to evaluate the use of ground PB in grain mixed diets on meat goat growth performance, blood metabolites, carcass characteristics, and animal health for grazing meat goats including potential anthelmintic effects.

2. Materials and methods

The Tuskegee University Animals Care and Use Committee approved the experimental protocol (R11-2012-31-1). The trial was conducted at the Caprine Research and Education Unit of George Washington Carver Agricultural Experiment Station of Tuskegee University.

2.1. Experimental design and diets

Twenty-four Kiko crossbred (*Capra aegagrus hircus*) growing male kids (BW = 36.9 ± 2.5 kg) at approximately 8 months of age were assigned randomly to 2 treatments to evaluate the effect of CT-rich PB supplementation in the grain mixes on animal performance, blood metabolites, and carcass traits. The 2 treatments consisted of 3 replicates per treatment and 4 goats per replicate. The goats were fed grain mixed diets composed of either 30% bermudagrass hay (BGH) plus concentrate (control) or 30% PB plus concentrate. Goats were fed one of 2 grains mixed diets (30% BGH + concentrate vs. 30% PB + concentrate) at 1.2% of BW. All goats grazed in a crabgrass/bermudagrass (CB)-based pasture. The feeding trial lasted for 55 d. Goats were weighed 5 d before study initiation, stratified by BW, and randomly assigned into six 0.5-ha CB-dominated pasture units. Freshly air-dried PB and BGH were ground (Hammer Mill Model 1250; Lorenz MFG Co., Benson, MN) to approximately 3-mm particle size before mixing with the

remaining ingredients of the concentrate portion of the diets. Supplement mixtures containing ground PB and BGH were commercially prepared at the local feed mill (Electric Feed Mill, Electric, AL, USA). As animals grow from 6 months to breeding age, growing goats required 0.5 to 1 kg of grain mix daily containing at least 14% to 16% protein, salt-mineral mix, and vitamins A and E (Solaiman, 2010). Experimental diets together with CB-based pasture met requirements of all animals for maintenance and growth (Table 1) according to the report of Solaiman (2010). Prior to using goats for the experiment, a 25-d adaptation period was used in an isolated quarantine pen. Health check was carried out by Tuskegee University Attending Veterinary. Subcutaneous clostridial vaccine (Vision 7 with Spur; Intervet Inc., Omaha, NE) was administered to all the animals. During the first 20 d of the adaptation period, goats were fed commercial alfalfa pellets with *ad libitum* access to BGH.

Animals were fed at 08:00 per day. Animal BW was measured at 2- to 3-wk intervals. Forage biomass for CB-basal diet was measured by clipping the forage to ground level in a 0.25-m² quadrat (3 samples per paddock by 3 replicates per treatment) in the middle of experimental period (d 30). Once samples were fully dried, they were ground, and placed in individual plastic storage bags for chemical analysis. Experimental control animals received Cydectin (Moxidectin; 1 mL every 14 kg BW) as a dewormer when fecal egg counts (FEC) was over 1,200 eggs/g of fecal sample on d 30 and 40, but PB group did not receive the anthelmintic. Therefore, we presented FEC data in discussion only. Fecal egg counts were measured at d 0, 30, 40, and 50 of the study using the McMaster techniques (Stafford et al., 1994). Blood samples (5 mL) were

Table 1

Composition of supplements, and ingredients and composition of diets fed to Kiko crossbred meat goats.

Item	Ingredients			Experimental diet ¹		SEM
	CB	PB	BGH	30% BGH	30% PB	
Ingredients, % as is						
Ground PB				0	30	
BGH				30	0	
Cracked corn				50	50	
Alfalfa meal				10	10	
Soybean meal				5	5	
Molasses				4.5	4.5	
Salt				0.5	0.5	
Chemical composition, % DM (n = 3)						
DM	91.9	91.9	91.8	92.1	92.5	0.15
CP	19.0	1.3	4.9	16.6	16.8	2.21
ADF	32.4	70.1	47.1	21.7	44.8	6.59
NDF	41.5	76.6	69.5	40.3	50.0	4.28
TDN ²	77.5	54.1	58.8	78.3	71.8	1.41
CT	0.05	12.10	0.89	0.12	3.2	0.45
Minerals, %						
Ca	1.02	0.25	0.39	1.14	0.79	0.19
P	0.56	0.04	0.19	0.60	0.23	0.08
Mg	0.52	0.02	0.24	0.54	0.22	0.08
Na	0.01	0.08	0.01	0.01	0.26	0.06
S	0.22	0.01	0.20	0.20	0.19	0.001
Minerals, mg/kg						
Cu	4.57	2.0	3.0	5.66	27.5	5.28
Mn	134.7	30.0	43.0	148.8	201.0	24.1
Zn	28.8	11.0	20.0	31.6	191.0	38.9
Fe	112.4	384.0	211.0	231.5	420.0	97.4

CB = crabgrass/bermudagrass; PB = pine bark; BGH = bermudagrass hay; DM = dry matter; CP = crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; TDN = total digestible nutrients; CT = condensed tannins (qubracho tannins equivalent).

¹ Both diets were fed at 1.2% BW to goats grazed on a CB. Experimental diets were non-agglomerated and ingredient composition differed only by roughage source: either ground BG hay or ground PB.

² TDN = 105.2 - NDF (%) × 0.667 (Undersander et al., 1993).

collected from the jugular vein in 5-mL ethylenediamine tetraacetic acid (EDTA) and 5-mL non-additive EDTA-containing vacutainer tubes (BD, Franklin Lakes, NJ) on d 50. Blood samples were placed on ice immediately following collection and analyzed for packed cell volume (PCV) and a standard blood metabolic profile.

Serum was then harvested by centrifugation ($1,500 \times g$) and stored at -20°C for analysis of blood serum metabolites (Blum et al., 1983) at the Tuskegee University Clinical Pathology Laboratory. Serum samples were diluted 4 times in distilled water, and mineral concentration was determined by flame atomic absorption spectrophotometry (Instrumentation Lab., model IL251; Lexington, MA). Supplemental feed (PB and control diets) samples were collected at 2-wk interval for dietary chemical analysis (Cherney et al., 2000). Feed and forage samples were dried at 60°C for 48 h, ground to pass a 1-mm screen (standard model 4; Arthur H. Thomas Co., Swedesboro, NJ) and stored for subsequent analyses.

2.2. Carcass evaluation

Carcass traits were measured after slaughter at the end of the experiment on d 55. At the end of the experiment, goats were weighed, transported, fasted for 24 h, re-weighed and then humanely slaughtered according to the guidelines (United States Department of Agriculture [USDA] IMPS, 2001) at Meat Science Laboratory, Fort Valley State University, GA.

The carcass and non-carcass organs and tissues were re-weighed, and the proportion of organs and tissues relative to empty body weight (EBW) was calculated. Hot carcass weight (HCW) was weighed at the day of slaughter, and carcasses were cooled at 4°C for 24 h; chilled carcass weight (CCW) was then measured. Dressing percentage (DP) was calculated from HCW and fasted weight. Longissimus muscle (LM) area was measured by a USDA certified grader 24 h post-mortem. Carcass was divided into primal cut (USDA-IMPS, 2001), and leg, loin, shoulder, breast, neck, rack, flank, hind shank, and shank were weighed.

2.3. Meat pH and meat color

Longissimus muscle (LM) pH was measured between the 12th to 13th ribs, 24 h postmortem using a pH piercing electrode (Thermo Orion meter, Orion Research; Boston, MA). Ribbed carcasses for meat color measurements were conducted at 4°C . *Commission Internationale de l'Éclairage* lean color lightness (L^*), redness (a^*), and yellowness (b^*) values were determined after carcasses were chilled for 24 h. The lean meat color values, L^* , a^* , and b^* , were determined from 2 readings at the 12th rib LM with a Hunter Miniscan XE Plus (Hunter Lab, Reston, VA) and averaged to acquire a representative measure of initial lean color. The mini-scan utilized a D 65 light source, 10° viewing angle and 35-mm^2 viewing area, and was calibrated according to the manufacturer's recommendations.

2.4. Chemical analysis

Ground feed samples were composited for each treatment group and analyzed for chemical composition methods described by AOAC (2000). Diet CP content was determined by Kjeldahl-nitrogen $\times 6.25$. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were sequentially determined using an ANKOM^{200/220} Fiber Analyzer (ANKOM Technology, Macedon, NY). Sodium sulfate and heat stable amylase (Type XI-A from *Bacillus subtilis*; Sigma–Aldrich Corporation, St. Louis, MO) were used in the procedure for NDF determination. Total digestible nutrients (TDN) was calculated as $105.2 - 0.667 \times \text{NDF} (\%)$; Undersander et al. (1993).

Acetone (70%) extractable CT in diet samples was determined using a butanol-HCl colorimetric procedure (Terrill et al., 1992).

2.5. Statistical analysis

Forage and dietary chemical composition, animal BW, blood plasma metabolites, and carcass traits were analyzed using the proc MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Treatment means were separated using Fisher's protected least significant differences. Animal BW changes and FEC data were collected across time and were analyzed using the repeated measures statement of the MIXED procedure. The compound symmetry covariance structure was used for the repeated measurements. Variables included in the model for the repeated measurements were treatment, time (sampling time), and the interaction. Treatment means were separated by least significant differences (LSD) when overall F -values were significant ($P < 0.05$).

3. Results and discussion

3.1. Chemical composition of diets

The addition of 30% PB was chosen in the present study based on previous reports that positive effects of CT in the grain mixes on meat goat performance, anthelmintic effects, and rumen digestibility occurs in the range of 25% to 30% of PB in the diet (or 2 to 4% CT DM) (Min et al., 2012, 2015). Concentration of CT in PB diets was 3.2% CT DM (Table 1). Diets were similar in composition for CP, but ADF and NDF concentrations were greater in 30% PB rations compared with BGH control diet (Table 1). The BGH had higher CP content compared to PB (4.9% vs. 1.3% DM). The CT concentration of PB used in the current study was 12.1% DM resulting in a maximum CT concentration of 3.63% in the mixed grain diets. Results from previous studies suggested that 2% to 4% CT (DM basis) is favorable to animal growth performance and rumen fermentation (Min et al., 2012, 2015). In addition, even though the BGH and PB materials did not contain significant amount of CP, the mixed grain diets contained recommended CP levels ($>16\%$ CP DM; NRC, 2007, Table 1).

3.2. Growth performance and carcass traits

In the present study, there were no differences between treatments (Fig. 1) in initial BW (35.1 vs. 37.5 kg), final BW (52.2 vs. 55.3 kg), and ADG (310.0 vs. 320.1 g/d) for BGH and PB treatments, respectively, with no treatment \times time interactions for BW changes. There were also no differences in carcass characteristics (Table 2), meat pH, and meat color (Table 3) between treatments, with no treatment \times replicates interactions.

The dietary fiber requirement for goats has not been defined by the current NRC guidelines (NRC, 2007). Whitney et al. (2017) reported that lambs consuming 30% ground wood products (e.g. *Juniperous* spp.) had reduced DMI by 22% when compared with 30% cottonseed hulls diet, but animal health and rumen fermentation parameters were not affected. Feeding high fiber diets (e.g. NDF and ADF) reduced growth rates and affected carcass quality as compared to the feeding of high energy grain diets (Mahgoub et al., 2005). Goats fed elevated fiber diets from 12.3% to 24.7% ADF or 23.6% to 43.4% NDF reduced their growth rate by 43%, while carcass fat was decreased by 18% (Mahgoub et al., 2005; Mahgoub and Lu, 2004). However, our study illustrated that diets containing 30% ground PB did not negatively affect animal growth performance and carcass characteristics. Similarly, Min et al. (2012) reported when PB was included at linear levels (0, 15%, and 30% PB) with a grain mix including soybean meal, alfalfa meals and other ingredients, DMI and ADG were increased compared to control non-

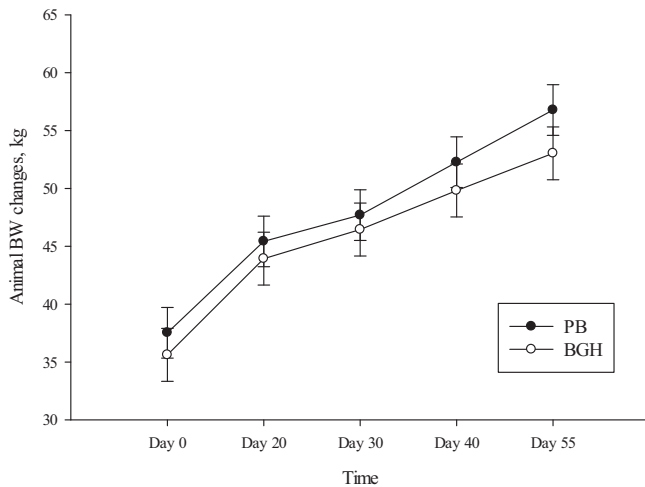


Fig. 1. Effects of replacing bermudagrass (BGH; control) hay with ground pine bark (PB) supplementation on body weight (BW) of goats. Both diets were fed at 1.2%/BW to goats grazed on a crabgrass/bermudagrass-dominant pasture. Experimental diets were non-agglomerated and ingredient composition differed only by roughage source: either ground BG hay or ground PB. There were no significant treatment \times time interactions for BW.

Table 2

Effects of replacing bermudagrass hay (BGH; control) with ground pine bark (PB) supplementation on goat carcass profile (kg).

Item	Treatment ¹		SEM	P-value		
	BGH	PB		Diet	Rep.	Diet \times Rep.
FBW	47.2	49.9	3.29	0.43	0.77	0.73
Carcass cuts (right and left sides)						
HCW	20.8	21.5	1.51	0.66	0.8	0.55
CCW	20.1	20.7	1.50	0.69	0.53	0.42
Legs	5.84	6.09	0.35	0.56	0.26	0.28
Loin	1.31	1.31	0.1	0.96	0.57	0.24
Rack	2.38	2.30	0.15	0.71	0.75	0.46
Shoulder	3.17	3.34	0.24	0.47	0.55	0.52
Neck	2.03	2.09	0.16	0.71	0.95	0.46
Shank	0.78	0.81	0.07	0.65	0.34	0.74
Breast	3.00	3.16	0.25	0.51	0.52	0.4
Flank	0.66	0.74	0.09	0.39	0.23	0.51
Hind shank	0.88	0.90	0.05	0.68	0.88	0.69
LMA, mm	15.4	14.9	1.42	0.74	0.42	0.49
DP, %	44	42	0.52	0.92	0.45	0.38

Rep. = replicates; FBW = fasting body weight; HCW = hot carcass weight; CCW = chilled carcass weight; LMA = *Longissimus* muscle area, DP = dressing percentage [(HCW \times 100)/FBW].

¹ Both diets were fed at 1.2% BW to goats grazed on a crabgrass/bermudagrass-dominant pasture. Treatment diets were non-agglomerated and ingredient composition differed only by roughage source: either ground BGH or ground PB.

PB diets. A meta-analysis by [Min and Solaiman \(2018\)](#) showed that goats appear to have more preference and tolerance of tannin-containing diets than sheep. The absence of effect of tannins in goats might result from the greater ability of their rumen microbiota (*Streptococcus caprinus*) population to degrade dietary tannins and their higher urea recycling and salivary secretion capabilities ([Brooker et al., 1994](#); [Cocimano and Leng, 1967](#)). In addition, [Turner et al. \(2005\)](#) and [Terill et al. \(1989\)](#) reported that daily dry matter intake of tannin-containing *Sericea lespedeza* (*Lespedeza cuneate*) hay and supplement in meat goats was higher (42.1 vs. 38.7 g/kg BW) for tannin-containing diets than for alfalfa hay, respectively. The higher DMI in goats compared to sheep was due to not only higher rumen digestibility, but also a higher rumen volume (0.23 vs. 0.14 L/kg BW) leading to a larger rumen fill of DM (25.8 vs. 15.7 g/kg BW; [Watson and Norton, 1982](#); [Alam et al., 1985](#)).

Table 3

Effects of replacing bermudagrass hay (BGH; control) with ground pine bark (PB) supplementation on hunter colorimetric co-ordinates L*, a* and b* of *Longissimus* muscle of goats measured 48 h postmortem.

Item	Treatment ¹		SEM	P-value		
	BGH	PB		Diet	Rep.	Diet \times Rep.
Color values ²						
L*	36.1	37.2	0.74	0.3	0.49	0.74
a*	11.9	11.7	0.51	0.67	0.09	0.15
b*	11.1	11.3	0.42	0.71	0.70	0.27
Initial pH	6.5	6.6	0.08	0.55	0.52	0.19
Ultimate pH	5.7	5.7	0.04	0.75	0.20	0.37

Rep. = replicates.

¹ Both diets were fed at 1.2% BW to goats grazed on a crabgrass/bermudagrass-dominant pasture. Treatment diets were non-agglomerated and ingredient composition differed only by roughage source: either ground BGH or ground PB.

² L* values are a measure of lightness (higher value indicates a lighter color); a* values are a measure of redness (higher value indicates a redder color); b* values are a measure of yellowness (higher value indicates a more yellow color). The color values were used according to the Hunter colorimetric scale.

It has been reported that CT-containing PB diets negatively impacted fiber, lignin, and protein digestibility, but positively impacted nitrogen balance ([Min et al., 2015](#)). This may be due to more rumen undegradable protein and less excreted nitrogen in the urine with the 15% PB in the mixed diets. In agreement with these results, [Solaiman et al. \(2010a\)](#) reported that ADG was improved as CT-containing sericea lespedeza increased up to 30% of total diet (2.22% CT DM). [Glasscock et al. \(2018\)](#) reported that DMI, ADG, G:F ratio, and BW were not different between goats fed cottonseed hulls and goats fed any of ground wood products from redberry (*Juniperus pinchotii*), blueberry (*J. ashei*), red cedar (*Juniperus* spp.), and mesquite (*Prosopis glandulosa*) trees. In both [Solaiman et al. \(2010a\)](#) and [Glasscock et al. \(2018\)](#) studies, diets were roughage based; therefore, further research is warranted to compare PB- or other CT-containing diets.

Meat pH and Hunter colorimetric co-ordinates L*, a*, and b* values for the LM of Kiko-crossbred goats are presented in [Table 3](#). There were no significant differences in meat pH and meat color between treatments. Goat meat is reported to be darker, yellower, and had a higher a* value when compared to lamb meat ([Babiker et al., 1990](#)). [Priolo et al. \(2000\)](#) found greater L* values in lambs fed a diet containing carob pulp, compared to lambs fed the same diet supplemented with polyethylene glycol (PEG; control). Other studies on small ruminants showed that CT-containing diets affect lamb meat color ([Priolo and Vasta, 2007](#); [Garg et al., 1992](#); [Luciano et al., 2009](#)). In Kiko-cross goats fed ground PB and BGH, the hunter colorimetric co-ordinate L* value was higher (36.8 vs. 29.3) and both a* (11.8 vs. 16.8) and b* (11.2 vs. 16.1) values were lower for LM of meat goats in our study compared to the values for Boer-crosses reported by [Solaiman et al. \(2010b\)](#). This may be due to breed (Kiko-cross vs. Boer-cross), castration (buck vs. wether), and diets (PB-based vs. Marshall ryegrass-based diet) in the present study compared to others ([Solaiman et al., 2010a](#)).

The final pH is crucial to the chilled meat because it influences shelf life, color, and quality. High pH has been associated with both undernourishment in ruminants and stress in general, and such meat is normally dark in color ([Priolo et al., 2000](#)). In the present study ([Table 3](#)), there were no difference ($P > 0.10$) in meat pH between treatments at 24 h postmortem. In contrast, [Min et al. \(2012\)](#) reported that meat goats receiving 30% PB diets had a 5.3% faster decline in muscle pH within 8 h postmortem than control and 15% PB treatment, but final pH at 24 h postmortem was similar between 2 treatments (pH 5.5 to 5.7).

3.3. Blood serum profiles

The effects of a PB diet on blood profiles and PCV in meat goats were not affected by diet (Table 4). However, gamma-glutamyl transferase (GGT; $P = 0.03$), glucose ($P < 0.01$) and Ca concentrations ($P = 0.04$) were higher for PB treatment than for BGH treatment. Serum metabolites were used as an indicative means for diagnosis of animal health problems and abnormality. In cattle, serum concentration of GGT has proven to be a sensitive indicator of minor hepatic damage, whereas alkaline phosphatase and cholesterol are used as indicators for bile obstruction and liver damage (Silanikove and Tiomkin, 1992). However, in the current study, all values for these parameters are generally lower than published data (Whitney et al., 2017; Stogdale, 1981; Olafadehan, 2011). In an experiment reported by Whitney et al. (2017), lambs were fed a basal diet containing 30% ground woody plants (*Juniperus* spp. and *P. glandulosa*), supplemented with concentrate feedlot diets, concentration of GGT (45 to 52 vs. 28.8 U/L), albumin (3.0 to 3.1 vs. 1.9 to 2.0 g/dL), alanine-aminotransferase (ALT; 7.8 vs. 10.0 U/L), and some minerals were higher than those of our current study, respectively, confirming the lack of toxic effects from PB tannins when animals received 30% ground PB supplementation. Glucose concentration was higher ($P < 0.01$) in PB diet as compared to BGH diet most probably because diet selection may be occurred with cracked corn (50% as fed basis) in the mixed rations with PB or BGH included. Collectively, results suggested that ground PB can replace BGH or other agricultural by-products such as corn stalk or wheat straw in goat supplemental diets without negatively affecting growth performance or animal health.

3.4. Packed cell volume and fecal egg counts

Results from the present study indicated that goats consuming CT-containing PB had lower FEC (log 3.0 vs. log 2.3 FEC/g of feces) compared to BGH group on d 50, respectively (data not shown in the text). The CT-containing diets or plant extracts from numerous forages have been shown to reduce the production of eggs (Molan et al., 1999; Min and Hart, 2003; Hur et al., 2005). One explanation for the reduced FEC in PB-supplemented group in the present study may be related to reduced fecundity of adult worm population (Min et al., 2015b). Also, the tannins may have increased rumen undegradable protein as evidenced by reduced rumen ammonia-N concentration (Min et al., 2012, 2015a; b) and the protein nutrition enhanced the immune response, reducing the numbers of adult worms established in the gastrointestinal tract (Min et al., 2019).

Previous researches reported that animals receiving CT-containing diets or forage (*Sericea lespedeza*) had lower FEC but greater PCV than those grazing on non-CT-containing forage (crabgrass or tall fescue forages; Min et al., 2005, 2012; Shaik et al., 2006). In the present study, however, no differences in blood PCV (Table 4) is due to deworming at 1,200 eggs/g so that worms did not get to a high enough level to cause anemia (Shaik et al., 2006; Huls et al., 2006). The mechanism of anthelmintic properties of tannins in PB is currently unknown. In spite of CT-internal parasite interactions, CT-containing diets or forages have potential as a practical means of reducing infection of pastures with parasite eggs and consequent infective larvae reducing adverse effects of worms in animals.

Table 4
Effects of replacing bermudagrass hay (BGH; control) with ground pine bark (PB) supplementation on blood serum metabolites of goats.¹

Item	Treatment ²		SEM	P-value		
	BGH	PB		Diet	Rep.	Diet × Rep.
Enzymes, U/L						
CK	136.5	133.1	6.73	0.73	0.01	0.61
ALT	10.20	9.66	1.71	0.72	0.39	0.79
Amylase	54.9	38.9	12.3	0.37	0.12	0.03
ALP	215.6	268.1	95.4	0.59	0.82	0.34
GGT	25.9	31.7	2.55	0.03	0.03	0.21
AST	61.0	66.5	5.2	0.31	0.52	0.21
Blood serum protein, g/dL						
Total Protein	4.92	5.63	0.33	0.07	0.43	0.19
Albumin	1.90	2.06	0.12	0.22	0.38	0.86
Blood serum metabolites, mg/dL						
DBILI	0.18	0.25	0.04	0.13	0.79	0.93
BUN	15.5	20	2.17	0.06	0.06	0.48
Creatinine	0.57	0.67	0.05	0.06	0.23	0.35
Cholesterol	60.6	59.8	4.83	0.91	0.86	0.75
Glucose	40.7	49.0	3.01	0.01	0.38	0.16
Total bilirubin	0.19	0.23	0.02	0.19	0.79	0.93
Triglyceride	36.2	45.7	9.36	0.33	0.58	0.79
Blood serum minerals, mg/dL						
Calcium	6.97	7.82	0.37	0.04	0.3	0.27
Phosphorus	5.19	4.07	0.49	0.05	0.24	0.92
Blood serum electrolytes, mmol/L						
CO ₂	18.1	19.9	1.39	0.2	0.98	0.1
Sodium	115.4	129.1	7.46	0.11	0.73	0.15
Potassium	4.43	4.79	0.36	0.35	0.56	0.59
Chloride	88.9	100.2	5.83	0.09	0.65	0.16
Blood variables						
PCV, %	29.6	30.4	1.79	0.78	0.85	0.71

Rep = replicates; CK = creatinine kinase; ALT = alanine-amino transferase; ALP = alkaline phosphatase; GGT = gamma-glutamyl transferase; AST = aspartate-amino transferase; DIBILI = direct bilirubin; BUN = blood urea nitrogen; CO₂ = carbon dioxide; PCV = packed cell volume.

¹ Blood serum was collected on d 50.

² Both diets were fed at 1.2% BW to goats grazed on a crabgrass/bermudagrass-dominant pasture. Treatment diets were non-agglomerated and ingredient composition differed only by roughage source: either ground BGH or ground PB.

4. Conclusions

Results from the current study suggest that substituting 30% PB for BGH does not negatively affect animal performance, blood metabolites, and carcass parameters. Tannin-containing PB has a potential for reducing cost of commercial goat diets while supporting similar levels of animal performance as a roughage source for meat goats.

Conflict of interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the content of this paper.

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