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Original Research Article

Peanut skin in diet alters average daily gain, ruminal and blood metabolites, and carcass traits associated with *Haemonchus contortus* infection in meat goats☆

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ABSTRACT

The aim of this study was to determine the effects of tannin-rich peanut skin (PS) supplementation on growth performance, ruminal and blood metabolites, and carcass traits associated with internal parasite infection in meat goats under confined conditions. Twenty-one Kiko crossbred male goats were blocked by body weight (BW) and randomly assigned to one of 3 treatment groups. Experimental diets contained different levels of peanut (*Arachis hypogaea*) skin replacing alfalfa (*Medicago sativa*) pellets (ALP) in a control diet. Experimental treatments included: 30% ALP (control), 15% PS and 15% ALP, and 30% PS. Peanut skin was incorporated in the grain mix portion of the diets. Animals were fed once daily, and the intake was adjusted every 3 to 4 d. Each animal was each artificially infected with 5,000 larvae of the 3rd stage of barber's pole worm (*Haemonchus contortus*). Body weights, dry matter intake (DMI), and fecal samples for fecal egg counts (FEC) were taken at d 0, 12, 23, and 41. Rumen fluid and blood samples were collected at d 45. The performance period lasted 45 d and at the completion of the study, goats were harvested, and carcass characteristics, abomasal worm counts were measured. The results showed that DMI, BW, carcass traits, and meat color were not affected by PS supplementation, whereas average daily gain (ADG, $P < 0.01$), blood glucose ($P < 0.001$), phosphorus ($P < 0.05$), and cholesterol levels ($P < 0.001$) significantly increased with increasing levels of PS supplementation. There was a linear ($P < 0.01$) reduction in rumen acetate to propionate ratio, ammonia-nitrogen, FEC, and *H. contortus* worm counts, with increasing levels of PS supplementation. This study shows that PS supplementation up to 30% of the diet can improve ADG and rumen fermentation while reducing gastrointestinal parasite infection in meat goats.

1. Introduction

Optimum levels of tannin-rich peanut skin (PS) feeding programs for meat goats and their potential anthelmintic effects are not well established. Because of high levels of tannins in PS, the proteins are poorly digestible and the feeding value is low despite high fat content, which limits the inclusion level in cattle rations. Beef cattle are the major livestock species fed PS, but diets are limited to 10% of PS for growing finishing cattle (Utley et al., 1993). Considerable research, however, has been conducted over the years on PS supplementation level in dairy cows (Utley et al., 1993), beef

☆ The mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.

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cattle (Hill, 2002), sheep (Abdelrahim et al., 2012), and goat (Shipp et al., 2017).

Previous researchers have shown that dietary PS had contradictory responses in fecal egg counts (FEC) in small ruminants (Shipp et al., 2017; Mackown et al., 2011). One reason for lack of response to high rate of PS supplementation in the study of Mackown et al. (2011) could be related to the over doses of PS supplementation (2.3% BW of PS) for the lambs, which might have caused depression of dry matter intake (DMI), reducing overall performance. Cattle (grazers), goats (browsers) unlikely be adapted handling moderate to high levels of tannins in their diets (Austin et al., 1989; Min et al., 2003). Because goats are capable of handling higher levels of condensed tannins (CT) in their diets, PS could have the potential to be used in goat feeds. Shipp et al. (2017) reported that animals that received PS supplementation (0, 25%, and 50% PS) had higher DMI and average daily gain (ADG), and reduced FEC, with maximum responses in 25% PS supplementation. However, data concerning the effects of different levels of PS supplementation on rumen fermentation, blood metabolites, carcass traits, and adult worm counts in meat goats are sparse. The objectives of this experiment were to determine the effects of PS supplementation on DMI, ADG, rumen and blood plasma metabolites, carcass traits, and parasites in goats housed indoors.

2. Materials and methods

Care and handling of all experimental animals was conducted under protocols approved by the Tuskegee University Institutional Animal Care and Use Committee (R02-2016-17 – Goats).

2.1. Experimental animals and diets

Twenty-one Kiko crossbred intact male goats were used in a 45-d confinement feeding trial from May to June, 2017. Animals were blocked by body weight (BW; average 38.6 ± 2.7 kg; approximately 9 months of age) and randomly assigned to one of 3 different treatment groups. Experimental diets contained different levels of the condensed tannin (CT)-rich peanut (*Arachis hypogaea*) skin (PS) replacing alfalfa (*Medicago sativa*) pellets (ALP) in a control diet. Experimental treatments included: 30% ALP (control), 15% PS and 15% ALP, and 30% PS as-fed basis. Peanut skin was incorporated in the grain mix portion of the diet (Table 1). Animals were fed the mix once daily at 08:00. However, the amount of feed offered was adjusted every 3 to 4 d to maintain the preferred daily refusal. Feed offered and refused were recorded at daily basis, but DMI estimation was measured between d 40 and 45 in the final week of trial. Supplements were formulated to be isonitrogenous and isocaloric and to meet NRC (2007) requirements.

All the goats were dewormed with Cydectin (Moxidectin, Fort Dodge Animal Health, Iowa, USA) before the trial (d −30), and fed a control diet without PS supplementation. Fecal samples were collected at d −20 for background FEC to make sure all animals were successfully dewormed, then all the experimental goats were transferred to individual pens. The goats were orally inoculated with an equal number of *Haemonchus contortus* larvae (5,000 at the 3rd stage larvae per goat; Min et al., 2015a) 2-wk before (d −14) the initiation of the study. Animals were confined indoors for a period of 45 experimental days (Fig. 1). The goats were individually housed in 1.1 m × 1.2 m pens with plastic-coated expanded mesh floors to allow simple passage of feces and urine to minimize parasite reinfection. An adjustment period of 2 wk allowed goats to be acclimated to pen environment and routine feeding (Goat Chow, Purina Co. with Bermudagrass hay) prior to the study initiation. From wk 1, all animals were fed a diet containing PS, preassigned experimental diets (the 1st day of feeding treatment diets, d 1).

Table 1
Feedstuffs used for this experiment and nutrient compositions of experimental diets and ingredients fed to meat goats.

Item	Diets			Ingredients		
	0 PS	15% PS	30% PS	PS	ALP	SEM
Ingredients of the grain, % as-fed basis						
ALP	30	15	0	–	–	–
PS	0	15	30	–	–	–
Soy hull	5	5	5	–	–	–
Soybean meal	10	10	10	–	–	–
Cracked corn	25	25	25	–	–	–
Chopped BG hay	25	25	25	–	–	–
Molasses	3.5	3.5	3.5	–	–	–
Vitamin and mineral mix[1]	1.0	1.0	1.0	–	–	–
Salt	0.5	0.5	0.5	–	–	–
Nutrient composition, % DM						
CP	22.7	23.2	22.8	19.4	23.4	1.41
NDF	40.4	39.9	37.0	39.5	39.3	0.69
ADF	33.4	36.7	34.9	34.9	32.9	1.88
TDN	57.6	57.8	59.2	58.02	58.1	2.71
CT[2]	0.12	2.4	4.9	16.1	0.16	0.19

ALP = alfalfa pellets; PS = peanut skin; BG = Bermuda grass hay; DM = dry matter; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; TDN = total digestible nutrients, TDN = 86.2 − (% NDF × 0.513) (Undersander et al., 1993).

[1] Vitamin and mineral mix: calcium, 9.0%; phosphorus, 8.0%; salt, 41%; potassium, 0.1%; copper, 1,750 mg/kg; selenium, 25 mg/kg; zinc, 7,500 mg/kg; vitamin A, 308,000 IU/kg; vitamin D, 24,200IU/kg; vitamin E, 1,650 IU/kg.

[2] Condensed tannins (CT) values based on PS in the diet and its CT concentration. Tannin values are relative to a purified PS CT standard (as-fed basis).

Body weights were measured once every second week, and fecal samples for FEC were collected at the d 0, 13, 23, and 41, and FEC were conducted using the McMaster techniques (Min et al., 2005). Rumen fluid (10 mL) and blood (5 mL) samples were collected once on d 45. Ruminal fluids were collected via a stomach tube 2 h after morning feeding, capped immediately and stored at −20 °C until analysis later that day. Blood samples were collected via jugular venipuncture using an vacutainer (ethylene diamine tetraacetic acid [EDTA]-treated) and immediately placed on ice. Blood samples were centrifuged at 3,000 ×*g* for 10 min (4 °C), and 1 mL aliquot of plasma was stored at -80 °C until analysis. Dietary samples were collected at the beginning of mixing to balance rations. Composite samples for grain mixes and ingredient samples were collected during the experimental period and dried for 48 h at 55 °C in a convection oven (model 420, NAPCO, Pittsburgh, PA). Samples were ground to pass a 1-mm screen (Wiley Mill, Arthur Thomas Co., Philadelphia, PA).

The performance period lasted 45 d, and at the completion of the study, goats were harvested, and carcass characteristics and abomasum worm counts measured. At the end of the experiment, goats were weighed, transported (2 h), fasted for 24 h, reweighed, and then humanely slaughtered at Meat Science Laboratory, Fort Valley State University, GA. Fasting weight loss was determined via subtracting the pre- and post-fasting period (24 h) weights of each animal. Immediately after slaughter, hot carcass weight (HCW) was determined on the day of slaughter, carcasses were chilled at 4 °C for 24 h for chilled carcass weight (CCW) measurement. Carcasses were ribbed at the 12th and 13th rib interface for further evaluation. Fat depth (body fat; cm) over the midpoint of longissimus muscle (LM) at the 12th rib and body wall fat (cm) at the lower point of the 12th rib was determined by a certified USDA grader 24 h postmortem. The dressing percentage (DP) and LM area (LMA) were determined by a certified USDA grader 24 h postmortem. Fecal egg counts were determined using a modified McMaster's procedure (Stafford et al., 1994). The whole abomasal contents were collected and preserved at 4 °C for counting of the adult worms.

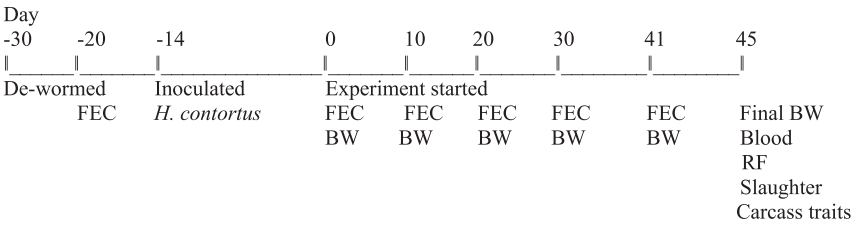

Fig. 1. Experimental procedures and time line, May to June, 2017. Goats were fed once daily at 08:00, and feed offered and refuged was monitored for 45 d for growth performance and parasites infection measurements. Animals had free access to water and salt mineral blocks *ad libitum*. FEC = fecal egg counts; *H. contortus* = *Haemonchus contortus*; BW = body weight; RF = rumen fluid samples.

2.2. Chemical analysis

Ground composite samples were analyzed for dry matter (DM), crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) according to the methods described by AOAC (1998). Nitrogen (N) concentration of diet samples was determined using Kjeldahl N method, and CP was calculated by multiplying N by 6.25. Concentrations of NDF and 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 nutrient (TDN) concentration was calculated based on NDF concentration using the following equation, TDN = 86.2 − (% NDF × 0.513) (Undersander et al., 1993). Acetone (70%) extractable CT in diet samples was determined using a butanol-HCl colorimetric procedure using a Quebracho CT equivalent (Terrill et al., 1994). For volatile fatty acids (VFA) analysis, 5 mL of ruminal fluid was diluted with 1 mL of 3 mol/L meta-phosphoric acids and quantified using a gas chromatograph (model 5890 series II; Hewlet Packard Co, Palo Alto, CA.) with a capillary column (30 m × 0.32 mm i.d., 1 μm phase thickness, Zebron ZB-FAAP, Phenomenex, Torrance, CA) and flame-ionization detection. The oven temperature was 170 °C held for 4 min, and was increased by 5 °C/min to 185 °C, and then increased by 3 °C/min to 220 °C, and held at this temperature for 1 min. The injector temperature was 225 °C, the detector temperature was 250 °C, and the carrier gas was helium (Eun and Beauchemin, 2007).

2.3. Parasitology measures

Adult worm counting was determined according to the methods described by Shaik et al. (2006). After slaughter, the abomasum of each goat was ligated, opened, and the contents washed into plastic buckets. The contents were brought up to 3 L with tap water, carefully mixed, and then two 5% aliquots (150 mL) taken into 250-mL storage containers. Approximately 100 mL of formalin (5%) was added to each aliquot as a preservative. The worms in one aliquot were washed on a mesh screen with tap water, the formalin discarded, and the nematodes recovered into a 50-mL centrifuge tube. All the nematodes in the tube were then counted using a phase contrast microscope.

2.4. Data processing and statistical analysis

All analyses were conducted using the PROC Mix procedure of SAS (SAS Inst., Cary, NC) with factors being examined at 3 levels of PS in the diets. Linear and quadratic effects were determined utilizing orthogonal contrasts for equally spaced treatments. Treatment effects were tested for linear and quadratic components with regards to PS supplementation levels. The FEC was log transformed and analyzed as repeated measures. There were no treatment × time interactions ($P > 0.10$) for FEC and BW changes, hence only main effects are reported in the result section. Animals were the experimental unit and treated as a random effect. The linear regression method was used to analyse the correlation between the molar proportions of VFA and ADG in g/goat per day (Fig. 1). Significance levels were predetermined as $P < 0.05$.

3. Results and discussion

3.1. Nutrient composition

The diets were formulated to meet or exceed dietary requirements (NRC, 2007). Ingredient and chemical compositions of the experimental diets are presented in Table 1. The chemical composition of the grain mix with PS combinations remained similar with varying level of PS in the diets. Level of CT in PS used in this experiment was similar to the values reported by Utley et al. (1993). The total concentration of CT in the PS was 16.1% DM. Total CT in the diet as % DM was 0.12, 2.4, and 4.9 for the 0, 15%, and 30% PS treatments. Both PS and ALP ingredients contained similar levels of NDF, ADF, and TDN, but ALP contained higher CP compared to PS.

3.2. Growth performance and rumen fermentation profiles

The DMI and growth performance are presented in Table 2, and rumen fermentation variables are presented in Table 3. The DMI, d 0 BW and d 45 BW were similar among treatments (Table 2). However, ADG ($P < 0.05$) and gain to feed (G:F) ratio increased linearly ($P < 0.01$) with the supplementation of PS. Moderate levels of CT in the diets (3% to 4% CT DM) can reduce protein digestion in the rumen and enhance protected protein flow to the small intestine (Min et al., 2003), thus facilitating more dietary protein in the

Table 2
Effects of levels of peanut skin (PS) supplementation on growth performance in meat goats.[1]

Item	Treatments				*P*-value	
	0 PS	15% PS	30% PS	SEM	Linear	Quadratic
n	7	7	7			
Feed intake						
DMI, g DM/d	914.7	895.0	912.8	29.46	0.64	0.12
Growth performance						
Day 0 BW, kg	44.8	45.1	45.1	2.38	0.62	0.86
Day 45 BW, kg	47.4	50.2	50.4	2.58	0.28	0.81
ADG, g/d	57.8	113.3	117.8	22.14	0.01	0.12
G:F ratio	0.06	0.12	0.12	0.01	0.01	0.15

[1] Based on orthogonal contrast for equal spaced treatments. Diets contained different levels of the condensed tannins containing PS replacing alfalfa pellets (ALP). Experimental treatments included 30% ALP (control diet), 15% PS and 15% ALP, and 30% PS and as fed basis. Peanut skin was incorporated in the grain mix portion of the diet and the mix was fed daily.

Table 3
Effects of levels of peanut skin (PS) supplementation on ruminal volatile fatty acid (VFA) and ammonia concentration profiles in the rumen in meat goats (%).[1]

Item	Treatments				*P*-value	
	0 PS	15% PS	30% PS	SEM	Linear	Quadratic
n	7	7	7			
Acetate, %	46.3	58.9	63.2	4.99	0.05	0.15
Propionate, %	10.2	14.9	16.6	1.29	0.001	0.37
Iso-butyrate, %	1.55	1.13	1.32	0.112	0.18	0.03
Butyrate, %	7.4	18.2	19.3	1.88	0.001	0.05
Iso-valerate, %	2.5	2.1	2.2	0.19	0.29	0.24
Valerate, %	1.03	1.27	1.35	0.10	0.05	0.51
Total VFA, %	63.0	96.5	104.1	8.07	0.01	0.32
A:P ratio	4.53	3.95	3.80	0.09	0.01	0.45
Ammonia-nitrogen, mg/dL	14.2	5.9	7.1	0.89	0.001	0.01

A:P ratio = acetate to propionate ratio.
[1] Based on orthogonal contrast for equal spaced treatments. Rumen fluid (10 mL) samples were collected once at d 45. Ruminal fluids were collected via stomach tubs 2 h after morning feeding, capped immediately, and stored at −20 °C until analysis later that day.

lower tract (Barry and McNabb, 1999). This is similar to the results obtained by Shipp et al. (2017) and Min et al. (2012), who found tannin-containing diets (2.0% to 3.2% CT DM) had a significant effect on DMI, ADG and carcass characteristics in meat goats. The improvement in ADG can be explained by the enhancement in the efficiency of G:F ratio (Min et al., 2012; Shipp et al., 2017) and greater protected protein flow to the lower tract in the tannin-rich PS supplemented group compared to the control group (Barry and McNabb, 1999). Other studies have found that intake of under 50 g CT per kg DM (<5% CT DM) improves the digestive utilization of dietary feed of ruminant animals, mainly due to a reduction in ruminal protein degradation and thus greater availability of amino acids, particularly essential amino acids, for absorption in the small intestine (Barry and McNabb, 1999; Min et al., 2003). However, Solaiman et al. (2010) stated that daily DMI of growing meat goats increased when tannin-rich sericea lespedeza (*Lespedeza cuneate*) replaced non-tannin-containing alfalfa meal in the grain mixes. In addition, Turner et al. (2005) and Min et al. (2012) stated that goats receiving the sericea lespedeza hay (2.3% CT DM) and ground pine bark (*Pinus taeda*; 1.6 to 3.2 CT DM) in the grain mixes (15% to 30% pine bark) had greater DMI than those fed the alfalfa hay-based diet or control diet (no CT diet), respectively. In addition, the CT extract from *Acasia mearnsii* (black wattle) at 2.5% of DM had no positive effects on ADG, G:F ratio, and carcass traits of feedlot cattle, but DMI was reduced when the concentration was increased to 3.5% (1.9% CT) of DM in beef steers (Koenig et al., 2018) and beef heifers (Koenig and Beauchemin, 2018) fed high protein diets containing corn distillers grains.

Treatments has similar iso-valerate, but total VFA ($P < 0.01$) linearly increased with increasing PS supplementation due to subsequently increasing molar proportions of acetate ($P < 0.05$), propionate ($P < 0.001$), butyrate ($P < 0.001$), and valerate ($P < 0.05$). There was a linear reduction of the acetate to propionate (A:P) ratio ($P < 0.001$) and ammonia-N ($P < 0.001$) as PS supplementation increased in goat diets (Table 3). Beauchemin et al. (2007) described that diets containing quebracho tannins (1% or 2% DM) in beef cattle decreased the proportion of acetate, A:P ratio, and ammonia-N concentration compared with the control diet without CT supplementation. The increased total VFA ($P < 0.01$; Table 3) concentration suggested that ruminal fermentation and nutrient utilization improved with PS supplementation in meat goats (Min and Solaiman, 2018). The decreased ruminal ammonia-N companied with the increased total VFA concentration suggested that microbial synthesis increased with PS supplementation. Ruminal cellulolytic bacteria use ammonia-N to synthesize microbial protein, and VFA provide C-skeletons energy for this process (Russell et al., 1992). Moreover, other studies indicated that increased ruminal VFA increased microbial protein synthesis *in vitro* and *in vivo* (Piva et al., 1988; Liu et al., 2009).

To further understand the effect of energy sources, as measured by VFA on ADG, the proportions of individual VFA and A:P ratio were regressed against ADG in meat goats (Fig. 2). We found that there is a positively correlation between ADG and percentage of butyrate ($y = 0.042x + 9.92$; $R^2 = 0.64$; $P < 0.001$) in the rumen, while negatively correlated between ADG and acetate ($y = -0.0293x + 67.063$; $R^2 = 0.56$: $P < 0.05$) and A:P ratio ($y = -0.0035x + 4.611$; $R^2 = 0.48$; $P < 0.05$). Feeding butyrate to young calves had a beneficial effect on gastrointestinal development and ADG (Niwińska et al., 2017). Furthermore, Guilloteau et al. (2009) compared supplementation of butyrate against the antibiotic and growth promoter Flavomycin in calf milk replacer. In this study, butyrate improved feed efficiency and ADG in calves by stimulating small intestine development, indicated by an improvement in villi length. Thus, increased butyrate concentration in the rumen of goats fed PS diet may accelerate rumen and intestinal development in growing young goats, thereby improving feed efficiency and enhancing ADG (Fig. 2).

It has been shown that as ruminal VFA production shifts toward more propionate at the expense of acetate, (i.e. a lower A:P ratio), more ADG was observed and presumably more energy was utilized for animal growth (van Nevel and Demeyer, 1996). One explanation for the results of the present study could be because bioactivity of CT in PS. Tannin analysis in PS revealed that epicatechins (13.4% DM) was the major unit in the total CT (16% CT DM; Min, unpublished data). This means that PS tannins were mostly procyanidins. However, ALP analysis resulted in 0.6% epicatechins on % DM for the dietary ingredients used in this study. Our findings and previous researches indicate that procyanidin content or procyanidin:prodelphinidin ratio in a CT may be important for determining the bioactivities of CT (Aerts et al., 1999; Schofield et al., 2001; Min et al., 2015c). The presence of gallate esters unit in tannins may also be important for their biological properties (Hagerman, 1992). In addition, reduced A:P ratios have also been associated with improved ADG (Waghorn and Barry, 1987; Min and Solaiman, 2018). The lower A:P ratios produced by tannin-rich PS diet in the present study is consistent with other studies regarding tannins in ruminant diets (Makkar et al., 1995; Min et al., 2015b; Min and Solaiman, 2018). It has been reported that an inhibition in cellulolytic bacterial activity in the presence of tannins is apparently a fundamental factor of such VFA shift for lowering the acetate production (Jayanegara et al., 2012). Black et al. (1987) reported that the efficiency of use of metabolizable energy is lower in ruminants fed forage-based diets for feed conversion per weight gain, with high A:P ratios. This inefficiency is due to insufficient nicotinamide adenine dinucleotide phosphate, a coenzyme produced from glucose metabolism, which allows for the acetate to be incorporated into body lipid. Beauchemin et al. (2007) reported that supplementation with quebracho tannins (1% to 2% CT DM) in beef cattle decreased the A:P ratios and ammonia-N concentration compared with the control group without CT supplementation. In agreement with previous studies, our results demonstrate that PS supplementation consistently decreased rumen ammonia-N concentration and A:P ratio, indicating the potential ability of CT in PS to modify rumen fermentation and bacterial activity (Min et al., 2014). Makkar (2003) and Schofield et al. (2001) indicated that CT have both beneficial (e.g. ADG and rumen fermentation) and adverse effects (e.g. reduced feed intake and digestibility) on growth performance depending on the composition, levels of CT and biological activity in the diets. Min et al. (2003) reviewed that beneficial effects of CT from CT-containing forages on sheep

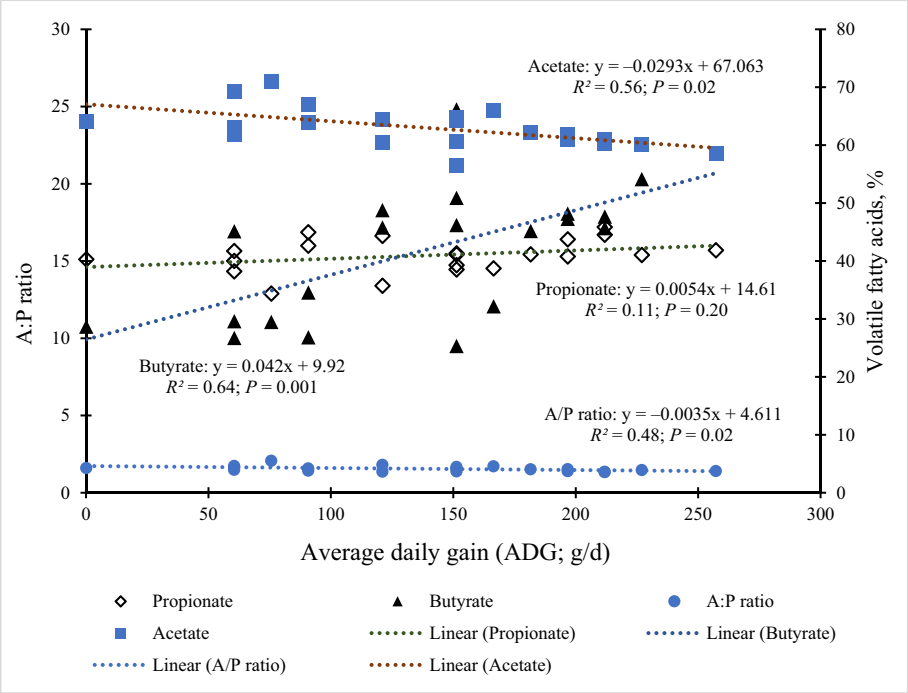

Fig. 2. Correlation ($n = 21$) between average daily gain, proportion of propionate, butyrate, acetate, and acetate to propionate (A:P) ratio in the rumen of meat goats fed tannin-containing peanut skin (PS) supplementation.

performance may occur in the range of 2% to 4% CT DM. However, sheep performance was negatively influenced when CT concentration was greater than 5% CT DM. Recently, however, Min and Solaiman (2018) reviewed that optimum levels of CT concentration in the meat goat diets may be 5% to 10% CT DM in terms of maximizing DMI in meat goats. This is could partially explain the higher ADG of goats receiving diets with 15% to 30% PS compared to those fed the control diet.

Aerts et al. (1999) and Molan et al. (2000) found that CT extracted from tannin-containing forages (e.g. *Lotus corniculatus*) protected soluble protein from degradation by mixed rumen microorganisms. Min et al. (2002) reported that sheep fed diets with the CT-containing forage *L. corniculatus* (3.2% CT DM) had lower populations of proteolytic bacteria and thus reduced proteolysis in the rumen. Moreover, CT-containing diets reduced ammonia-N concentrations in sheep (Christensen et al., 2016) and increased plasma essential amino acids out-flow from the rumen into the small intestine. In the present study, goats supplemented with PS had a linear reduction of rumen ammonia-N concentration compared to goats fed the control diet. In general, this reduction in protein degradation is associated with a lower production of ammonia-N and a greater non-ammonia-N flow into the duodenum (Barry and Manley, 1984; Waghorn, 1996). Increasing the greater microbial protein synthesis and decreasing degradability of dietary protein in the rumen are advantageous for ruminants as these processes increase the supply of non-ammonia-N to the lower intestine for production purposes, resulting in higher meat and milk production (Makkar, 2003). These effects lead to protein-sparing effects in ruminants and nitrogen excretion to the environment, thereby reducing emission of environmental pollutants while improving animal productivity. Using data obtained from *in vivo* study, Bach et al. (2005) reported that as efficiency of nitrogen utilization increases, ammonia-N accumulation in the rumen decreases. Therefore, it is important to design feeding strategies for CT-containing diets such as PS that exploit these beneficial effects.

3.3. Blood metabolites

The effect of levels of PS supplementation on blood serum chemistry in meat goats are presented in Table 4. Treatments had similar blood creatinine, urea-N, Ca, total protein, albumin, globulin, alanine transferase (ALT), alkaline phosphatase (ALKP), and gamma-glutamyl transferase (GGT), but serum glucose ($P < 0.05$), serum P ($P < 0.05$), and serum cholesterol were linearly increased ($P < 0.001$) with increasing levels of the PS supplementation. These results are in agreement with other studies (Frutos et al., 2000; Salem et al., 2011) indicating that quebracho CT (50 g/kg live weight [LW]) supplementation with alfalfa hay-based diet was not affected for blood plasma metabolites, i.e. ALKP, GGT, glutamic

Table 4
Effects of levels of peanut skin (PS) supplementation on blood serum chemistry in meat goats.[1]

Item	Treatments				*P*-value	
	0 PS	15% PS	30% PS	SEM	Linear	Quadratic
n	7	7	7			
Glucose, g/dL	17.1	22.4	24.1	2.18	0.05	0.51
Creatinine, IU/L	0.8	0.7	0.7	0.03	0.35	0.39
Urea-N, mg/dL	12.5	12.5	11.7	1.15	0.64	0.76
P, mg/dL	3.35	6.9	6.8	0.43	0.05	0.13
Ca, mg/dL	9.28	8.9	9.1	0.13	0.26	0.09
TP, g/dL	6.9	6.9	6.9	0.19	0.96	0.88
ALB, g/dL	2.6	2.8	2.8	0.11	0.13	0.55
GLB, g/dL	4.3	4.1	4.1	0.18	0.39	0.84
ALT, IU/L	11.3	14.3	15.1	2.04	0.21	0.68
ALP, IU/L	134.5	172.6	142.4	20.42	0.79	0.18
GGT, IU/L	44.8	53.4	54.7	4.82	0.16	0.55
CHOL, mg/dL	45.2	74.4	97.6	7.18	0.001	0.70

TP = total protein; ALB = albumin; GLB = globulin; ALT = alanine transferase; ALP = alkaline phosphatase; GGT = gamma-glutamyl transferase; CHOL = cholesterol.

[1] Based on orthogonal contrast for equal spaced treatments. Blood samples (5 mL) were collected, once at d 45.

oxaloacetic transaminase, and creatinine as indicators of liver and kidney functions in sheep and goats. However, changes in absorption of macrominerals or in digesta of animals fed a CT-rich diet were not consistent (Waghorn et al., 1994; Min et al., 2012; Acharya et al., 2016). It has been shown that a reduction in serum concentrations of trace minerals such as Mo, Mn, Zinc, and Se occurred in lambs fed CT-rich sericea lespedeza (*Lespedeza cuneate*) diet (Acharya et al., 2016). Elevated plasma glucose may be due to greater quantities of propionate generated from the rumen of goats as a precursor. However, the lack of differences in plasma urea despite differences in rumen ammonia-N could not be explained. In the present study, blood serum profiles (ALT, ALKP, GGT, etc.) were not influenced by the dietary treatments, which indicated that all values were within the normal range for goats.

In the present study, blood metabolites, especially cholesterol levels, increased with increasing PS supplementation up to 30%. Little is known about the effect of PS on elevated blood serum cholesterol in meat goats. The PS contained up to 19% fat (as a measured by ether extract) in our previous study (Stone et al., 2016). The possibility that the PS supplemented group in the present study may have received more dietary fat (not measured) compared to the control diet, may have resulted in the elevated blood cholesterol levels. As expected, the different amount of PS in the diets resulted in different concentrations of ether extract percentage in the diets ranging from 1.6% in control diet to 5.7% in 30% PS diet (Stone et al., 2016). In our previous study, Stone et al. (2016) reported that total saturated fatty acid and monounsaturated fatty acid increased linearly in LM fat, indicating that the blood cholesterol and fatty acid composition of goat carcasses can be altered with the addition of PS.

During processing of carcasses, no abnormalities or lesions were found by the USDA inspector on the liver and kidney (USDA, 2001; Silanikove and Tiomkin, 1992). Serum chemistry data obtained from the present study showed that the level of PS up to 15% to 25% or the level of CT up to 2.5% to 4.9% DM is safe and beneficial, with no detrimental effects in meat goat (Table 4). It was observed that sheep dosed intra-ruminally (0.75 g/kg BW per day) for 60 d remained healthy throughout the experiment, and no signs of intoxication were found either at necropsy or on histological examination (Frutos et al., 2000).

3.4. Carcass traits and meat color

The effect of different levels of PS supplementation on carcass traits and meat color in meat goats are presented in Tables 5 and 6. There were no differences ($P > 0.10$) in HCW, CCW, neck, shoulder, breast, rack, loin, frank, leg, hind shank, fat thickness, body wall, and pHamong treatments (Table 6), but there was a quadratic effect of treatment on meat color, specifically a* (redness; $P < 0.01$) and b* (yellowness; $P < 0.05$) values. Dressing percentage tended to decline ($P = 0.09$) with increased PS supplementation. Previous research reported that animals grazing on CT-containing diets such as sulla (*Hedysarum coronarium*; 5% to 7% CT DM) and birdsfoot trefoil (*L. corniculatus*; 3% to 4% CT DM) had greater carcass production compared to those grazing on alfalfa (*Medicargo sativa*; Hoskin et al., 1999; Wang et al., 1996). Additionally, quebracho CT supplementation (8.9% CT DM) increased a* values and reduced b* values of the lambs when compared to no-CT control group (Luciano et al., 2009).

In the present study, there were no differences in carcass traits (Table 5) and L* (lightness) value of meat color (Table 6) among treatments. However, a* and b* values responded quadratically to PS supplementation, indicating that diets containing moderate levels of CT in PS (2.4% CT DM) had affected meat colors. Results obtained by Solaiman et al. (2010) showed tannins in sericea lespedeza dried meal (0.2% to 2.2% CT DM) had no effect on carcass characteristics in meat goats during 63 d of the experimental period. Carcass characteristics are known to respond slowly to changes in nutrition and longer periods of PS supplementation maybe needed to exhibit any effects. Min et al. (1998) reported that 18 wk of CT-supplementation were necessary before the effect of CT on sheep performance were apparent.

Table 5
Effects of levels of peanut skin (PS) supplementation on selected carcass characteristics in meat goats.[1]

Item	Treatments				*P*-value	
	0 PS	15% PS	30% PS	SEM	Linear	Quadratic
n	7	7	7			
Fasting LW, kg	43.9	45.4	48.0	2.01	0.05	0.83
HCW, kg	26.9	26.0	28.0	1.01	0.51	0.28
CCW, kg	20.1	19.3	21.2	0.91	0.50	0.30
DP, %	61.0	57.0	58.0	2.28	0.09	0.67
Neck, kg	1.2	1.1	1.28	0.08	0.82	0.11
Shoulder, kg	6.1	5.8	6.5	0.33	0.51	0.23
Fore shank, kg	0.88	0.91	0.88	0.05	1.0	0.64
Breast, kg	0.32	0.29	0.36	0.05	0.39	0.21
Rack, kg	2.8	2.6	3.1	0.19	0.43	0.28
Loin, kg	1.8	1.8	1.9	0.16	0.65	0.63
Frank, kg	0.7	0.7	0.8	0.05	0.70	0.49
Leg, kg	4.9	4.6	5.1	0.29	0.71	0.19
Hind shank, kg	1.2	1.2	1.3	0.08	0.32	0.52
Fat depth, cm	0.7	0.7	0.8	0.19	0.78	0.96
Body wall, cm	2.8	2.6	3.9	0.62	0.23	0.31

LW = live weight; HCW = hot carcass weight; CCW = chilled carcass weight; DP = dressing percentage.
[1] Based on orthogonal contrast for equal spaced treatments. At the end of the experiment, goats were weighed, transported (2 h), fasted for 24 h, reweighed (empty body weight), and then humanely slaughtered at Meat Science Laboratory, Fort Valley State University, GA.

Table 6
Effects of levels of peanut skin (PS) supplementation on L*, a* and b* of longissimus muscle from meat goats measured 48 h postmortem and meat pH in meat goats.[1]

Item	Treatments				*P*-value	
	0 PS	15% PS	30% PS	SEM	Linear	Quadratic
n	7	7	7			
L* value	34.1	35.9	35.6	1.06	0.36	0.43
a* value	12.4	11.4	12.6	0.35	0.65	0.01
b* value	7.0	5.7	7.1	0.60	0.89	0.05
pH	6.5	6.4	6.4	0.07	0.36	0.57

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).
[1] Based on orthogonal contrast for equal spaced treatments.

3.5. Fecal egg counts and adult worm counts

The effect of different dose levels of PS supplementation on FEC and on adult worm counts in meat goats are summarized in Table 7. Average FEC ($P < 0.05$) and *H. contortus* adult worm prevalence in abomasum were linearly reduced ($P < 0.001$) when goats received PS supplementation. The repeated measurement of FEC results showed significantly differences among treatment groups on d 40 of the experiment. This might be explained by the reduction of the adult worm populations by this time. Also, the results confirm that the effect of the CT-rich PS diet may need prolonged time to amplify their effects on the *H. contortus*. Strategies for control of gastrointestinal parasites utilizing non-synthetic chemicals have recently been suggested based on tannin-rich forages (Min et al., 2003; Min and Hart, 2003). Min et al. (2005a; 2012) reported that there was a direct or indirect effect of CT-containing diets (e.g. sericea lespedeza, pine bark) on FEC and adult worm numbers compared to

Table 7
Effects levels of peanut skin (PS) supplementation on adult worm counts and fecal egg counts (FEC) in meat goats.[1]

Item	Treatments				*P*-value	
	0 PS	15% PS	30% PS	SEM	Linear	Quadratic
n	7	7	7			
Haemonchus contortus, per L	14.0	3.5	4.1	0.51	0.001	0.001
Average FEC, per g feces	1,950.0	1,242.8	557.1	321.10	0.05	0.34
Log FEC						
Day 0	2.98	3.07	2.79	0.133	0.62	
Day 13	2.96	2.59	2.65	0.261	0.34	
Day 23	2.76	2.97	2.89	0.196	0.44	
Day 41	3.19	2.85	2.68	0.141	0.05	

[1] Based on orthogonal contrast for equal spaced treatments.

goats fed non-CT diets. The present study strongly supports this view, showing that meat goats consuming PS diets up to 30% or CT levels up to 4% CT DM reduced adult worm counts, fecal egg counts as measured by FEC ($P < 0.05$) compared to those receiving non-CT diets. These results may be due to the direct effects of CT in PS on the *H. contortus* cuticle (Min et al., 2018a) and/or an indirect effect through stimulation of the host immune pathways (Hoste et al., 2006; Min et al., 2018b) and improved protein nutrition (Min et al., 2003) against infection with intestinal parasites. This effect of CT on parasite explains the results seen in this study; however, more research should be conducted for a longer period of time to examine supplementation of PS in grazing small ruminants.

4. Conclusions

This study has highlighted that dietary supplementation of goats with CT-containing PS has the potential to increase ADG, to reduce the burden of gastrointestinal parasites, and therefore warrants further investigation regarding its effects. Present results indicate that the optimum level of PS supplementation ranges from 15% to 30% PS (as-fed basis) or CT levels of from 2.4% to 4.9% DM in the diet have potential to be an anti-parasitic agent or an energy supplement in feeds.

Conflicts of interest

The authors declare no conflicts of interest.

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