Research Article

iMedPub Journals
http://www.imedpub.com

DOI: 10.21767/2572-5459.100005

Journal of Animal Research and Nutrition
ISSN 2572-5459

2015
Vol. 1 No. 1:5

Effect of plant tannin-containing diet on fatty acid profile in meat goats

Min, B.R.[1], Solaiman, S.[1], Taha, E.[1] and Lee, J [2].

1 Department of Agricultural and Environmental Sciences, Tuskegee University, Tuskegee, AL, USA
2 Department of Animal Science, Fort-valley State University, Fort-valley, GA, USA

Corresponding author: B.R. Min

minb@mytu.tuskegee.edu

Citation: Min, B.R, Solaiman, S, Taha E, et al. Effect of plant tannin-containing diet on fatty acid profile in meat goats. J Anim Res Nutr. 2015, 1: 1.

Abstract

Phytochemical plant tannins are phenolic compounds that interfere with biohydrogenation (BH) of monounsaturated-(MUFA) and poly-unsaturated fatty acids (PUFA). The objective of the present animal study was to investigate the effects of three different levels of phytochemical tannin-containing ground pine bark diet on fatty acid profiles of goat meat, with particular reference to MUFA and PUFA. The saturated fatty acids (SFA), PUFA, and PUFA/SFA ratios in subcutaneous adipose tissue as well as MUFA and PUFA composition of mesenteric kidney fat were increased with increasing phytochemical tannin-containing ground pine bark supplementation. The study showed that phytochemical plant tannins could be a means to moderate the accumulation of unsaturated fatty acids with the aim of improving percentage of these PUFA/SFA ratios in goat meat. The effects would be useful to improve carcass fatty acids composition and human health.

Keywords: Goats, Fatty acids, Meat, Tannins

Received: November 01, 2015, **Accepted:** November 21, 2015, **Published:** December 04, 2015

Introduction

The effect of phytochemical condensed tannins (CT) on the nutritive value, animal performance, carcass evaluation of forages and on the health of grazing ruminant animals have been investigated (Min et al., 2003; Solaiman et al., 2010; Min et al., 2012). Goats fed a diet containing CT up to 30% DM ground pine bark (PB) have also been shown to increase dry matter intake (DMI), average daily gain (ADG), improve meat tenderness, and overall consumer acceptability of goats loin (Min et al., 2012, Leick et al., 2012), but CT containing-PB supplementation in relation to fatty acid profile and lipid oxidation state has not been conducted in goats.

Recently, Min et al. (2012) have described improved animal performance and ADG in goats fed phytochemical CT-containing ground PB (0, 15, and 30% PB/kg of DMI), while linearly decreased rumen ammonia-N, acetate, and acetate to propionate ratio. Acetic acid is utilized as the major source of acetyl-CoA for synthesis of lipids in ruminants (Hanson and Ballard, 1967). Hanson and Ballard (1967) reported that considerable amounts of [^{14}C] acetate are incorporated into fatty acids synthesis and are associated with acetyl-CoA synthetase enzyme in ruminant liver. Min et al. (2014) reported that tannins containing ground PB diet had a detrimental effect on survival of certain rumen microorganisms. Rumen bacteria are responsible for biohydrogenation of dietary polyunsaturated fatty acids (PUFA), the products of which include conjugated linoleic acid (CLA) and saturated fatty acids (SFA; Priolo and Vasta, 2007). It has been shown that feeding tannins to ruminants can favorably alter ruminal biohydrogenation of dietary linoleic acid, enhancing accumulation of trans-11 18:1 (vaccenic acid) in the rumen and thereby the content of some human health promoting fatty acids, such as vaccenic acid and rumenic acid (Toral et al., 2011). If hydrogenation is reduced, the potential for oxidation of PUFA in the tissue may be increased as a result of feeding dietary tannins. Conversely, derivatives of tannins extracts directly added to ground beef have been shown to have antioxidant effects and reduce lipid oxidation of cooked patties (Ahn et al., 2006). Subsequent work has been shown that thiobarbituric acid reactive substances (TBARS) for 30% PB diet were less than that of 0% PB diet. (Leick et al., 2012). However, reports on impacts of these phenolic compounds on meat fatty acids profile are very limited and inconsistent. The objective of this experiment was to assess the effects of a partial replacement of ground wheat straw (WS) with CT-containing PB on a potential utilization of PB as feed replacement on fatty acids composition and lipid oxidation state in goats associated with different level of PB powder diets.

Materials and Methods

The animals used in this study were cared for according to the

Live Animal Use in Research Guidelines of the Institutional Animal Care and Use Committee of the Tuskegee University (Tuskegee, AL).

Animals and diets

Twenty-two Kiko crossbred male goat kids (*Capra hircus*; initial BW = 27.5 ± 1.04 kg) were used in this study during 83 days. Goat kids, approximately 5 month of age, were blocked by body weight and randomly assigned to the experimental treatment groups in a randomized complete block design experiment. Goats were individually housed indoors in pens of approximately 1.2 x 2 m with elevated floors and were fed grain mixes with different amounts of ground PB (*Pinus taeda* L.) and Bermuda grass hay (BGH; *Cynodon dactylon*) at 85:15 on an as-fed basis. An adjustment period of 3 weeks allowed goats to become acclimated to pen living and routine feeding and to allot time for proper diet adjustment before the start of the study. Experimental diets (**Table 1**) were isonitrogenous and contained different amounts of the CT-containing ground PB replacing ground wheat straw (WS; *Triticumaestivum*). Experimental treatments included the control diet (0% PB), 15% ground PB, and 30% ground PB on an as-fed basis. Experimental diets contained corn (20%), soybean meal (19.5%), alfalfa meal (4%), molasses (6%), and vitamins and minerals (0.5%).

The fresh PB was donated by a wood-processing company (West Fraser Timber Co. Ltd, Opelika, AL) and air dried under the shed before processing. Freshly dried PB (10.25% CT) was ground (Hammer Mill Model 1250; Lorenz MFG Co., Benson, MN) to approximately 3 mm particle size before mixing with the remaining ingredients of the diets. The WS (0.03% CT) was also ground (3 mm) and incorporated in the grain mix portion of the diets. Concentration of CT in 15% PB and 30% PB diets was 1.63% and 3.2% DM, respectively (**Table 1**). Mixtures containing ground PB and WS were commercially prepared at the local feed mill (Eclectic Feed Mill, Eclectic, AL). Experimental diets met requirements of all animals for growth and BW gain according to the NRC (2007).

Animals were fed once a day at 0800 h and had free access to water and a trace mineral salt block. Grain mixes and hay were offered separately, and refusals were recorded daily. Feed intake and refused feed were treated as daily repeated measures for 83 days for growth performance and body weight gain efficiency determination.

Sample collection and laboratory analysis

Diet samples were collected every 2 week. Composite samples for grain mixes and ingredient samples for BGH, PB, and WS (n = 3) were 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, standard model 4, Arthur Thomas Co., Philadelphia, PA). Ground composite samples were analyzed for DM, lignin, and minerals according to the methods described by AOAC (1998). Crude protein was determined using a Kjeldahl N method (AOAC, 1998) by multiplying nitrogen by 6.25. Dietary neutral detergent fiber (NDF; N included) and acid detergent fiber (ADF) were sequentially determined using an ANKOM200 Fiber Analyzer (ANKOM Technology, Macedon, NY) according to the methodology supplied by the company, which is based on the methods described by Van Soest et al. (1991). Acetone (70%) extractable CT in grain mixes was determined using a butanol-HCl colorimetric procedure (Terrill et al., 1992).

Carcass samples of subcutaneous adipose muscle and mescentric kidney tissue (MKF) postmortem were taken for fatty acid analysis. Samples of subcutaneous adipose tissue from the region of the ninth rib were vacuum-packed and stored at −20°C until analysis. Fatty acids profile was determined by gas chromatography (GC; HP 5890 Series II, autosampler 7673, HP 3365 ChemStation; Hewlett-Packard Co., Avondale, PA, USA) with a flame ionization detector in accordance with procedures established by Noci et al. (2007). The thiobarbituric acid reactive substances (TBARS) test was used to quantify the amount of malondialdehyde (MDA; ng/g) of fresh meat. Total fat content in the diet as a measured by ether extract was analyzed according to the methods described by AOAC (1998). Individual fatty acids profile in the diet was not conducted because total fat content (ether extract) was similar among diets (**Table 1**).

Statistical analysis

Data were analyzed by the Mixed Model procedure of the SAS (SAS, Inst., Inc., Cary, NC) for completely randomized design with the factors examined being three levels of PB supplementation in the diets. Linear and quadratic effects were determined utilizing poly-nominal orthogonal contrasts for equally spaced treatments (Min et al., 2012). Animals were the experimental unit and were treated as a random effect. The variables included were diet-composition, feed intake, and fatty acids profile. Data are presented as LS mean values together with the standard error of the mean (SEM).

Results

Chemical composition of diets

Diets were isonitrogenous and isocaloric but differed in NDF, lignin, and CT concentrations; lignin and CT concentrations were greater in 15% and 30% PB rations, whereas NDF concentration was decreased compared with control diet (**Table 1**). Total fat content as measure by ether extract was similar between BGH and ground PB (1.65 vs. 1.5% DM), but fatty acids profiles were different. Saturated fatty acids (28.94 vs. 19.68% DM) and PUFA (47.21 vs. 21.67 %DM) were higher in BGH than the ground PB, but MUFA were lower in BGH than ground PB.

Intake and growth performance

Body weight and dry matter intake (DMI) of Kiko crossbred goats are summarized in **Table 2**. Total DMI (linear; $P = 0.001$) was increased as ground PB increased in the diets. There was no difference in initial BW of goats among treatments; however, final BW tended to increase ($P = 0.06$) linearly as the level of ground PB increased in the diets (**Table 2**). Diet containing 30% ground PB had higher total DMI when compared to other treatments.

Table 1 Mean chemical compositions and fatty acids profiles (%) of the pine bark (PB), wheat straw (WS), bermudagrass hay (BGH), and experimental diets fed to Kiko crossbred male goat kids.

		Ingredient		Experimental diet			
Item	PB	WS	BGH	Control	15% PB	30% PB	SEM
----------- (%) ---------------							
Chemical composition	% DM (n = 3)						
DM	83.6	83.5	91.4	86.6	86.2	85.8	0.77
CP	1.2	4.14	7.3	15.3	15.7	14.9	0.41
NDF	78.6	79	69.2	41.6	39.7	38.7	1.77
ADF	72.1	49.2	37.3	29.8	32.5	35.7	1.47
Ether extract	1.65	0.42	1.5	2.5	2.5	3.2	0.25
Condensed tannins	10.2	0.03	0.04	0.19	1.63	3.2	0.14
Fatty acid, %							
C12:0	0.43	-	2.41	-	-	-	-
C13:0	0.1	-	0.8	-	-	-	-
C13:1n9	0.07	-	0.37	-	-	-	-
C14:0	0.91	-	3.75	-	-	-	-
C14:1n5	0.06	-	0.67	-	-	-	-
C15:0	-	-	0.58	-	-	-	-
C16:0	10.55	-	18.66	-	-	-	-
C16:1n7	0.46	-	1.54	-	-	-	-
C17:0	0.75	-	0.7	-	-	-	-
C18:0	8.22	-	6.53	-	-	-	-
C18:1n9	27.6	-	11.2	-	-	-	-
C18:2n6	18.81	-	20.71	-	-	-	-
C18:3n3	2.51	-	26.23	-	-	-	-
C20:0	2.97	-	1.82	-	-	-	-
C20:1n9	0.3	-	1.62	-	-	-	-
C20:5n3	0.35	-	0.27	-	-	-	-
Unidentified	17.61	-	-	-	-	-	-
C22:0	7.41	-	0.7	-	-	-	-
C22:5n3	0.28	-	0.32	-	-	-	-
SFA	29.94	-	19.68	-	-	-	-
MFA	14.36	-	28.36	-	-	-	-
PUFA	47.21	-	21.67	-	-	-	-

Control or 0% PB, 15% PB, and 30% PB as-fed basis. Except Bermuda grass hay, all ingredients were incorporated in the grain mixes.
SFA= saturated fatty acid =(C14:0+C16:0+C18:0+C20:0).
MFA=Monounsaturated fatty acid = (C17:1+C18:1+C20:1).
PUFA- polyunsaturated fatty acid = (C18:2+C18:3+C20:2+C20:3+C20:4+C22:4).

Fatty acids profile and lipid oxidation

Fatty acids profile in subcutaneous adipose tissue and MKF samples are summarized in **Tables 3 and 4**, respectively. Present research showed that the SFA (linear; $P < 0.01$) and PUFA (linear; $P < 0.008$) in subcutaneous adipose tissue (**Table 3**) were increased but PUFA/SFA ratios were decreased ($P < 0.03$) with increasing ground PB supplementation. Mono unsaturated fatty acids tended to be higher ($P < 0.10$) in goats fed ground PB diet as compared to control. Fatty acids percentages increased linearly ($P < 0.05$-0.01) for 10:00, 14:00, 16:00, 18:00, 18:1 n-7c, 18:1 n-7t, 18:2 n-6c, 18:3 n-3, and 20:2 n-6 compared to control diet.

The MUFA and PUFA composition of MKF (**Table 4**) were increased (linear; $P < 0.01$) with increasing ground PB supplementation. However, SFA and PUFA/SFA ratios in MKF were not affected by feeding PB diet. These results indicated that goats receiving PB supplementation produced carcasses with more MUFA and higher PUFA. Fatty acids percentages increased linearly ($p < 0.05$-0.01) for 13:1, 16:1t, 16:10, 17:00, 18:1 n-9c, 18:1 n-7c, 18:3 n-6c, and 22:6 n-3 in goats receiving PB diets compared to control diet. These changes were characterized by an increase in PUFA with 18C and a concomitant increase in most medium chain saturated fatty acids (10:0 to 17:0), which is unknown at this point and need further study. The TBARS increased from d 1 to d 5 of storage ($p < 0.001$), but were not affected by ground PB diet (**Table 5**).

Discussion

Available reports on impacts of tannin consumption on milk and meat fatty acids profile are inconsistent. In addition, plant extracts such as grape seed, green tea, pine bark, rosemary, pomegranate and cinnamon have exhibited similar or better antioxidant properties compared to some synthetic ones.

Table 2 Effects of pine bark (PB) supplementation on body weight (BW) change and dry matter intake (DMI) of Kiko crossbred male goat kids.

	Diets				P values‡	
	Control	**15% PB**	**30% PB**	**SEM**	**Linear**	**Quadratic**
Initial BW, kg	27.4	27.5	27.3	1.04	0.97	0.91
Final BW, kg	34.9	37	38	1.29	0.06	0.89
DMI, (g/d)	1279.3	1320.1	1509.2	54	0.001	0.3

Control = 0% pine bark (PB), 15% PB, and 30% PB on as-fed basis. Number of animals was 8, 7, and 7 in control, 15% PB, and 30% PB diet, respectively.
‡Polynomial contrasts for equally spaced treatments.

Table 3 Effects of pine bark (PB) on fatty acids composition (mg/g of tissue) of subcutaneous adipose tissue from Kiko crossbred male goat kids.

	Diets†				P values‡	
Item	Control	15% PB	30% PB	SEM	Linear	Quadratic
Number of animals	8	7	7			
10:00	1.8	2	2.7	0.32	0.04	0.52
C13:1	1.3	1.2	0.9	0.21	0.27	0.91
14:00	41.7	46.5	61.1	6.07	0.03	0.54
14:01	3.4	2.8	2.4	0.66	0.29	0.87
15:00	12.9	13.8	15.9	2.34	0.37	0.83
16:00	340.2	402.6	496.1	43.81	0.02	0.78
16:1t	7.8	8.8	10.6	1.14	0.1	0.79
16:10	34.5	36.1	48.9	8.01	0.21	0.58
17:00	30.7	35.6	37.6	4.7	0.31	0.81
17:10	23	22.7	30.4	6.07	0.39	0.61
18:00	312.2	385.5	443.6	45.5	0.05	0.89
18:1n9c	657.4	758.7	931.6	98.19	0.06	0.78
18:1n7c	16.8	18.8	25.3	2.75	0.04	0.52
18:1n7t	4.1	4.3	6.4	0.85	0.06	0.42
18:2n6t	7.5	8.5	11.3	1.37	0.06	0.59
18:2n6c	29.6	35.2	51.1	5.01	0.006	0.43
18:3n3	2.9	3.3	4.4	0.44	0.03	0.47
18:3n6c	1.5	1.9	2	0.59	0.56	0.89
20:00	0.4	0.5	0.9	0.24	0.12	0.65
20:2n6	0.6	1.2	2.8	0.74	0.04	0.58
20:4n6	3.3	3.2	4.5	0.47	0.06	0.27
22:6n3	0	0	0	0	0	0
SFA	694.8	835.1	1001.7	85.05	0.01	0.91
MFA	89.9	99.3	122.5	14.3	0.1	0.71
PUFA	45.6	53.3	76.3	7.47	0.008	0.43
PUFA/SFA	52	24.4	4.55	0.003	0.03	0.1

†Control = 0% pine bark (PB), 15% PB, and 30% PB on as-fed basis. Number of animals was 8, 7, and 7 in control, 15% PB, and 30% PB diet, respectively.
‡Polynomial contrasts for equally spaced treatments.
SFA= saturated fatty acid =(C14:0+C16:0+C18:0+C20:0).
MFA=Monounsaturated fatty acid = (C17:1+C18:1+C20:1).
PUFA- polyunsaturated fatty acid = (C18:2+C18:3+C20:2+C20:3+C20:4+C22:4).

Diet supplementation with 0.7% DM of quebracho CT extract resulted in no change in the fatty acid composition of bovine milk (Benchaar and Chouinard, 2009). In contrast, cows or sheep grazing tannin containing legume forages (3-4% CT DM), showed changes in the milk content of 18 C fatty acids when polyethylene glycol was supplemented, indicating that tannins could be responsible for a decrease (Turner at al., 2005) or an increase (Cabiddu et al., 2009) in the extent of ruminal biohydrogenation of dietary PUFA to 18:0. Min et al. (2012) reported that rumen acetate and acetate:propionate ratios, and ammonia-N were reduced with increasing PB supplementation. Beauchemin et al. (2007) reported that supplementation with quebracho CT (1 or 2% DM) in beef cattle decreased the molar proportion of acetate, acetate: propionate ratio, and rumen ammonia-N concentration compared with control group without CT supplementation. Corresponding to the previous studies, our results demonstrated that CT-containing ground PB supplementation consistently decreased the rumen ammonia-N concentration and acetate:

Table 4 Effects of pine bark (PB) on fatty acids composition (mg/g of tissue) of mescentric kidney fat (MKF) from Kiko crossbred male goat kids.

Item	Diets†			SEM	*P* values‡	
	Control	15% PB	30% PB		Linear	Quadratic
Number of animals	8	7	7			
10:00	1.9	1.3	2.6	0.42	0.29	0.12
C13:1	23.1	31.7	41.9	2.36	0.001	0.8
14:00	0.1	0.3	2.5	0.81	0.11	0.45
14:01	4.1	4.2	4.9	0.35	0.12	0.56
15:00	0.04	0.59	0.23	0.28	0.66	0.23
16:00	0.06	0.01	0.01	0.03	0.31	0.54
16:1t	8.3	10.6	13.8	0.89	0.001	0.65
16:10	6.01	6.4	7.6	0.49	0.05	0.53
17:00	4.7	5.4	6.7	0.54	0.03	0.74
17:10	1.8	1.8	1.4	0.22	0.19	0.38
18:00	0	0	0	0	-	-
18:1n9c	271.9	345.4	470.1	24.58	0.001	0.43
18:1n7c	2	2.3	3.6	0.27	0.003	0.21
18:1n7t	0.05	0.01	0.01	0.02	0.31	0.54
18:2n6t	0	0	0	0	-	-
18:2n6c	0	0	0	0	-	-
18:3n3	0.5	0.07	0.01	0.38	0	0.12
18:3n6c	0.47	0.007	0.1	0.13	0.03	0.33
20:00	0	0	0	0	-	-
20:2n6	0	0	0	0	-	-
20:4n6	0	0	0	0	-	-
22:6n3	1022.9	1239.6	1571.3	84.6	0.001	0.61
SFA	0.15	0.32	2.15	0.81	0.12	0.44
MFA	21.2	24.7	31.7	2.02	0.003	0.54
PUFA	7.8	7.8	9.8	0.42	0.006	0.09
PUFA/SFA	169.9	96.3	116.4	47.5	0.47	0.46

†Control = 0% pine bark (PB), 15% PB, and 30% PB on as-fed basis. Number of animals was 8, 7, and 7 in control, 15% PB, and 30% PB diet, respectively.
‡Polynomial contrasts for equally spaced treatments.
SFA= saturated fatty acid =(C14:0+C16:0+C18:0+C20:0).
MFA=Monounsaturated fatty acid = (C17:1+C18:1+C20:1).
PUFA- polyunsaturated fatty acid = (C18:2+C18:3+C20:2+C20:3+C20:4+C22:4).

Table 5 Effects of pine bark (PB) on the thiobarbituric acid reactive substances (TBARS) test as measured with the amount of malondialdehyde (MDA; ng/g) concentration of fresh meat in Kiko crossbred male goat.

	Diets†				P values‡	
Item	Control	15% PB	30% PB	SEM	Linear	Quadratic
Number of animals (n)	8	7	7	-	-	-
D 0	55.38	51.43	37.21	12.86	0.52	0.41
D 5	107.1	119.1	92.3	26.6	0.58	0.32

† Control = 0% pine bark (PB), 15% PB, and 30% PB on as-fed basis. Number of animals was 8, 7, and 7 in control, 15% PB, and 30% PB diet, respectively.
‡Polynomial contrasts for equally spaced treatments.

propionate ratio, indicating the ability of plant CT to modify rumen fermentation and bacterial community composition (Min et al., 2003). In addition, predominant hindgut archeal species among methanogens were *Methanobrevibacter*, *Methanosphaera,* and *Methanobacteriaceae* population in control, 15, and 30% PB, respectively (Min et al., 2012), and they were linearly decreased ($p<0.05$) or increased ($p<0.05$) with increasing PB concentration. One of the possible explanations for the decreased in *Methanobrevibacter* spp. prevalence are assumed to be linked to the substantial relationship between these archaea and protozoa (Histrove et al., 2012) and the protozoa and subsequent reduction in reducing equivalent (H_2) cross-feeding between archaea and protozoa (Shi et al., 2012). Vasta et al., (2009) reported that the concentration of PUFA was greater and SFA less in the longissimus muscle from lambs fed the tannin-containing diets (4% CT DM) as compared with the animals receiving the tannin-free diets. These results confirm, in vivo, that tannins-containing diets reduce ruminal biohydrogenation, as previously reported. This implies that tannin supplementation could be a useful strategy to increase the rumenic acid and PUFA content and to reduce the SFA in ruminant meats, in agreement with our results. Fatty acids percentages linearly increased for 10:00, 14:00, 16:00, 18:00, 18:1 n-7c, 18:1 n-7t, 18:2 n-6c, 18:3 n-3, and 20:2 n-6 in PB supplemented goats compared to control diet. This may suggest the ineffectiveness of the type of tannins used, the level of dosage rate, or both, at exerting major effects on rumen biohydrogenation, while most temporal changes in meat fatty acids profile were likely explained by the presence of level of CT in the diet.

Moreover, MUFA and PUFA composition of MKF were increased with increasing PB supplementation. These results indicated that goats receiving PB supplementation produced carcasses with more MUFA and higher PUFA. These changes were characterized by an increase in PUFA with 18C and a concomitant increase in most medium chain saturated fatty acids (10:0 to 17:0), which is unknown at this point and need further study.

Antioxidants are used to minimize the oxidative changes in meat and meat products. The TBARS increased from d 1 to d 5 of storage ($p<0.001$), but were not affected by PB diet. Tannins may serve to impede muscle oxidation during storage serving to increase shelf life of whole muscle products. It has been shown in rats consuming high-tannin sorghum, to have lowered markers of protein oxidation in rat muscle after 6 d of refrigerated storage (Larrain et al., 2007). Du et al. (2002) showed higher a* (redness) values in thigh patties after 7 d storage at 4 ◦C from chickens fed 10% high-tannin sorghum. This antioxidant effect of dietary tannins may assist to improve meat product acceptance by maintained redness and decreased oxidation. Evidence of this work was not found in the present study, but may have research merit as tannin supplementation in finishing beef and small ruminants may help to meet product stability expectations of the consumer as well as being a “natural” product.

Although goats can tolerate relatively high levels of phytochemical tannins, supplemental tannin-containing forages in goat’s diet is accepted as an important factor affecting feed intake. Solaiman et al. (2010) reported that total DMI of growing goats increased when tannin-containing Sericea lespedeza (*Lespedeza cuneata*) ground hay (6.5% CT in DM) replaced alfalfa meal in the grain mixes, and Turner et al. (2005) reported that goats receiving the CT-containing Sericea lespedeza hay (23.1 mg CT/g soluble protein) had higher DMI than those fed the alfalfa hay based diet. This may be attributed to the fact that goats naturally prefer browse that contains phytochemical secondary compounds including tannins and other alkaloids. In addition, animals previously exposed to plant secondary compounds eat much more secondary compounds-containing feeds than inexperienced animals (Villalba et al., 2004).

Min et al. (2003) reported that beneficial effects of CT in the diet on sheep performance may occur in the range of 2 to 4% CT of diet DM. However, the wool growth response was negative when the CT concentration was above 5% CT of diet DM. Conversely, when CT concentration decreased below 2 % of diet DM, the production response was variable. This may partially explain why the growth performance of goats in the present study was improved for those goats receiving diets containing 15 (1.63% DM CT) and 30% (3.2% DM CT) PB compared with control diet (0.19% DM CT). In addition to the effect of CT in ground PB on intake and growth performance, one may assume that changes in chemical composition of the diets by replacing WS with PB may have affected DMI and digestibility and consequently the animal performance. Min et al. (2014b; unpublished data) have found that ground PB supplementation replaced with WS did not affected total DM digestibility, but the NDF, ADF, and lignin digestibility linearly decreased as PB was increased in the diet. Acid detergent fiber and lignin have a primary effect on reducing digestibility (Van Soest, 1994).

Pine bark is one of the abundant timber industry by-products in the USA and it is only $38/ton in a local timber company (Opelika, AL). If we include PB as a feed ingredient up to 30% of total diets, it is only requires $11.40 PB/ton. Therefore, it has potential for economic and nutritional benefit to modify carcass meat quality. The current study indicated that plant tannins could be a means to moderate the accumulation of USFA with the aim of improving percentage of these PUFA/SFA ratios in goat meat. The effects would be useful to improve carcass fatty acids composition and human health.

Acknowledgement

This project was supported by the Sustainable Agriculture Research and Education (SARE) program, which is funded by the U.S. Department of Agriculture National Institute of Food and Agriculture (USDA-NIFA), the USDA/NIFA Evans-Allen Research Program and Tuskegee University, George Washington Carver Agricultural Research Station.

References

1 Ahn J, Grün I.U, & Fernando L.N (2006). Antioxidant Properties of Natural Plant Extracts Containing Polyphenolic Compounds in Cooked Ground Beef. Journal of Food and Science 67: 1364-1369.

2 AOAC (1998). Official Methods of Analysis, [16thedn.] Assoc. Official Analytical Chemistry Gaithersburg, MD.

3 Barry T.N, & McNabb W.C (1999). The implications of condensed tannins on the nutritive value of temperate forages fed to ruminants. British Journal of Nutrition 81: 263-272.

4 Benchaar C, and Chouinard P.Y (2009). Assessment of the potential of cinnamaldehyde, condensed tannins, and saponins to modify milk fatty acid composition of dairy cows. Journal of Dairy Science 92: 3392-3396.

5 Cabiddu A, Molle G, Decandia M, Spada S, Fiori M, et al. (2009). Responses to condensed tannins of flowering sulla (Hedysarum coronarium L.) grazed by dairy sheep. Part 2: Effects on milk fatty acid profile. Livestock Science 123: 230-240.

6 Du M, Cherian G, Stitt P.A, & Ahn D.U (2002). Effect of dietary sorghum cultivars on the storage stability of broiler breast and thigh meat. Poultry Science 81: 1385-1391.

7 Hanson R. W, & Ballard F.J (1967). The relative significance of acetate and glucose as precursors for lipid synthesis in liver and adipose tissue from ruminants. Biochemistry Journal 105: 529-536.

8 Hagerman A. E, Robbins C.T, Weerasuria Y, Wilson T.C, & McAarthur C, et al. (1996). Tannin chemistry in relation to digestion. Journal of Range Management 45: 57-62.

9 Hristov A.N, Callaway T.R, Lee C, & Dowd S.E (2012). Rumen bacterial, archaeal, and fungal diversity of dairy cows in response to lauric or myristic acids ingestion. Journal of Animal Science 90: 4449-4457.

10 Larrain R.E, Richards M.P, Schaefer D.M, Ji L.L, & Reed J.D, et al. (2007). Growth performance and muscle oxidation in rats fed increasing amounts of high-tannin sorghum. Journal of Animal Science 85: 3276-3284.

11 Leick C. M, Broadway P.R, Solaiman A, & Behrends J.M (2012). Quality and consumer acceptability of salt and phosphate enhanced goat loin from goats fed varying levels of pine bark. Meat Science 90: 665-669.

12 Min B. R, & Hart H.P (2003). Tannins for suppression of internal parasites. Journal of Animal Science 81 (E. Suppl. 2), E102-E109.

13 Min B. R, Barry T.N, Attwood G.T, & McNabb W.C (2003). The effect of condensed tannins on the nutrition and health of ruminants fed fresh temperate forages: a review. Animal Feed Science and Technology 106: 3-19.

14 Min B.R, Solaiman S, Gurung N, Behrends J, Eun J.S, et al. (2012). Effects of pine bark supplementation on performance, rumen fermentation, and carcass characteristics of Kiko crossbred male goats. Journal of Animal Science 90: 3556-3567.

15 Min B.R, Solaiman S, Shange R, & Eun J.S (2014). Gastrointestinal bacterial and methanogenic Archaea diversity dynamics associated with condensed tannins-containing pine bark diet in goats using 16S rDNA amplicon pyrosequencing. International Journal of Microbiology. Volume 2014, Article ID 141909, 11 pages.

16 Noci F, French P, Monahan F.J, & Moloney A.P (2007). The fatty acid composition of muscle fat and subcutaneous adipose tissue of grazing heifers supplemented with plant oil-enriched concentrates. Journal of Animal Science 85: 1062-1073.

17 NRC (2007). Nutrient Requirement of Sheep, Goats, Cervids, and Camelids. Academy Press. Washington, D.C.

18 Priolo A, & Vasta V (2007). Effects of tannin-containing diets on small ruminant meat quality. Italian Journal of Animal Science 6: 527-530.

19 Satter L. D, & Slyter L.L (1974). Effect of ammonia concentration on rumen microbial protein production in vitro. British Journal of Nutrition 32: 199-208.

20 Shaik S. A, Terrill T.H, Miller J.E, Kouakou B, Kannan G, et al. (2006). Sericea lespedeza hay as a natural deworming agent against gastrointestinal nematode infection in goats. Veterinary Parasitology 139: 150-157.

21 Shi X, Xiao C, Wang Y, & Tang H (2012). Gallic acid intake induces alterations to systems metabolism in rats. Journal of Proteome Research, 12: 991-1006.

22 Silanikove N, & D. Tiomkin (1992). Toxicity induced by poultry litter consumption: effect on parameters reflecting liver function in beef cows. Animal Production 54: 203-209.

23 Silanikove N, Gilboa N, Perevolotsky A, & Nitsan Z (1996). Goats fed tannin-containing leaves do not exhibit toxic syndromes. Small Ruminant Research 21: 195-201.

24 Solaiman S, Thomas J, Dupre Y, Min B.R, Gurung N, et al. (2010). Effect of feeding sericea lespedeza hay on growth performance, blood metabolites, and carcass characteristics of Kiko crossbred male kids. Small Ruminant Research 93: 149-156.

25 Toral P. G, G. Hervas, E. Bichi, A. Belenguer, & P. Frutos, et al. (2011). Tannins as feed additives to modulate ruminal biohydrogenation: effects on animal performance, milk fatty acid composition and ruminal fermentation in diary ewes a diet containing sunflower oil. Animal Feed Science and Technology. 164: 199-206.

26 Terrill T.H, Rowan A.M, Douglas G.B, & Barry T.N (1992). Determination of extractable and bound condensed tannin concentrations in forage plants, protein concentrate meals and cereal grains. Journal of Science Food and Agriculture 58: 321-329.

27 Turner K. E, Wildeus S, & Collins J.R (2005). Intake, performance, and blood parameters in young goats offered high forage diets of lespedeza or alfalfa hay. Small Ruminant Research 59: 15-23.

28 Van Soest P. J (1994). Integrated feeding systems. In: Van Soest, P.J. (ed.), Nutritional Ecology of the Ruminant. 2nd ed. Cornell Univ. Press, Ithaca, New York. 402-424.

29 Van Soest P. J, Robertson J.B, & Lewis B.A (1991). Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74: 3583-3597.

30 Vasta V, Mele M, Serra A, Scerra M, Luciano G, et al. (2009). Metabolic fate of fatty acids involved in ruminal biohydrogenation in sheep fed concentrate or herbage with or without tannins. Journal of Animal Science 87: 2674-2684.

31 Villalba J.J, Provenza F.D, & GouDong H (2004). Experience influences diet mixing by herbivores: Implications for plant biochemical diversity. Oikos 107: 100-109.