Global Veterinaria 15 (6): 570-578, 2015
ISSN 1992-6197

DOI: 10.5829/idosi.gv.2015.15.06.10144

A Disparity Effect of Polyethylene Glycols on Comparative Feed Efficiency and Growth Performance of Sheep and Goats Fed High Tannin Diet

[1]*Kibreab Yoseph,* [2]*Yisehak Kechero and* [3]*Taye Tolemariam*

[1]Bonga Agricultural Research centre, P.O. Box 96, Bonga, Ethiopia
[2]Department of Animal Sciences, Arba Minch University, P.O. Box 21, Arba Minch, Ethiopia
[3]College of Agriculture and Veterinary Medicine, Jimma University, Jimma, Ethiopia

Abstract: It is commonly thought that typical grazers have evolved with tannin free diets have little reason for coping high tannin diets but browsers (e.g. goats), which generally consume a wide variety of tannin containing trees and shrubs, are known to deal with tannins. Supplementation with tannin-complexing agents are considered to enhance the feeding value of high tannin feeds and overcoming the detrimental effects of tannins. The study was, therefore, conducted to compare the effects dietary application of tannin-binding agents (Polyethylene glycol 4000 and 6000 ((PEG)) on nutrient use efficiency and growth performance of Bonga sheep (Grazer) and Kaffa goats (Browser) received high tannin diets. A randomized crossover design with 2 animal species, 3 diets and 3 periods (15d adaptation + 10d collection) was used. The dietary treatments consisted of a high tannin diet: 36% *Albizia schimperiana* (AS) + 9% *Ficus elastica* (FE) + 55% hay (=tan); Tan+PEG_{4000} (=tPEG_{4000}) and Tan+PEG_{6000} (=tPEG_{6000}). Animals were individually fed at 50 g DM/kg BW and had free access to clean drinking water and mineralized salt licks. The condensed tannin (CT) contents of AS and FE were 110 and 191 g/kg DM, respectively. Goats ate 8% more CP in Tan than sheep and protein which further increased by 5 and 6% in tPEG_{4000} and tPEG_{6000}, respectively, with clear difference in effect size between goats and sheep as well as PEG types (P<0.001). The effect of CT addition (Tan) was higher for nutrient digestibility in goats than in sheep (P<0.05), pointing to a better coping with the tannins by goats than sheep. Additionally, PEG addition induced a larger improvement in nutrient digestibility in sheep than in goat (P<0.001). However, the addition of PEG_{6000} had a bustling advantage over PEG_{4000} regarding the technical performance in both species (P<0.001). This study demonstrated that also in a tropical setting, goats' digestion seems better adapted to tannin-rich diets than sheep. This confirms earlier statements on the differences between browsers and grazers, although the difference in performance is sounded as clear. The addition of PEG as a tannin-binder improved digestion and performance in both species, but with the highest effect size in sheep.

Key words: Goat · Nutrient Digestibility · Nutrition · Polyethylene Glycol · Sheep · Tannin

INTRODUCTION

Small ruminant production is the main source of income of farmers living in arid, semiarid [1] and semi-humid regions of the world [2, 3]. Sheep and goats raised in these areas are generally confronted with severe nutritional deficits throughout the year which intensify health problems and consequently low productive and reproductive performances [4, 5]. The feed shortage is exacerbated by the continuous increase of feedstuffs' prices, grazing land degradation and frequent and extended drought periods [1, 6].

Innovative technologies targeting the increase of feed resources availability, improving diets' quality, lessening of feeding cost could be considered as options to improve small ruminant-based production systems in tropical regions. Several tannin rich fodder trees and shrubs (TRFTS) [7, 8] have high protein contents and are potentially promising to overcome nutrient deficiencies. This is because they do not compete with human food and can provide significant protein supplements [9] throughout the year [10]. However, these feed resources are generally rich in antinutritional factors, particularly tannins. The CT values above 100 g/kg DM in tanniferous

Corresponding Author: Yisehak Kechero, Department of Animal Sciences, Arba Minch University, P.O. Box 21, Arba Minch, Ethiopia.

diets reduce nutrient digestibility when present in the diet of ruminants [11, 12] ultimately leading to depressed animal performance [9].

The detrimental effects of tannins can be enhanced by simple methods based on supplementation with tannin-binding agents [9, 13]. Recently there is a need to use TBAs for neutralizing the negative effects of tannins on performance of ruminant animals [14-16].

No report has been published so far on nutrient utilization and growth performance of the tannin rich foliage sources with comparison of both types of TBAs, polyethylene glycol MW4000 and 6000 (PEG) in goats vs. sheep elsewhere. Consequently it would be possible to increase the nutritive value of TRFTS by adding compounds such as PEG which preferentially binds the tannins, making plant proteins more available for digestion. This strategy would be very useful in situations where feedstuffs contain high concentrations of tannins. The relatively low dose of PEG (40 mg for 1kg of CT) for smallholder farmers encouraged to be considered as more cost effective means of administering PEG, thereby economizing in the use of this tannin-neutralizing agent. Therefore, the present trial was aimed to assess the comparative nutrient use and growth performance of sheep and goats supplemented with two types of PEG in the diets containing high concentration of CT.

MATERIALS AND METHODS

The Feed Sampling Area: The leaves of tannin rich A. schimperiana and *F. elastica* were collected from the Kitimbile village of Kersa district (7° 45' 0? N, 37° 5' 0? E, altitude 1782 meters), Jimma zone, south western Ethiopia. The climate where *A. schimperiana* and *F. elastica* trees are grown is characterized as semi-humid tropical with bimodal heavy rainfall, ranging from 1000 to 3000 mm per year. In the last twenty years, annual minimum and maximum temperature of the area were 10°C and 30°C, respectively. According to Driessen *et al*. [17] the most common soil types around the study area are nitisols and planosols.

Collection and Preparation of Experimental Diets: The basal diet (Hay) was collected from Kito-Furdisa campus of Jimma University natural pasture site with the coordinate points 037°039’55”N, 37°48’57” E and altitude of 1705m. The botanical composition of the natural pasture hay was assessed directly before harvest and the percent biomass was expressed as dry matter basis following [18]. The hay was composed of about 50% *Poaceae*, 31% *Asteraceae*, 18.5% *Fabaceae*, 0.5% *Cyperaceae* and *Juncaceae*. The natural pasture was cut when the majority of plants attained 50% flowering stage and let dry for 7 days to have average 90% DM. The hay was stored in bales under shade until use as the basal diet.

A. schimperiana and *F. elastica* were selected because of their higher crude protein content, superior fodder biomass, wide distribution in the study region and many other tropical countries and because are commonly consumed by browsers [19]. Fresh leaves of A. schimperiana and *F. elastica* were hand plucked from 30 randomly selected farm grown trees from one farm site with average age of 3.5±0.12 years. Leaves from the different trees were pooled together and taken to, Small Ruminant Research facility of Jimma University College of Agriculture and Veterinary Medicine within 40 minutes. After arrival, the fresh leaves were spread on a plastic sheet and left to dry for about 7 days under shade (25°C). After air drying (≥ 90% DM), leaves were packed in polythene bags (15 kg DM per bag) and stored under cover until use as the test diet. This drying approach was chosen because oven drying of CT- rich feeds, even at temperatures below 60×C, is known to polymerize tannins and increase neutral detergent fiber (NDF), fiber bound nitrogen and lignin contents [9].

Animals, Experimental Design, Feed Management and Sample Collection: Six intact male Bonga lambs (22.2 ± 2.90 kg) and 6 Kaffa goats (23.1 ± 1.50 kg) and of 1 year of age on average were used. The sheep and goats were purchased from Seka local livestock market in the Jimma zone/southwest Ethiopia. Care was taken to minimize variation in age determined by dentition and birth history. Animals were allowed to adapt to the experimental conditions and basal diet for one month. Prior to experiment, the animals were dewormed and vaccinated against common diseases of small ruminants especially against gastro-intestinal parasites in the study area. Pens were in a well-ventilated shed with one side open to natural light and roofing to protect animals against sun and rain. They were randomly housed in individual holding pens (1.5 × 2.5 m^2) with concrete floors on an open-air platform.

Table 1: Treatment combinations used in the experiment

Treatment	Composition
T_1	*Albizia schimperiana* (36%) + *Ficus elastica* (9%) + hay (55%)
T_2	*Albizia schimperiana* (36%) + *Ficus elastica* (9%) + hay (55%) + PEG_{4000}
T_3	*Albizia schimperiana* (36%) + *Ficus elastica* (9%) + hay (55%)+ PEG_{6000}

T_1, treatment one; T_2, Treatment two; T_3, treatment three

The experimental design was a randomized 2×3 crossover trial (Table 1), with 21 days for each period, two weeks for adaptation and one week for data collection. In the beginning and last day of each of the experimental periods, all animals were weighed individually following overnight fasting and data for the next period were recalculated according to BW. Body weight was measured using a manual weighing balance which was calibrated manually and body weight was recorded after the animals stand calmly on it.

During the whole experimental trial, animals had free access to clean drinking water. Total diets composed of pasture hay (55%) and test diets (36% were leaves of *A. schimperiana* and 9 % were leaves of *F. elastica*) were given to the animals at an estimated 50 g DM/kg LW daily [20]. Test diets were provided once daily at 8:00AM prior to the provision of basal diet (Pasture hay) at 10:00 AM in a separate trough individually prepared for each pen. The offered and refused amounts of all feeds were recorded to estimate the actual voluntary feed intake for each treatment. Every sheep and goat received PEG at a rate of 40 mg PEG 4000 (PEG_{4000}) or PEG 6000 (PEG_{6000}) to 1.0 kg of AS + FE [12] after mixing it with water at a rate of 0.5 g PEG/ml [21]. In general, the daily diet (basal + supplement) was balanced to provide 8.36 MJ/kg metabolisable energy and 70 g/kg crude protein on dry matter basis [22].

To assess total diet digestibility total fecal collection was performed. For this, sheep and goats were fitted with fecal collection bags using harnesses. Animals were allowed to adjust to the fecal collection bags 3 days before true collection. Feces were quantitatively collected on a daily basis from each animal, weighed and 10% was sub-sampled, pooled on animal basis per period and frozen (-20°C) until chemical analysis. Feed leftovers were removed daily at 08:00 AM and weighed. During the collection period, samples of test and basal diets and refusals were collected, composited by animal per period, ground (1 mm screen) and kept frozen (-20°C) until laboratory analysis.

Chemical Analysis of Feed and Feces: Samples of feedstuffs and feces were analyzed for dry matter, crude protein, crude ash, crude fibre and ether extract contents according to AOAC [23] guidelines and for neutral detergent fiber, acid detergent fiber according to Van Soest *et al*. [24]. For chemical analysis (Excluding N), the feces samples were oven dried at 105 °C for 24 h. Non-oven dried but well-mixed feces were directly used for N analyses. All chemical analyses were carried out in duplicate.

Determination of total extractable CT was based on oxidative depolymerization of CTs in butanol-HCl reagent using 2% ferric ammonium sulfate in 2N HCl catalyst [25]. All chemical analyses were carried out in duplicate.

Calculations: The crude protein content (CP/kg) was calculated as:

$$CP\ (g/kg\ DM) = \%\ N \times 6.25 \times 10 \quad [eq.1]$$

Where, 6.25 is the protein-nitrogen conversion factor for forages and mixed feedstuffs

Average daily gain *(*ADG*)* was calculated as:

$$ADG\ (g/day) = [Weight\ at\ end\ of\ trail\ (g) - weight\ at\ start\ of\ trial\ (g)]/days\ in\ trial \quad [eq.\ 2]$$

Daily feed intake (DFI) was calculated as:

$$DFI = Total\ feed\ consumed\ (g)/\ days\ in\ trial \quad [eq.3]$$

Feed conversion ratio (FCR) was calculated as:

$$FCR = Feed\ consumed\ (g)/body\ weight\ gained\ (g) \quad [eq.4]$$

Metabolic mid weight (MMW) was calculated as:

$$MMW = [(Weight\ at\ start\ of\ trial\ (kg) + weight\ at\ end\ of\ trial\ (kg))/2]^{0.75} \quad [eq.5]$$

Apparent digestibility of nutrients in diets content (g/kg) was calculated as:

$$[(Nutrient\ consumed\ (g) - Nutrient\ excreted\ (g))/\ Nutrient\ consumed] \times 1000)) \quad [eq.6]$$

Metabolizable energy intake (MEI) (kJME/kg $BW^{0.75}$) was estimated according to Luo *et al*. [26] as:

$$MEI = 533 + (43.2 \times ADG\ (g/kg\ BW^{0.75})) \quad [eq.7]$$

Metabolisable energy (ME, MJ/Kg DM) contents of total diets were predicted from the equations of Abate and Meyer (1997)[27] as:

$$ME = 5.34-0.1365CF + 0.6926NFE - 0.0152NFE^2 + 0.0001NFE^3 \quad [eq.8]$$

Protein efficiency ratio (PER), McDonald *et al*. [28] was determined as follow:

$$PER = \%\ Protein\ in\ diet \times weight\ of\ diet\ consumed \quad [eq.9]$$

Statistical Analysis: The 2×3 factors ANOVA was followed according to repeated measures design. Data was analyzed using mixed model procedures (PROC MIXED) of SAS version 9.3. Duncan's multiple range test procedure was used to obtain differences between means. Mean differences were considered significant at $P \leq 0.05$. The appropriate statistical model is indicated below:

$$Y_{ijk} = \mu + A_i + B_j + C_k + AC_{ik} + BC_{ik} + \sum_{ijk}$$

Where, Y_{ijk} = the response due to the animal i; in period j; received treatment k; μ = the overall mean effect; A_i = the fixed effect of the i^{th} sheep or goat (subject; i = 1, 2, 3… 6); B_j = the random effect of the j^{th} collection period (j = 1, 2, 3); C_k = the fixed effect of the k^{th} treatment (k = 1, 2, 3); AC_{ik} = the fixed interaction effect between species i and treatment k; $\sum_{ijk}$ = the random error.

RESULTS

Table 2 presents the chemical composition of basal and test diets. Despite their high amount of CT (110 and 191 g CT/kg DM), the CP content of *A. schimperiana* and *F. elastica* leaves were 459% and 313% higher than that of the basal diet (Hay). Condensed tannins were not expected to be present in the hay based on earlier observations [10].

Average daily intakes of nutrients are presented in Table 3. The DMI of goats fed T_1 (Hay, 55% + *A. shimperiana,* 39% + *F. elastica,* 9%) was found to be significantly higher (P<0.001) than sheep fed the same diet. The highest DMI (P<0.001) was recorded for sheep

Table 2: The chemical composition (g/kg DM) and metabolisable energy content (MJ ME/kg DM) of the feedstuffs used in the study

Diet sources	DM	Ash	OM	EE	CP	NDF	ADF	ADL	CT	ME
Hay	904	117	883	39	63	653	511	129	-	9.74
A. schimperiana	900	77	923	31	289	417	309	110	110	8.50
F. elastica	901	111	889	29	197	445	314	103	191	9.15

DM, dry matter; OM, organic matter; EE, ether extract; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; CT, condensed tannin; ME, metabolisable energy

Table 3: Least square means compared for daily nutrient (g/ kg DM /d) and energy intake (MJ ME/kg DM) in Bonga sheep and Kaffa goats fed hay supplemented with or without leaves of tannin-rich trees with polyethylene glycol

		Treatment, mean				P		
Nutrients	Species (L)	T_1	T_2	T_3	SEM	L	T	L×T
DM	S	916^b	962^b	990^b	1.245	<0.001	<0.001	<0.001
	G	925^a	976^a	996^a	1.113	<0.001	<0.001	<0.001
CP	S	91^b	161^b	176^b	2.021	<0.001	<0.001	<0.001
	G	98^a	169^a	185^a	1.024	<0.001	<0.001	<0.001
EE	S	20^b	24^b	24^b	2.203	<0.001	<0.001	<0.001
	G	22^a	25^a	25^a	1.213	<0.001	<0.001	<0.001
OM	S	731^b	809^b	812^b	3.253	<0.001	<0.001	<0.001
	G	735^a	814^a	817^a	3.243	<0.001	<0.001	<0.001
ADF	S	359^b	397^b	438^b	4.082	<0.001	<0.001	<0.001
	G	380^a	412^a	471^a	1.542	<0.001	<0.001	<0.001
NDF	S	370^b	410^b	460^b	5.245	<0.001	<0.001	<0.001
	G	397^a	430^a	490^a	3.551	<0.001	<0.001	<0.001
ME	S	876^b	943^b	949^b	4.442	<0.001	<0.001	<0.001
	G	885^a	947^a	957^a	3.253	<0.001	<0.001	<0.001

DM, dry matter; CP, crude protein; EE, ether extract; OM, organic matter, ADF, Acid detergent fiber; NDF, neutral detergent fiber; ME, metabolisable energy; SEM, standard error of mean; DF, degree of freedom; T, treatment; P, period; S, sheep; G, goats; L, subject (species); L×T, interaction effect of species and treatment; [a,b]Means with different superscripts in the same column are significantly different (P< 0.05);***P<0.001

Table 4: Least square means for apparent digestibility of nutrients (%) compared between Bonga sheep and Kaffa goats fed hay with or without mixes of tannin-rich trees leaves with PEG

		Treatment, %				P		
N000utrients	Species (L)	T_1	T_2	T_3	SEM	L	T	L×T
DM	S	59[b]	63[b]	66[b]	1.306	<0.001	<0.001	<0.001
	G	68[a]	69[a]	77[a]	2.012	<0.001	<0.001	<0.001
CP	S	53[b]	65[b]	67[b]	0.553	<0.001	<0.001	<0.001
	G	65[a]	69[a]	72[a]	2.041	<0.001	<0.001	<0.001
EE	S	56[b]	63[b]	63[b]	1.442	<0.001	<0.001	<0.001
	G	58[a]	64[a]	64[a]	1.353	<0.001	<0.001	<0.001
OM	S	61[b]	65[b]	67[b]	2.156	<0.001	<0.001	<0.001
	G	63[a]	66[a]	69[a]	0.306	<0.001	<0.001	<0.001
NDF	S	50[b]	52[b]	56[b]	1.356	<0.001	<0.001	<0.001
	G	53[a]	55[a]	63[a]	0.354	<0.001	<0.001	<0.001
ADF	S	40[b]	42[b]	45[b]	1.356	<0.001	<0.001	<0.001
	G	45[a]	47[a]	51[a]	1.132	<0.001	<0.001	<0.001

DM, dry matter; CP, crude protein; EE, ether extract; OM, organic matter; NDF, neutral detergent fiber; ADF, Acid detergent fiber; SEM, standard error of mean; T, treatment; L, subject (species); L×T, interaction effect of species and treatment; [a,b]Means with different superscripts in the same column are significantly different (P<0.001);***P<0.001

Table 5: Least square means for ADG (g/day), FCR (g DMI/ g ADG) and PER (g ADG/g CP) compared between Bonga sheep and Kaffa goats fed hay with or without leaves of tannin-rich trees with or without PEG

		Treatment, mean				P		
Parameters	Species(L)	T_1	T_2	T_3	SEM	L	T	L×T
ADG	S	16[b]	31[b]	37[b]	0.124	<0.001	<0.001	<0.001
	G	22[a]	36[a]	41[a]	0.113	<0.001	<0.001	<0.001
FCR	S	49[b]	30[b]	26[b]	0.203	<0.001	<0.001	<0.001
	G	57[a]	35[a]	31[a]	0.186	<0.001	<0.001	<0.001
PER	S	0.16[b]	0.19[b]	0.21[b]	0.315	<0.001	<0.001	<0.001
	G	0.19[a]	0.27[a]	0.29[a]	0.211	<0.001	<0.001	<0.001

ADG, average daily weight gain; FCR, feed conversion ratio (DM intake /ADG); PER, protein efficiency ratio; SEM, standard error of means, T, treatment; L, subject (species); L×T, interaction effect of species and treatment; L×T, interaction effect of treatment and period; [a,b]Means with different superscripts in the same column are significantly different (P< 0.001); ***P<0.001

and goats fed with T_3 (Hay, 55% + *A. shimperiana,* 39% + *F. elastica,* 9% + PEG_{6000}) compared to T_2 (T_1 + PEG_{4000}). In the current trial, feeding T_3 significantly improved DMI of sheep and goats compared with other treatments (*P*<0.001). Treatments combined with PEG_{4000} had also improved the DMI of sheep and goats compared to T_1, though the effect was greater for goats compared with sheep (*P*<0.001). Differences in DMI were also highly significant (*P*<0.001) among species×treatment interaction.

Apparent digestibility coefficients (The weights of nutrients digested as proportions of the weight consumed) of the test and basal diets is presented in Table 4. In sheep, apparent DM digestibility (DMD) was higher for T_3 (*P*<0.001) compared with other treatment groups. Similarly in goats, the DMD for T_3 was also found to be highest value compared to other dietary treatments (*P*<0.001). Goats showed superior digestion capacity of DM than sheep fed the same diet, T_1 through T_3 and the lowest values were recorded for (T_1) (*P*<0.001). Similar to DMD, sheep had higher OMD (67%) (*P*<0.001) fed T_3 compared to other dietary treatments. On the other hand, goats fed T_3 showed the same trend i.e., higher OMD (69%) was recorded with T_3, compared to other treatments (*P*<0.001). The CP digestibility (CPD) was also significantly improved (*P*<0.001) for both animal species after feeding *A. shimperiana* and *F. elastica* with T_3 than browse species alone (T_1) or with T_2. There were also highly significant differences in sheep and goats (Table 4), overall CPD values were found to be higher in goats (P<0.001). The ADF digestibility (ADFD) and NDFD values were varied significantly among treatments and animal species where the highest fiber digestibility values are recorded for goats (P<0.001). When fed T_3, sheep performed higher NDFD (56%) compared to T_1 which showed the lowest NDFD (50%). Goats also performed highest NDFD (63%, P<0.001) when fed in with T_3 compared to other treatments. The interaction effect between species, treatment and period was also found to be significant for ADFD and NDFD (P<0.001).

Sheep supplemented T_3 showed the highest ADG (37 g/day) followed by T_2 whereas sheep fed the high tannin diet (T_1) gained 16 g/day (P<0.001) (Table 5). Whereas, goats fed T_3 showed the highest average daily weight gain (41 g/day) compared to other treatments even as goats fed (T_1) gain only 22g/day (P<0.001). Mean daily weight changes as shown in Table 5 were also highest in goats compared to sheep for all dietary treatments (P<0.001). The PEG inclusion with high tannin feedstuffs improved weight gain and feed conversion ratio both in sheep and goats, yet the overall values were singly higher for goats (P<0.001). Although goats can make better use of tannins in comparison to sheep, PEG inclusion further improved their daily weight gain, feed conversion ratio and protein efficiency ratio considerably (P <0.001).

DISCUSSION

The CP contents of tannin-rich test diets are by far above the minimum daily CP requirement of small ruminants to support the optimum microbial activity in the digestive tract (70-80 g CP/kg DM) [28, 29]. The intake of roughages is limited when their CP content is less than 100 g/kg DM [10, 30]. The threshold level of NDF in tropical forages beyond which DM intake of ruminants affected is 600 g NDF/kg [31] suggesting that both of the test diets had acceptable NDF values. Tree forages with a low NDF content (200–350 g/kg) are usually of high digestibility [31]. Although the test diets had a high concentration of CTs (>100 g/kg DM), the dietary inclusion of PEG could alleviate the inhibitory effects of CTs against nutrient use efficiency. Higher tannin levels (>50 g/kg DM) become highly detrimental [21,33] as they reduce digestibility of fiber in the rumen by inhibiting the activity of bacteria and anaerobic fungi, high levels also lead to reduced intake. Brooker *et al*. [34] also reported that ruminants consuming tannin-rich diets usually develop a negative nitrogen and energy balance and lose weight and body condition unless supplemented with non-protein nitrogen, carbohydrate and minerals.

The substantial improvement of DMI in sheep and goats after PEG inclusion in high CT containing treatments could be associated with the tannin deactivating capacity of PEG_{6000} and PEG_{4000}. The superior performance of PEG_{6000} treated groups in deactivating tannins from tannin rich browses compared to PEG_{4000} might be associated to high affinity of tannins to PEG_{6000}. Yisehak *et al*. [12] confirmed the better *in vitro* fermentation performances of tannin-rich feedstuffs after incubation with PEG_{6000} compared to several tannin binding agents such as PEG_{4000}, polyvinyl polypyrrolidone (PVPP) and polyvinyl pyrrolidone (PVP). The higher NDFI intake of goats with or without PEG compared to sheep might be associated with the better CP utilization ability of goats on tannin rich diets compared with sheep. Efficient protein utilization in goats can stimulate proliferation of fibre degrading bacteria in the digestive tract of goats. It suggests that goats are more efficient in the digestion of crude fibre and the utilization of poor roughages than sheep. In general, the improved capacity of goats consuming high-tannin browses and detoxifying the tannins as compared to sheep under comparable conditions might be associated with the evolutionary adaptation of goat breeds to tannin rich browses in tropical environments through secretion of special tannin binding proteins [35].

The superiority in apparent DM digestion coefficients of goats over sheep for all treatments might be associated with goat's digestive physiology which appears to be associated with lower retention of ingested feeds [36]. Similarly, the supplementation of PEG_{6000} could lead to efficient utilization of protein in the rumen rather than escaping as by-pass protein because of tannin-binding. The tannin adapting physiological features in goats could be linked to a large absorptive area of their rumen epithelium and a capacity to change the volume of the foregut rapidly in response to environmental changes. The low CPD both in sheep and goat for non-PEG treated diets might be associated with protein binding effects of CTs. Several researchers have reported a reduction in protein digestibility in ruminants fed diets containing high levels of CTs without tannin binding agents [10, 37, 38]. In addition to complexion with dietary proteins, CTs combine with and hinder digestibility of cellulose, hemicelluloses and pectin either by preventing microbial digestion or by directly inhibiting cellulolytic micro-organisms [39].

Goats showed a better fibre digestibility over sheep which reflects a better adaptation of the species to particular environmental tannin load. This might be also attributed to their longer retention time of digesta in the rumen. Although goats are considered as opportunistic feeders with a very flexible foraging behavior, they are the most appropriate animals to utilize the high-fibre, low nitrogen forage produced on shrub lands and woodlands [40]. It is likely that the improved daily weight gain and feed conversion efficiency of PEG_{6000} supplemented sheep and goats is due to the binding ability of CTs by PEG resulting in greater availability, digestion and absorption of nutrients contributed for the best average daily weight gain of experimental animals.

The best performance of goats in ADG, FCR and PER compared to sheep across all treatments might be associated with better nutrient utilization efficiency of goats to tanniferous and fibrous feed sources. Within grazers, we were able to demonstrate a salivary adaptation to tannin-rich diets in zebu (*Bos indicus; evolved in tannin-rich environment*) versus *Bos indicus* × *Bos taurus (Evolved in low-tannin environment)* [41, 42]. Yet, if a similar adaptation would have occurred in the studied sheep, the extent was still much lower than what was observed in the goats.

CONCLUSION

The comparison between goats and sheep that both evolved in a tannin-rich environment revealed that when fed tannin-rich diets, goats scored better than sheep for particular features such as protein digestibility although the overall performance was not distinctly different between both species. Strategies that reduce the dietary tannin load, such as PEG supplementation, therefore have a slightly better impact on overall performance in sheep than in goats in tropical conditions.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the VLIR-UOS institutional university cooperation (IUC-JU) program for funding the research budget.

REFERENCES

1. Abidi, S., H. Ben Salem and V.P.A. Vasta, 2009. Spineless cactus (*Opuntia ficus indica* f. inermis) cladodes in the diet of lambs and kids: Digestion, growth and intramuscular fatty acid composition. Small Ruminant Research, 87: 9-16.
2. Devendra, C., 2013. Investments on Pro-poor Development Projects on Goats: Ensuring Success for Improved Livelihoods. Asian-Australasian Journal of Animal Sciences, 26(1): 1.
3. Aboul-Naga, A., Mona A. Osman, V. Alary, F. Hassan, I. Daoud and J.F. Tourrand, 2014. Raising goats as adaptation process to long drought incidence at the Coastal Zone of Western Desert in Egypt. Small Ruminant Research. DOI: 10.1016/j. Smallrumres.
4. Hernandez, I. and M.D. Sánchez, 2014. Small ruminant management and feeding with high quality forages in the Caribbean, 2014. Inter-American Institute of Cooperation in Agriculture (IICA). Santo Domingo, Dominican Republic, pp: 122.
5. Diego Valbuena, Sabine Homann-Kee Tui, Olaf Erenstein, Nils Teufel, Alan Duncan, Tahirou Abdoulaye, Braja Swain, Kindu Mekonnen, Ibro Germaine and Bruno Gérard, 2014. Identifying determinants, pressures and trade-offs of crop residue use in mixed smallholder farms in Sub-Saharan Africa and South Asia. DOI: 10.1016/j.agsy.2014.05.013
6. Martinele, I., G.R.A. Santos, D.S. Matos, A.M.V. Batista and M. D'Agosto, 2010. Diet botanical composition and rumen protozoa of sheep in Brazilian Semi-Arid area. Arch. zootec, 59: 226.
7. Rahim, I., J.I. Sultan, M. Sharif and M.Q. Bilal, 2013. Chemical composition, mineral profile, palatabiltiy and *in vitro* digestibility of shrubs. The Journal of Animal and Plant Sciences, 23(1): 45-49.
8. Khan, M.A., M.H. Ammar, H.M. Migdadi, E.H. El Harty, M.A. Osman, M. Farooq and S.S. Alghamdi, 2015. Comparative nutritional profiles of various faba bean and chickpea genotypes. Int. J. Agric. Biol., 17: 449-457.
9. Makkar, H.P.S., 2003. Effects and fate of tannins in ruminant animals, adaptation to tannins and strategies to overcome detrimental effects of feeding tannin-rich feeds. Small Ruminant Research, 49: 241-256.
10. Yisehak Kechero, Taye Tolemariam and Aynalem Haile, 2013. Characteristics and Determinants of Livestock Production in Jimma Zone/Southwestern Ethiopia. African Journal of Basic and Applied Sciences, 5(2): 69-81.
11. Jayanegara, A., F. Leiber and M. Kreuzer, 2011. Meta-analysis of the relationship between dietary tannin level and methane formation in ruminants from *in vivo* and *in vitro* experiments, DOI: 10.1111/j.1439-0396.2011.01172.x.

12. Yisehak, K., K. Biruk, B. Abegaze and Geert P.J. Janssens, 2014. Growth performance, nutrient digestibility and carcass evaluation of Bonga sheep fed tannin rich diet (*Albizia gummifera*) with or without polyethylene glycol. Tropical animal health and production-Springer, 46(7): 1113-1118.
13. Frutos, P., G. Hervás, F.J. Giráldez and A.R. Mantecón, 2004. Review. Tannins and ruminant nutrition. Spanish Journal of Agricultural Research, 2(2): 191-202.
14. Kondo Makoto, Yoshiaki Hirano, Kazumi Kita, Anuraga Jayanegara and Hiro-omi Yokota, 2014. Fermentation characteristics, tannin contents and *in vitro* ruminal degradation of green tea and black tea by-products ensiled at different temperatures. Asian-Australian Journal of Animal Science, 27(7): 937-945.
15. Mlambo, V., F.L. Mould, T. Smith, E. Owen, J.L.N. Sikosana and I. Mueller-Harvey, 2009. *In vitro* biological activity of tannins from Acacia and other tree fruits: Correlations with colorimetric and gravimetric phenolic assays. South African Journal of Animal Science, 39(2): 131-143.
16. Krebs, G.L., D.M. Howard and K. Dods, 2007. The effects of feeding Acacia saligna on feed intake, nitrogen balance and rumen metabolism in sheep. Asian-Australasian Journal of Animal Sciences, 20(9): 1367-1373.
17. Driessen, P., J. Deckers, O. Spaargaren and F. Nachtergaele, 2001. Lecture notes on the major soils of the World. World Soil Resources Report 94, FAO, Rome.
18. Baars, R.M.T., E.C. Chileshe and D.M. Kalokoni, 1997. Technical note: range condition in cattle density areas in the western province of Zambia. Tropical Grasslands, 3: 569-573.
19. Yisehak, K., D. Belay, T. Ayalew, T. Taye and G.P.J. Janssens, 2010. Botanical diversity of potential forage plants in range and farming systems of Gilgel Ghibe catchment, Jimma zone. Proceedings of the 5th all Africa conference on Animal Agriculture, October, 25 – 28, 2010, Addis Ababa, Ethiopia.
20. Osuji, P.O., I.V. Nsahlai and H. Khalili, 1993. Feed evaluation. ILCA Manual 5. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia.
21. Getachew, G.H., P.S. Maker and K. Becker, 2001. Method of polyethylene glycol application to tannin containing browses to improve microbial fermentation and efficiency of microbial protein synthesis from tannin-containing browses. Animal Feed Science Tech., 92: 51-57.
22. NRC, 1985. Nutrient requirements of sheep. 6th rev.edn. Washington, DC, National academy press.
23. AOAC (Association of Official Analytical Chemists) International, 2005. Official Methods of Analysis of AOAC International, 18th Edition. Gaithersburg, Maryland, USA, AOAC International.
24. Van Soest, P.J., J.B. Robertson and B.A. Lewis, 1991. Methods of fiber, neutral detergent fiber and non-starch carbohydrates in relation to animal nutrition. Journal of dairy science, 74: 3583-3597.
25. Porter, L.J., L.Y. Foo and R.H. Furneaux, 1985. Isolation of three naturally occurring O-β-D-glucopyrosides of procyanidin polymers. Phytochemistry, 24: 567-569.
26. Luo, J., A.L. Goetsch, T. Sahlu, I.V. Nsahlai, Z.B. Johnson, J.E. Moore, M.L. Galyean, F.N. Owens and C.L. Ferrell, 2004. Voluntary feed intake by lactating, Angora, growing and mature goats. Small Rumin. Res., 53: 357-378.
27. Abate, A.L. and M. Meyer, 1997. Prediction of the useful energy in tropical feeds from proximate composition and *in vivo* derived energetic contents. 1. Metabolisable energy. Small Ruminant Research, 25(1): 51-59.
28. McDonald, P.J., J.F.D. Greenhalgh, C.A. Morgan, R. Edwards, Liam Sincliar and Robert Wilkinson, 2010. Animal nutrition. 7th ed. Prentice Hall, NY, USA.
29. National Research Council, 2007. Nutrient Requirements of Small Ruminants. National Academy Press: Washington DC.
30. Ranjhan, S.K., 2001. Animal Nutrition in the Tropics. 5th Edn., Vikas Publishing House, New Delhi, pp: 593.
31. Meissner, H.H., M.O. Viljoen and W.A. Van Niekerk, 1991. Intake and digestibility by sheep of Antherphora, Panicum, Rhodes and Smooth finger grass. In: Proc. 4th International Rangeland Congress, September 17th–21st, Montpellier, France.
32. Norton, B.W., 1994. Tree legumes as dietary supplements for ruminants. In: R.C. Gutteridge and H.M. Shelton (eds): Forage Tree Legumes in Tropical Agriculture. 20th Ed. CABI International, Wallingford, UK.
33. Leng, R.A., 1997. Tree Foliage in Ruminant Nutrition. FAO, Rome.
34. Brooker, J.D., L. O'Donovan, I. Skene and G. Sellick, 1999. Proceedings of the 8th International Symposium on Microbial Ecology C.R. Bell and M. Brylinsky, Johnson-Green P (ed) Atlantic Canada Society for Microbial Ecology, Halifax, Canada.

35. Agrawal, A.R., S.A. Karim, Rajiv Kumar, A. Sahoo and P.J. John, 2014. Sheep and goat production: basic differences, impact on climate and molecular tools for rumen microbiome study. Int. J. Curr. Microbiol. App. Sci., 3(1): 684-706.
36. Lamy, E., H. Rawel, F.J. Schweigert, F. Capela e Silva, A. Ferreira, A.R. Costa, C. Antunes, A.M. Almeida, A.V. Coelho and E. Sales-Baptista, 2011. The Effect of Tannins on Mediterranean Ruminant Ingestive Behavior: The Role of the Oral Cavity. Molecules, 16: 2766-2784.
37. Decandia, M., G. Molle, S. Ligios and G. Scanu, 1999. Effect of different levels of polyethylene glycol and concentrate on the nutritional value of *Pistacia Lentiscus* L. fed to goats. In: Atti XIII° Congresso ASPA, Piacenza, Italy, 21-24 June, 1999, pp: 384-386.
38. Halim, R., M.K. Danquah and P.A. Webley, 2012. Extraction of oil from microalgae for biodiesel production: A review, Biotechnol. Adv., 30: 709-732.
39. McSweeney, C.S., B. Palmer, D.M. McNeill and D.O. Krause, 2001. Microbial interactions with tannins: nutritional consequences for ruminants. Anim. Feed. Sci. tech, 91: 83-93.
40. Mui, N.T., D.V. Binh and E.R. Orskov, 2005. Effect of foliages containing condensed tannins and on gastrointestinal parasites. Animal Feed Science and Technology, 121: 77-87.
41. Yisehak, K. and D. Belay, 2011. Evaluation of nutritional potentials of foliages of a tannin rich tropical multipurpose tree (*Albizia gummifera*). International Journal of Agricultural Research, 6(2): 45-55.
42. Yisehak, K., B. Biruk, Abegaze and G.P.J. Janssens, 2012. Effect of dietary inclusion of polyethylene glycol on *in vivo* and *in vitro* nutritional parameters for a tropical condensed tannin rich diet. Proceeding of the 16th Meeting of European Society of Veterinary and Comparative Nutrition (ESVCN), September 13-15, 2012, Bydgoszcz, Poland.