Blueprint Academic Publishers

Journal of Crops, Livestock and Pests Management
Journal ISSN: 3005-2181
4(3)
Received: September 03, 2025
Accepted: October 25, 2026
Published: October 29, 2026

Effects of Drying and Wood-Ash Treatment of *Acacia brevispica*, *A. mellifera* and *A. tortilis* Pods on Tannin Content, In Vitro Gas Production and Growth Performance of Growing Small East African Goats in Baringo County, Kenya

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Abstract

This study evaluated the effects of processing method on the tannin content, in vitro gas production (GP) characteristics and supplementary feeding value of mature green pods of *Acacia brevispica*, *A. mellifera* and *A. tortilis* for growing Small East African goats (SEAGs) in Baringo County, Kenya. Pods were subjected to four treatments: untreated (control), shade-drying for 48 h, sun-drying for 48 h, and soaking for 48 h in a wood-ash (alkali) solution (200 g ash/L water; pH 10–12). Chemical composition was determined by proximate and Van Soest procedures, tannins by Folin–Ciocalteu and butanol–HCl assays, and fermentability by the in vitro gas production technique. Twenty SEAG bucks (4–5 months; 12.0 ± 1.05 kg) were allocated to five treatments in a randomized complete block design and fed a basal diet of Rhodes grass (*Chloris gayana*) hay with wheat bran, supplemented with 300 g/buck/day of the processed pods for 84 days. *A. mellifera* pods had the highest crude protein (207.1 g/kg DM) but also the highest condensed tannin concentration (0.01070 mg/g DM), whereas *A. tortilis* had the lowest (0.00020 mg/g DM). Wood-ash treatment lowered total tannins in *A. tortilis* from 11.513 (untreated) to 11.025 mg/g DM and produced the highest GP response in all three species ($p < 0.05$), followed by sun-drying. Bucks supplemented with alkali-treated *A. tortilis* pods attained the highest final weight (14.07 ± 0.34 kg) and the best average daily gain (15.03 ± 2.01 g/day), with the lowest feed conversion ratio. Wood-ash treatment is a cheap, practical method of reducing the anti-nutritional effects of tannins, and mature green *A. tortilis* pods are recommended as a dry-season protein supplement for growing goats in the ASALs of Kenya.

Keywords: Acacia pods; condensed tannins; growth performance; in vitro gas production; Small East African goat; wood-ash treatment

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Funding: The research was funded by University of Eldoret Annual Research Grants

Data Availability Statement: The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials or upon reasonable request.

Competing interests: The authors declare no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Introduction

Livestock production contributes about 40% of the global value of agricultural output and underpins the livelihoods, nutrition and incomes of close to one billion of the world's poor (Tella & Chineke, 2022; Adesogan et al., 2025). In Kenya, the sub-sector is dominated by small ruminants in the arid and semi-arid lands (ASALs), which cover more than 80% of the country's land mass (Gachohi et al., 2024). The national goat herd stood at 35.0 million head in 2023, up from 30.0 million in 2022, with the majority of meat goats kept in the ASALs (KNBS, 2024). Goat keeping is thus central to the food and income security of agro-pastoral households, yet productivity remains low, largely because of seasonal feed scarcity and poor forage quality, with recurrent droughts periodically decimating herds (Opiyo et al., 2015).

Supplementation with conventional commercial concentrates is rarely practised by ASAL goat keepers because of high cost and the human–livestock competition for grains. Locally available browse tree legumes offer a practical alternative protein source (Kemboi et al., 2021; Ratemo et al., 2024). More than 1,300 acacia species occur worldwide and about 52 are distributed across Kenya's varied agro-ecological zones (Dharani, 2006). Following phylogenetic reclassification, the African species are now placed in the genera *Vachellia* and *Senegalia* (Kyalangalilwa et al., 2013), with *A. tortilis*, *A. mellifera* and *A. brevispica* now recognised as *Vachellia tortilis*, *Senegalia mellifera* and *Senegalia brevispica*, respectively; the traditional nomenclature is retained here for consistency with the animal nutrition literature. The pods of these species are abundant at the onset of the dry season and contain moderate to high crude protein (117–207 g/kg DM) with dry-matter digestibility of about 46%, making them candidate dry-season supplements (Abdulrazak et al., 2000; Ondiek et al., 2017; Hidosa and Kibiret, 2020; Kandie et al., 2020; Osuga et al., 2020).

Their utilisation is, however, constrained by tannins polyphenolic anti-nutritional factors that bind dietary proteins and microbial enzymes to form indigestible complexes, thereby reducing organic matter digestibility, nitrogen retention, palatability and voluntary intake (Makkar, 2003; Mueller-Harvey, 2006). Recent in vivo evidence confirms the magnitude of these effects: graded inclusion of condensed tannins in dairy goat diets linearly depressed dry-matter (−11%), crude protein (−21%) and neutral detergent fibre (−23%) digestibility (Battelli et al., 2024). Goats nonetheless tolerate tannins better than sheep and cattle, partly through proline-rich salivary proteins and a tannin-tolerant rumen microbiota (Min and Solaiman, 2018), and

moderate tannin levels can even be beneficial by shifting protein digestion to the lower gut (the bypass-protein effect) and suppressing gastrointestinal nematodes (Min et al., 2004; Costa et al., 2018).

Several processing strategies can reduce tannin activity. Polyethylene glycol (PEG) is the reference tannin-binding agent but is too costly for pastoralist use; wood ash, an alkaline household residue (pH > 10), is a cheap alternative that deactivated tannins and improved digestion of *Acacia cyanophylla* foliage in sheep (Ben Salem et al., 2005), while drying alters extractable tannin fractions in browse (Mlambo and Mapiye, 2015). The in vitro gas production technique of Menke and Steingass (1988) is well suited to evaluating such tanniniferous feeds because gas output closely tracks substrate fermentation and is depressed in proportion to active tannins (Makkar, 2005). Despite the abundance of *A. brevispica*, *A. mellifera* and *A. tortilis* in Baringo County, the combined effect of low-cost processing methods on their tannin content, in vitro fermentability and the growth of supplemented goats has not been fully documented (Mutai et al., 2022).

The objectives of this study were therefore to: (i) determine the chemical composition and tannin concentrations of mature green pods of the three *Acacia* species; (ii) evaluate the effect of shade-drying, sun-drying and wood-ash treatment on in vitro gas production of the pods; and (iii) assess the growth performance of growing Small East African goat bucks supplemented with the processed pods. It was hypothesised that alkali (wood-ash) treatment would reduce tannin activity, increase in vitro fermentability and improve growth performance relative to untreated pods.

Materials and Methods

Description of the study area

The study was conducted at Radat sub-location, Emining ward, Mogotio Sub-County, Baringo County, Kenya (0.4° N, 35.8° E; 1,000–1,500 m above sea level) as indicated in Figure 1. The area receives a unimodal rainfall of 400–700 mm per year, mainly between April and June, with daytime temperatures of 29–32 °C. The site falls within agro-ecological zone IV of the Kenyan ASALs, supports a high goat population kept by the Tugen agro-pastoral community, and is naturally endowed with the three study acacia species (Mutai et al., 2022).

Collection and processing of Acacia pods

Mature green pods of *A. brevispica*, *A. mellifera* and *A. tortilis* were harvested daily from at least 7–10 randomly selected trees per species, washed, rinsed and allocated to four processing treatments: T1, untreated (control); T2, shade-dried for 48 h; T3, sun-dried for 48 h; and T4, soaked for 48 h in a wood-ash (alkali) solution prepared at 200 g of sieved wood ash per litre of water (pH 10–12), following Ben Salem et al. (2005). Processed pods were then oven-dried at 50 °C for 24 h, and representative sub-samples were ground to pass through a 1-mm sieve for laboratory analyses.

Chemical analyses and tannin bioassay

Dry matter, ash, ether extract and crude protein (CP; micro-Kjeldahl, N × 6.25) were determined according to AOAC (1995), while neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were analysed by the detergent procedures of Van Soest et al. (1991). Total extractable phenolics were determined with the Folin–Ciocalteu reagent against a tannic-acid standard, total tannins indirectly after precipitation with

polyvinylpolypyrrolidone (PVPP), and condensed tannins by the butanol–HCl–Fe^{3+} assay (Porter et al., 1986; Makkar, 2003). Tannin concentrations were expressed as tannic-acid equivalents per gram of dry matter.

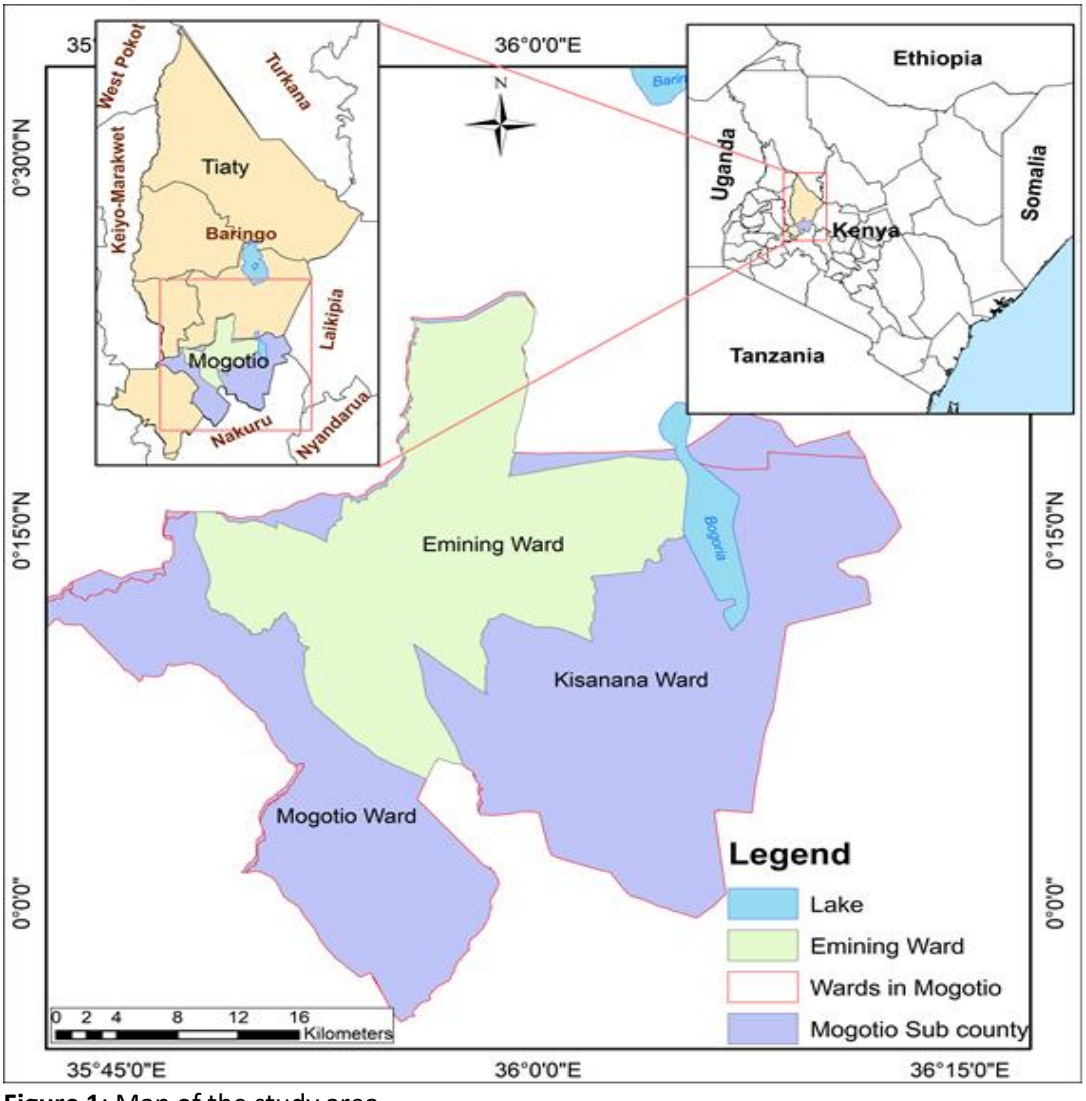


Figure 1: Map of the study area

In vitro gas production

In vitro fermentability of the pods was assessed by the Hohenheim gas test of Menke and Steingass (1988). Approximately 200 mg of each sample (DM basis) was weighed into 100-ml calibrated glass syringes, in triplicate for each species × treatment combination. Rumen fluid was collected before the morning feed from a three-year-old rumen-fistulated SEAG buck maintained on the same basal diet, filtered through two layers of cheesecloth into a flask held at 38 °C and flushed with CO_2, then mixed with pre-warmed buffer medium at a ratio of 1:2 (v/v). Thirty millilitres of the rumen-fluid–buffer mixture was dispensed into each syringe; blank syringes and syringes with reference standards of known gas production were included in every run. Syringes were incubated at 39 ± 0.5 °C and gas volumes recorded at 3, 6, 12, 24, 48, 72 and 96 h. Net gas production (GP, ml/200 mg DM)

was obtained after correcting for the blank and the standard, and the kinetics were described with the model Y = a + b(1 − e^(−ct)) (Ørskov and McDonald, 1979), where Y is the gas volume at time t, a the intercept, b the asymptotic gas production and c the fractional rate constant.

Experimental animals, design and feeding

Twenty intact SEAG bucks aged 4–5 months (mean initial weight 12.0 ± 1.05 kg) were purchased from goat keepers at Radat market, ear-tagged, dewormed with albendazole 2.5% (Alfa Vet Ltd) according to live weight, and sprayed with an acaricide (Duodip®, Norbrook Ltd) against ectoparasites. After a seven-day adaptation period, the bucks were blocked by body condition score and randomly allocated to five treatments of four bucks each in a randomized complete block design (RCBD): T1–T4 received the basal diet plus 300 g/buck/day of pods processed as described above, while T5 (negative control) received the basal diet only. The basal diet consisted of Rhodes grass (*Chloris gayana*) hay and wheat bran (3:1), offered daily at levels intended to meet maintenance and growth requirements (NRC, 2007); refusals were collected and weighed each morning before the next feeding (08:00–09:00 h). Water and mineral salts were available ad libitum. Bucks were housed individually in raised pens (1.5 × 1.5 m slatted floor, 1 m high) and weighed fortnightly for the 84-day feeding period; body-weight change was monitored per species feeding trial.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) and treatment means separated using Fisher's least significant difference (LSD) at $p < 0.05$ in Statgraphics Centurion XII (Statgraphics Technologies, Inc., The Plains, VA, USA). Gas production and fortnightly live-weight changes were further assessed by simple linear regression against time, and goodness of fit was assessed from the coefficient of determination (R^2) and the F-test.

Results

Chemical composition and tannin concentration of the pods

The chemical composition of the mature green pods differed significantly ($p < 0.05$) among the three species (Table 1).

Table 1. Chemical composition of mature green pods of the three *Acacia* species (means pooled across processing treatments)

Component	*A. brevispica*	*A. mellifera*	*A. tortilis*
Dry matter (%)	96.72[b]	90.97[a]	96.14[b]
Moisture (%)	3.28[b]	9.03[a]	4.53[b]
Crude protein (% DM)	9.36[b]	20.71[a]	9.88[b]
Crude fibre (% DM)	28.88	30.08	23.78
Organic matter (% DM)	92.58[a]	84.14[b]	91.41[a]
Ether extract (% DM)	1.88	1.66	2.15
Ash (% DM)	4.13	6.83	4.73
NDF (g/kg DM)	284.98	237.86	222.50
ADF (g/kg DM)	34.66	39.67	35.50
ADL (g/kg DM)	32.40	28.63	29.81

NDF = neutral detergent fibre; ADF = acid detergent fibre; ADL = acid detergent lignin. [a] [b] Means with different superscripts within a row differ significantly ($p < 0.05$).

A. mellifera had the highest CP (207.1 g/kg DM) and moisture (9.03%) but the lowest organic matter (841.4 g/kg DM), whereas *A. tortilis* combined intermediate CP (98.8 g/kg DM) with the lowest crude fibre (237.8 g/kg DM), NDF (222.5 g/kg DM) and ADL (28.63 g/kg DM), indicating the best overall nutritive potential. All three species exceeded the 70–80 g/kg DM CP threshold required for optimal rumen microbial function (Van Soest, 1994).

Condensed tannin (CT) concentration differed widely among the species, being lowest in *A. tortilis* (0.00020 mg/g DM) and highest in *A. mellifera* (0.01070 mg/g DM), with *A. brevispica* intermediate (0.00138 mg/g DM) (Table 2) species means for total tannins were otherwise similar ($p > 0.05$). Processing reduced total tannins (TT) in *A. tortilis* pods from 11.513 mg/g DM in untreated pods to 11.243 (shade-dried), 11.051 (sun-dried) and 11.025 mg/g DM (wood-ash treated), equivalent to reductions of 2.3%, 4.0% and 4.2%, respectively, with no significant difference among treated samples and the control ($p > 0.05$).

Table 2. Tannin concentrations (mg/g DM) of the pods by species and processing treatment

Assay / treatment	*A. brevispica*	*A. mellifera*	*A. tortilis*
Condensed tannins (mg/g DM)	0.00138	0.01070	0.00020
Total tannins — untreated (T1)	11.900	12.820	11.513
Total tannins — shade-dried (T2)	11.650	12.470	11.243
Total tannins — sun-dried (T3)	11.480	12.310	11.051
Total tannins — wood-ash (T4)	11.350	12.180	11.025

In vitro gas production

Gas production (GP) increased significantly with incubation time for every species × treatment combination, and all twelve linear regressions were significant (R^2 = 69.0–86.6%; $p \leq 0.008$; Table 3). The treatment ranking, however, differed among species in a way that mirrors their tannin contents. In *A. mellifera* and *A. tortilis* the species with the highest and lowest condensed tannin concentrations, respectively wood-ash (alkali) and sun-dried pods gave both higher intercepts and steeper slopes than untreated pods, indicating improved fermentability once tannins were deactivated; the alkali response was significant at all incubation times. In *A. tortilis*, treatment effects were otherwise modest and differed significantly mainly from the negative control, consistent with its intrinsically low tannin content (Table 2).

The fitted equations (GP = intercept + slope × t) quantify these patterns. In untreated pods, GP rose fastest in *A. brevispica* (β = 0.516 ml/unit time; R^2 = 86.6%) and slowest in *A. mellifera* (β = 0.363), while *A. tortilis* recorded the highest intercept (42.02 ml). Shade-drying steepened the response of *A. brevispica* to the highest slope of the series (β = 0.576) and raised the *A. tortilis* intercept to 50.38 ml. Sun-dried pods combined the highest intercepts (47.06–50.23 ml) with steep slopes (β = 0.446–0.561) in all three species. Under wood-ash treatment, *A. tortilis* attained its steepest response (β = 0.506) and *A. mellifera* improved markedly over the control (intercept 44.93 ml; β = 0.404), whereas the alkali-treated *A. brevispica* series, although increasing significantly with time, recorded the lowest intercept and slope of all regressions (36.57 ml; β = 0.238).

Table 3. Linear regression parameters of in vitro gas production (GP, ml/200 mg DM) of processed *Acacia* pods

Processing	Species	Intercept (ml)	Slope (ml/unit time)	R^2 (%)	F(1,7)	p-value
Wood-ash (alkali)	*A. brevispica*	36.57	0.238	83.07	34.37	0.0006
	A. mellifera	44.93	0.404	82.83	33.78	0.0007
	A. tortilis	45.39	0.506	80.72	29.31	0.0010
Sun-dried	*A. brevispica*	47.06	0.561	81.53	30.92	0.0009
	A. mellifera	50.23	0.446	76.61	22.92	0.0020
	A. tortilis	49.27	0.506	81.57	30.98	0.0008
Shade-dried	*A. brevispica*	42.95	0.576	86.44	44.62	0.0003
	A. mellifera	42.70	0.373	77.97	24.78	0.0016
	A. tortilis	50.38	0.404	69.01	24.78	0.0016
Untreated (control)	*A. brevispica*	39.53	0.516	86.57	45.15	0.0003
	A. mellifera	39.68	0.363	77.97	32.18	0.0080
	A. tortilis	42.02	0.468	82.19	32.29	0.0007

GP model: GP = intercept + slope × time. All regressions were significant ($p < 0.05$)

Growth performance of the goats

Derived total gains and average daily gains from the fortnightly weights are summarised in Table 4 where every supplemented group out-gained the basal-diet control (12.3 g/day), with sun-dried *A. tortilis* (15.0 g/day) and wood-ash-treated *A. brevispica* (14.0 g/day) the fastest-gaining groups.

Table 4. Growth performance of SEAG bucks fed the processed *Acacia* pods over 84 days (means ± SE)

Processing	Species	Initial BW (kg)	Final BW (kg)	Total gain (kg)†	ADG (g/day)†
Untreated (T1)	*A. brevispica*	12.63 ± 0.48	13.64 ± 0.71	1.01	12.0
	A. mellifera	12.38 ± 0.95	13.47 ± 1.30	1.09	13.0
	A. tortilis	12.58 ± 0.56	13.59 ± 0.36	1.01	12.0
Shade-dried (T2)	*A. brevispica*	12.05 ± 0.50	13.07 ± 0.61	1.02	12.1
	A. mellifera	12.30 ± 1.29	13.41 ± 0.47	1.11	13.2
	A. tortilis	12.63 ± 0.85	13.78 ± 0.72	1.15	13.7
Sun-dried (T3)	*A. brevispica*	12.31 ± 0.48	13.47 ± 0.47	1.16	13.8
	A. mellifera	12.23 ± 0.48	13.27 ± 0.48	1.04	12.4
	A. tortilis	12.75 ± 0.65	14.01 ± 0.22	1.26	15.0
Wood-ash (T4)	*A. brevispica*	12.63 ± 0.48	13.81 ± 0.47	1.18	14.0
	A. mellifera	12.63 ± 0.48	13.72 ± 0.47	1.09	13.0
	A. tortilis	12.90 ± 0.64	14.07 ± 0.34	1.17	13.9

Basal diet only (T5)	All (no pods)	12.08 ± 0.92	13.11 ± 0.92	1.03	12.3

† Total gain and ADG computed from the reported initial and final weights over the 84-day feeding period. BW = body weight; ADG = average daily gain. Within-processing species contrasts for final weight: control, F(2,15) = 6.28, p = 0.0196; shade-dried, p = 0.0066; sun-dried, p = 0.0070; wood-ash, p = 0.0066. T5 values are pooled across the three species trials (initial weights 12.00–12.14 kg; final 13.00–13.18 kg).

Initial live weights did not differ among species or treatments ($p > 0.05$), confirming successful randomization. After 84 days of supplementation, however, final weights differed significantly: *A. tortilis* pods gave the highest final weights under every processing method, and across processing treatments *A. tortilis* attained the highest final weight of 14.20 ± 0.36 kg ($F(2,15) = 6.28$, $p = 0.0196$). Within species, alkali treatment produced the greatest gains, with bucks on alkali-treated *A. tortilis* pods recording the best average daily gain (15.03 ± 2.01 g/day), followed by alkali-treated *A. brevispica* (14.13 ± 1.94 g/day), while *A. mellifera* was significantly lower ($p < 0.05$) (Mutai et al., 2022). Supplement intake followed the same pattern: alkali-treated *A. tortilis* pods were consumed in the largest amounts (416.50 ± 6.50 g/day; $p = 0.0012$), and the best (lowest) feed conversion ratio was recorded for the alkali-treated *A. tortilis* group.

Discussion

The crude protein of the pods (93.6–207.1 g/kg DM) agrees with values reported for *A. tortilis* pods in Kenya and Ethiopia (117–126 g/kg DM; Ondiek et al., 2017; Hidosa and Kibiret, 2020) and with the 120–213 g/kg DM range documented for ASAL browse pods (Osuga et al., 2020; Kandie et al., 2020). All three species exceeded the 70–80 g/kg DM CP threshold required for optimal rumen microbial activity (Van Soest, 1994), confirming that the pods can correct the protein deficiency of mature Rhodes grass hay. *A. tortilis* combined adequate protein with the lowest crude fibre, NDF and ADL, which is consistent with its top palatability ranking among Kenyan browses (Ondiek et al., 2017) and explains its superior fermentation and growth responses in this study.

Condensed tannin concentrations differed markedly among species, being highest in *A. mellifera* and lowest in *A. tortilis* , mirroring the species variation in total extractable phenolics reported for Kenyan browses (Ondiek et al., 2017). Wood-ash (alkali) treatment produced the largest tannin reduction, followed by sun-drying. In an alkaline medium (pH 10–12), tannins are thought to polymerise and oxidise into inert compounds, releasing bound protein for microbial degradation (Ben Salem et al., 2005). The percentage reduction in total tannins observed here (up to 4.2% in *A. tortilis*) was smaller than the reductions reported for wood-ash-treated *A. cyanophylla* foliage (Ben Salem et al., 2005), probably because of differences in substrate (pods versus foliage), baseline tannin concentration and contact time; nevertheless, the biological effect of the treatment was clearly detectable in the gas-production response. Sun-drying performed close to alkali treatment, which supports the view that drying immobilises soluble tannins onto plant cell walls (Mlambo and Mapiye, 2015), although alkali treatment has the practical advantage of remaining effective even on over-mature, field-dried pods.

Gas production increased with incubation time in all species, and processing generally enhanced fermentation — most consistently in the wood-ash- and sun-treated pods of *A. mellifera* and *A. tortilis*. Because gas output closely tracks fermentable organic matter and short-chain fatty acid yield (Blümmel and Becker, 1997; Makkar, 2005), the higher GP of treated pods indicates improved ruminal degradability once tannins are deactivated. This in vitro pattern mirrors recent in vivo evidence in goats, where graded condensed tannin inclusion linearly depressed dry-matter, crude-protein and fibre digestibility (Battelli et al., 2024) and modified the rumen microbiota and methane yield (Cremonesi et al., 2025). The comparatively strong fermentation of goat rumen inoculum on tanniniferous substrates is also consistent with the known tolerance of goats to dietary tannins through proline-rich salivary proteins and tannin-tolerant microbes (Min and Solaiman, 2018).

The growth responses followed the fermentation results: bucks on alkali-treated *A. tortilis* pods attained the best average daily gain (15.03 g/day) and the lowest feed conversion ratio, with the highest supplement intake (416.5 g/day), and every supplemented group out-gained the basal-diet control. These gains are comparable to those reported for browse-supplemented SEAGs in Kenya (Kemboi et al., 2021), for *A. tortilis* pod-fed Woyto-Guji goats in Ethiopia (Hidosa and Kibiret, 2020) and for *Prosopis juliflora* pod-supplemented Galla goats (Ratemo et al., 2024). Improved growth after deactivation of tannins is consistent with the release of protein from tannin–protein complexes and, at moderate residual tannin levels, with the bypass-protein effect that shifts amino-acid absorption to the small intestine (Mueller-Harvey, 2006; Battelli et al., 2024); low-to-moderate tannins may additionally suppress gastrointestinal nematodes (Min et al., 2004). For resource-poor pastoralists, wood ash is essentially cost-free compared with polyethylene glycol or commercial alkali (Ben Salem et al., 2005; Mlambo and Mapiye, 2015), and raising feed efficiency in these extensive systems also moderates the environmental footprint per unit of animal product (Steinfeld et al., 2006; Aboagye and Beauchemin, 2019).

Conclusions and Recommendations

Mature green pods of *A. tortilis* had the best overall nutritive profile with the lowest condensed tannin concentration and the lowest fibre fractions and elicited the strongest in vitro fermentation and the best growth performance in growing Small East African goats. Among the processing methods, wood-ash (alkali) treatment gave the greatest tannin reduction, the highest gas production and the best average daily gain and feed conversion, followed closely by sun-drying. Wood-ash treatment of mature green pods is therefore recommended as a cheap, practical strategy for reducing the anti-nutritional effects of tannins in browse supplements, and *A. tortilis* pods are recommended as a dry-season protein supplement for goats in Baringo County and similar ASAL areas of Kenya. Wider planting of *A. tortilis* in silvo-pastoral systems, together with on-farm validation of the wood-ash protocol, is encouraged.

Acknowledgements

The authors thank the University of Eldoret for research support through the Annual Research Grant (ARG); the School of Agriculture and Biotechnology (Mr Steve Kipno and Mr Chemitei Kogey); and the Egerton University Nutritional

Laboratory staff (Mr Kibitok and Mr Eshakala) for technical assistance.

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