RESPONSE OF METHANE EMISSION AND GROWTH PERFORMANCE OF YEARLING MALE BOER GOATS TO AN INCLUSION OF *ACACIA KARROO* (SWEET THORN) IN *AVENA SATIVA* (COMMON OAT) HAY BASED DIET

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Abstract. This study determined the response of methane emission and growth performance of yearling male Boer goats fed a basal diet of *Avena sativa* hay supplemented with Acacia karroo (sweet thorn*)* leaf meal. Twelve yearling male Boer goats with initial mean live weights of 23 ± 2 kg were used in a 21-day experiment. The goats were randomly assigned to four dietary treatments, each containing sweet thorn leaf meal at 10, 15, 20 and 30% with *Avena sativa* hay as a basal diet. The data collected was subjected to analysis of covariance and analysis of variance in a completely randomized design using Statistical Analysis Software. Differences were separated at 5% level of probability. Sweet thorn leaf meal inclusion level had no effect ($p > 0.05$) on diet intake, methane emission, live weight changes and digestibility. Feed conversion ratio improved linearly with increased Sweet thorn leaf meal inclusion level. The low tannin contents in sweet thorn leaves indicate that these leaves can be safe to use as a source of protein in animal nutrition if used sparingly. Although, sweet thorn leaf meal reduced methane emission, the optimal dose was not determined. Further validation is required to determine sweet thorn inclusion levels for optimal methane production and emission by goats.

Keywords: *feed conversion ratio, optimal dose, live weight, leaves, tannins*

Introduction

Africa's livestock accounts for one-third of the global livestock population (AU-IBAR, 2015) and about 40% of agricultural GDP in Africa, ranging from 10% to 80% in individual countries. Livestock will be increasingly important in the future in sub-Saharan Africa (SSA) because the demand for animal-source food is projected to increase due to population growth, increased incomes, and urbanization. In South Africa, goats play multiple roles in the livelihoods of the populace (Ng'ambi et al., 2013). The total national goat population in the commercial sector of South Africa is approximately 3.2 million (DALRRD, 2020). Although the exact population of goats in the South African communal sector cannot be readily established, the Eastern Cape and Limpopo provinces are the largest communal goat-producing provinces. However, methane produced by goats from enteric fermentation contributes to the emission of greenhouse gases (GHG) into the atmosphere. According to Peters et al. (2018), methane along with other GHG arising from anthropogenic activities have a greater contribution to global warming. Furthermore, Canul-Solis et al. (2020) stated that ruminant production systems contribute between18% and 33% of total methane emissions. Gerber et al. (2013) reported that African livestock have significant impacts on the environment. Tubiello et al. (2014) ascertained that more than 70% of agricultural GHG emission in Africa comes from the livestock sector dominated by

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enteric methane (CH_4) emission. Production of methane translates into lost energy which can negatively affect ruminant productivity (Ramin and Huhtanen, 2013). Therefore, in Africa, sustainable livestock production must address food security and climate change concerns simultaneously in addition to social and economic aspects. Currently, most countries in Africa rely on the Intergovernmental Panel on Climate Change (IPCC) tier 1 methodology to estimate their livestock-based emissions.

Furthermore, there is a general lack of detailed, precise activity data and accurate estimates of natural resource use and environmental impact by livestock to inform the adoption of climate-smart livestock interventions (Gaitán et al., 2016. This situation calls for more research into the potential use of tropical foliage trees, pods, and secondary metabolites to reduce methane emissions from ruminant supply chains. Optimal livestock production that couples the use of environmentally friendly practices within the tropical regions is attainable when the relevant stakeholders have a better knowledge of the available strategies for efficient foliage use (Ku-Vera, 2020). Most tropical forages contain high tannin levels and some studies have reported beneficial effects of tannins in livestock production and more recent studies have revealed beneficial effects of tannins in domestic ruminants. For example, Anantasook et al. (2014), Gunun et al. (2016) and Canul-Solis et al. (2020) reported that tannins containing plants contribute to inhibiting the enteric methane emission. Thus, the mitigation of rumen methane production with the foliage and metabolites of tropical trees represents an interesting challenge in the field of ruminant nutrition. Research on the utilization of tropical forages is particularly important in goat production. Goat mouth structure allows them to select the high-quality parts of the woody plants and they can effectively detoxify secondary compounds such as tannins and terpens. These observations have led to a growing interest in finding feed alternatives, which may help to mitigate methane production in the goat rumen. It was observed by Canul-Solis et al. (2020) that the presence of a vast range of secondary metabolites in tropical trees (coumarins, phenols, tannins, and saponins, among others) may be a valuable alternative to manipulate rumen fermentation and partially defaunate the rumen, and thus reduce enteric methane production.

This study explored sweet thorn as an alternative for sustainable livestock production in South Africa. Sweet thorn is one of the tropical trees that have been reported to have a potential to mitigate methane emissions from Boer goats. Aboagye and Beauchemin (2019) pointed out that CH4 mitigation options that are inexpensive would allow wide implementation to reduce enteric CH4 emissions associated with ruminant production. The use of tannins may offer such a possibility because they are naturally occurring in numerous plants, and hence widely available to ruminant producers. There is neither extensive nor conclusive data on tanniniferous sweet thorn leaf meal inclusion levels for optimal reduction in methane production and emission in the ruminant animals. Additionally, extensive knowledge on inclusion levels of sweet thorn leaf meal for optimal goat productivity is also minimal.

Materials and methods

This study was conducted at the University of Limpopo Experimental farm, Limpopo province, South Africa. The farm is situated 10 km north-west of main campus of the University of Limpopo. The University of Limpopo lies at latitude 27.55°S and longitude 24.77°E. The ambient temperatures around this area are above 32 °C during summer and between 5 and 25 °C during winter seasons. The mean annual rainfall ranges between 446.8 and 468.4 mm. The dry season occurs between April and October and the rainy season occurs between November and March (Kutu and Asiwe, 2010). Vegetation structure is a Savanna type (bushveld) that is characterised by trees, shrubs and grass undercover. Browsing animals, traditionally, keep a balance between trees and grass.

The experimental diets consisted of *Avena sativa* hay as a basal diet mixed with sweet thorn leaves. Sweet thorn leaves were hand-harvested at the University of Limpopo Experimental farm. The leaves were then shade-dried and stored indoor for 14 days prior to chopping. The samples were chopped, using a 2 mm screen, and then stored in airtight bags until needed for analysis and feeding. *Avena sativa* hay was bought from a local supplier. The hay was harvested before summer rains while still green, soft and less stalky. It was shade-dried before being chopped and stored in bags under a shade until needed for analysis and feeding.

The first part of the study determined tannin levels of sweet thorn leaf meals and *Avena sativa* hay. The dietary means were compared using Fisher’s least significant difference at the 5% level of probability. The second part of the study determined the effect of sweet thorn leaf meal inclusion level on diet intake and digestibility, methane emission and growth response of yearling male Boer goats. Twelve yearling male Boer goats with initial mean live weights of 23 ± 2 kg were used in a 21-day experiment. The goats were randomly assigned to four dietary treatments, each containing sweet thorn leaf meal inclusion levels at 10, 15, 20 and 30% with *Avena sativa* hay as a basal diet. The experimental diets were as indicated in *Table 1*. These inclusions include high and low tannin-levels as indicated in the literature (Makkar, 2003). The pens and surrounding environment were cleaned thoroughly and disinfected. Each goat was housed in well-ventilated individual metabolic pen. The diets were replicated three times. The data collected were subjected to analysis of covariance and analysis of variance in a completely randomized design using SAS. Differences were separated at 5% level of probability.

The feeding trial lasted for 21 days, with the last 7 days being for data collection. The goats were fed once at 8:00am on daily basis. The feed was offered *ad libitum*. The goats were weighed at the start of the experiment, on the 14th day when data collection commenced and on the last day of the experiment. Methane emissions were measured at the start of the experiment and again on the last 5 consecutive days of the experiment together with intake and digestibility. Dry matter digestibility was calculated according to Khan et al (2003). Methane emissions were measured using a hand-held portable laser methane detector (LMD) manufactured by Growcon according to Chagunda et al. (2009).

Table 1. *Dietary treatments for sweet thorn and Avena sativa hay diet*

Diet code	Diet description
$H_{As90}AK_{10}$	Yearling male Boer goats fed a mixed diet of 90% *Avena sativa* hay and 10% *sweet thorn*
$H_{As85}AK_{15}$	Yearling male Boer goats fed a mixed diet of 85% *Avena sativa* hay and 15% *sweet thorn*
$H_{As80}AK_{20}$	Yearling male Boer goats fed a mixed diet of 80% *Avena sativa* hay and 20% *sweet thorn*
$H_{As70}AK_{30}$	Yearling male Boer goats fed a mixed diet of 70% *Avena sativa* hay and 30% *sweet thorn*

All the diets and faecal output were analysed for dry matter, organic matter, ash, crude protein, fat, energy and minerals according to AOAC (2002). Neutral and acid detergent fibre contents of feeds and faeces were determined according to Van Soest et al (1991). Tannin contents were determined using the methods of Waterman and Mole (1994). The total phenolic and tannin contents were measured using Folin-Ciocalteu method according to Makkar (2000). Hydrolysable tannins were measured using a modified method of Hartzfeld et al. (2002).

The nutrient and tannin contents of sweet thorn leaves and *Avena sativa* hay diets were subjected to analysis of variance (ANOVA) using SAS (2008). Intake, digestibility, live weight, weight gain and feed conversion ratio (FCR) were adjusted for final weight, FCR, dry matter intake, FCR and weight gain, respectively, by covariance analysis and were presented as adjusted least-square means. In the case of methane, data was scrutinised by ANCOVA using methane baseline values as the covariates to control statistically for differences in baseline values. Where the covariates showed no significant effect, the data were analysed with ANOVA in a completely randomized design at 5% ($p < 0.05$) level of probability with diet as a fixed factor (SAS, 2008). Where significant treatment effects were detected, means were separated by Fisher's least significant difference (LSD) using SAS (2008).

Results

Table 2 shows the tannin contents of sweet thorn leaves. Total tannins and condensed tannins were found in sweet thorn leaves. However, no hydrolysable tannins were detected. Sweet thorn leaf meal inclusion level had no effect on diet dry matter (DM) intake. Increasing sweet thorn leaf meal inclusion level in the diet increased total phenolics, total tannins and condensed tannins (CT). Sweet thorn leaf meal inclusion level had no effect on diet intake, methane emission, live weight and weight gain of goats (*Table 3*). Similarly, sweet thorn leaf meal inclusion level had no effect on diet DM digestibility by goats. Feed conversion ratio improved with increased sweet thorn leaf meal inclusion level. Boer goats on a diet containing a 30% sweet thorn leaf meal inclusion level had a higher ($p < 0.05$) FCR value than those on diets having 10, 15 or 20% sweet thorn leaf meal inclusion levels. Similarly, goats on a diet with a 15% sweet thorn leaf meal inclusion level had a higher ($p < 0.05$) FCR value than goats on a diet having a 10% sweet thorn leaf meal inclusion level. However, goats on diets having 10 or 20% sweet thorn leaf meal inclusion levels had similar ($p > 0.05$) FCR values. Similarly, goats on diets containing 15 or 20% sweet thorn leaf meal inclusion levels had similar ($p > 0.05$) FCR values.

Table 2. *Composition of tannins in the experimental sweet thorn diets*

Nutrient	**Diet$^{\#}$**			
	$H_{As90}AK_{10}$	**$H_{As85}AK_{15}$**	**$H_{As80}AK_{20}$**	**$H_{As70}AK_{30}$**
Total phenolics*	$0.28^{d} \pm 0.002$	$0.41^{c} \pm 0.002$	$0.55^{b} \pm 0.003$	$0.83^{a} \pm 0.005$
Total tannins*	$0.21^{d} \pm 0.001$	$0.32^{c} \pm 0.002$	$0.43^{b} \pm 0.003$	$0.64^{a} \pm 0.004$
Condensed tannins**	$0.16^{d} \pm 0.001$	$0.24^{c} \pm 0.001$	$0.32^{b} \pm 0.002$	$0.48^{a} \pm 0.003$
Hydrolysable tannins (mg/g)	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000

$^{a, b, c, d}$Means in the same row not sharing a common superscript are different ($p < 0.05$)
*Percentage DM tannic acid equivalent
**Percentage DM leucocyanidin equivalent
$^{\#}$Diet codes are explained in *Table 1*

Table 3. *Effect of sweet thorn leaf meal inclusion level on diet intake, digestibility, methane emission, live weight change and feed conversion ratio of yearling male Boer goats fed an Avena sativa hay-based diet*

Variable	**Diet**$^{\#}$			
	$\mathbf{H_{As90}AK_{10}}$	$\mathbf{H_{As85}AK_{15}}$	$\mathbf{H_{As80}AK_{20}}$	$\mathbf{H_{As70}AK_{30}}$
Intake (g/goat/day)				
DM	264 ± 40.223	337 ± 40.451	370 ± 40.602	288 ± 40.247
Digestibility (decimal)				
DM	0.55 ± 0.147	0.55 ± 0.063	0.63 ± 0.078	0.42 ± 0.277
Methane emission (ppm-m)	13.80 ± 1.668	13.07 ± 0.668	13.33 ± 0.668	12.40 ± 0.698
Initial live weight (kg)	23.15 ± 3.715	22.52 ± 2.639	23.97 ± 2.965	22.85 ± 2.707
Final live weight (kg)	23.38 ± 3.534	22.88 ± 2.511	24.33 ± 2.821	23.27 ± 2.576
Weight gain (g/goat/day)	46.00 ± 200.621	73.33 ± 86.252	73.33 ± 106.608	83.33 ± 379.350
Feed conversion ratio	5.74^{a} ± 0.241	4.60^{b} ± 0.238	5.04^{ab} ± 0.238	3.45^{c} ± 0.242

$^{a, b, c}$Means in the same row not sharing a common superscript are different ($p < 0.05$)
$^{\#}$Diet codes are explained in *Table 1*

Discussion

Some studies have attempted to provide dose-response information on the effect of including tannin based diets on methane emission in goats. Naumann et al. (2017) showed that total condensed tannins vs. methane production gave a correlation of $R^2 = 0.44$, suggesting that only 44% of the reduction in methane production is explained by total CT. Many studies have demonstrated that forage plants with diverse natural products as well as tannin rich legumes such as *Mimosa* spp. and *Acacia mearnsii* can decrease gas production by ruminants, including methane emissions (Bhatta et al., 2013; Durmic et al., 2014). Generally, condensed tannins (CT) and hydrolysable tannin (HT) supplementation have no deleterious effects (dose dependent) on animal performance (Krueger et al., 2010). Several studies reported that some tannins based forage are beneficial and some are deleterious (Dey and De, 2014). Tannins in higher concentrations reduce feed intake, carbohydrates metabolism, protein digestibility and ultimately animal production performance (Shewangzaw, 2016.

Sweet thorn leaf meal inclusion levels of 10 - 30% in the present study had no effect on nutrient intake per goat. The intakes, irrespective of dietary treatments, are consistent with the previous reports (Bwire et al., 2004; Pathak et al., 2014; Dey and De, 2014). These authors reported that moderate levels of 1 - 4% of CT in the diet from various plant sources exerted no significant effect on diet intake. Values of CT of 0.16 - 0.48% in sweet thorn leaf meal diets in the current study fell below the moderate levels of CT reported. The non-significant effect of sweet thorn leaf meal inclusion on intake by goats may be attributed to low concentration of CT in the diets. Pathak et al. (2013), also, reported non-significant differences in total intake of DM in lambs fed on diets with or without tannin leaf meal mixtures. It has been reported that diets containing up to 5% tannins are utilised efficiently by the animals without any harmful effect on intake (Barry and McNabb, 1999). This differs from the findings of Gwanzura et al. (2011) who reported a high level of voluntary intake by goats, which were fed tannin-rich diets. Ramírez and Ledezma-Torres (1997) reported that inclusion of *Acacia rigidula* and *Acacia farnesiana* did not adversely affect forage intake of goats. Nunez-

Hernandez et al. (1989) observed similar DM intakes for Angora goats on a diet containing a high tannin shrub (*Juniperus monosperma*) compared with goats fed an alfalfa hay diet. Other studies have indicated that plant secondary metabolites (PSM) such as tannins may reduce dry matter intake of forage legumes by decreasing palatability (Estell, 2010). Brown et al. (2016) observed that tannin-rich plant leaves when fed in a mixed diet can influence preference and intake by goats. Tannins have been associated with low palatability values, however, medium to low levels may be tolerated by ruminant animals (Lamy et al., 2011). Reduced dry matter intake associated with tannin supplementation have been reported in some studies (Fernández, 2012). In a study by Aboagye et al. (2018), dry matter intake of beef steers was not affected by hydrolysable or a combination of hydrolysable and condensed tannin, at the inclusion level of 15 g/kg DM. The influence of tannin on nutrient intake may vary widely and depend on several factors such as the concentration of tannin in the diet, animal factor, biological characteristics of the tannin compound, effect of prolonged adaptation, rumen fermentation or diet characteristics (Dschaak, 2011; Archimède, 2016). The methane-reducing potential of Acacia tannin and other tannin additives has been noted in previous studies (Carulla, 2005; Grainger, 2009). The methane suppressing effects of tannins relate to a combination of direct toxicity on the methanogenic archaea or reduced fibre degradation (Patra and Saxena, 2011; Beauchemin, 2007). Feed conversion ratio (FCR) measures the amount of feed an animal requires to gain per unit body weight. In the present study, feed conversion ratios significantly improved as Sweet thorn inclusion level increased.

Ngambu et al. (2013) reported a higher growth performance in Xhosa lop-eared goats that were supplemented with sweet thorn and attributed this to the high nutritive value of the foarge (Ngongoni et al., 2007; Mapiye et al., 2009; Marume et al., 2012). The significance of tannins in ruminant diets lies in their effect on protein digestion. It has been observed that tannins can reduce the amount of protein that is degraded in the rumen and increase the protein flow for digestion in the small intestine (Mueller-Harvey, 2006). This tannin-protein interaction leads to increased protein metabolism into the muscle, leading to higher slaughter weights and heavier carcasses (Gleghorn et al., 2004). In a study by Mapiliyao et al. (2012), goats, which were allowed access Sweet thorn encroached areas, had higher growth responses as compared to those in open grassland.

Brown et al. (2018) reported improved body weight gains in Pedi goats on diets higher in sweet thorn inclusion levels and attributed this to an improved protein utilization in line with the findings of Solaiman et al. (2010). Similarly, Gwanzura (2011) reported higher body weight gains in Pedi goats fed taninniferous Mucuna hay. The variation in the feed conversion ratio among goats in the present study as compared to previous studies could be due to other factors which were not controlled which also concurs with previous studies that compared performance of sheep (Mukasa-Mugerwa et al., 2000; Mapiliyao et al., 2012), goats (Rumosa-Gwaze et al., 2009) and cattle (Mapiye et al., 2009). Results of Njidda and Ikhimioya (2010) with tannin-rich plants revealed that some rumen microorganisms are able to metabolize tannins or remain active in a high tannin environment and overcome their detrimental effects, which in turn improves animal performance. A study by Ash and Norton (1987) observed higher average daily gains in goats consuming a diet with a 50% sweet thorn leaf meal inclusion level and attributed this to increase in diet digestibility with an increase in sweet thorn inclusion level. However, Tanner et al. (1990) observed that higher concentrations of total polyphenols in a diet tended to reduce nutrient availability to the animals, thus adversely affecting their body weight gains. In the present study, the highest inclusion level for sweet thorn was 30% and this could have been lower to yield significantly higher weight gains.

Dry matter digestibility was affected by sweet thorn leaf meal inclusion level even though the differences across the treatments were not significantly different. Digestibility was optimised at 13.50 and 16.75% sweet thorn leaf meal inclusion levels, respectively. Boer goats on diets having 30% sweet thorn leaf meal inclusion level had the lowest digestibility values. The reduction in digestibility could be due to the negative effect of tannins and phenolics through formation of indigestible complexes with proteins and other nutrients (Dubey et al., 2012). This is also supported by the findings of Salem et al. (2006). The authors reported that ingestion of tannin-containing feed by ruminants may reduce nutrient digestibility. In other studies, digestibility in sheep was decreased by adding CT of *A. mearnsii* to grass-based diets (Carulla et al., 2005). Thus, effects of CT on dry matter digestion, in the present experiment, were expected.

Daily gain indicates production performance of animals which is determined by the feeding value of the feed consumed (Waghorn, 2008). In the present study, the goats attained desired live weight gains and remained in good health condition throughout the experiment. Initial and final live weights of Boer goats were similar irrespective of sweet thorn leaf meal inclusion levels. This accounted for comparable daily weight gains of the goats. These comparable results are in conformity with the findings of several workers (Anbarasu et al., 2001). The authors observed similar body condition in animals on various tannin-rich forage meals. However, Waghorn (2008) reported improved live weight gain in sheep fed temperate forages with CT. The author suggested that increased protein due to higher levels of sweet thorn leaf meal inclusion might also have contributed to improvements in live weight gains.

In the present study, inclusion of tanniferous sweet thorn in the diet showed a potential to reduce methane emission. However, the differences in the amount of methane emitted across the treatments were not significant. Earlier studies suggested that feeding forages that contain tannins for ruminants generally effectively inhibit CH_4 produced during enteric fermentation (Puchala et al., 2005; Animut et al., 2008). In this regard, tannins of lower molecular weights were found to be more effective against methanogens than their monomeric precursors or tannins of higher molecular weight (Tavendale et al., 2005). However, there is huge diversity in tannin structure and concentration, and other chemical constituents among the browses, which may affect variably, the observed response in rumen fermentation, digestibility of nutrients and methanogen activity (Mueller-Harvey, 2006**).** This indicates that tannin from different plants might show a different response in gas production, true digestibility and methane production. Tan et al. (2011) reported that with different graded levels of CT inclusion, total gas production, CH_4 production and total VFA concentration decreased at a decreasing rate with increasing levels of CT and so were the in vitro DM degradation and N disappearance.

Estimates of rumen methanogenic archaea and protozoa populations later showed linear reductions in total methanogens and total protozoa with increasing levels of CT (Tan et al., 2011) and this may justify the observed outcome. In another study, reduced emissions of CH_4 were observed at all levels with the greatest reduction observed at 50%. The values of methane (CH_4) emissions for goats are still being estimated (IPCC, 2006; Moeletsi, 2017). There are reports indicating a decrease in CH_4 emission with inclusion of CT-containing forage (Carulla et al., 2005; Puchala et al., 2005). In the current study, variations in sweet thorn leaf meal inclusion level had different effects on the enteric CH_4 emission by the goats. Different effects of sweet thorn leaf meal inclusion levels on CH_4 emission may indicate that inclusion level of CT (0.16-0.48%) in this study were below the required effective level.

Inclusion of sweet thorn leaf meal in the diets of male Boer goats did not cause a significant reduction in CH_4 emission. This indicates that tannins in sweet thorn leaf meal at the inclusion levels used in the present study were not enough to inhibit methanogens. This differs from Woodward et al. (2001) who reported lower (decreased by 24 - 29%) CH_4 production relative to digestible dry matter intake (DMI) in sheep when CT-containing forage, *Lotus pedunculatus,* was fed compared with ryegrass or alfalfa. The same authors observed a similar decrease of 23% in CH_4 emission relative to DMI when cows were fed *Lotus corniculatus* silage compared with ryegrass silage. This is because CH_4 emission is less in animals fed legumes than grasses (Benchaar et al., 2001; Van Dorland et al., 2007). Grobler et al. (2014), also, did a study comparing CH_4 production in different cattle breeds and reported that Bonsmara, Jersey and Nguni cattle produced less CH_4 on forage sorghum compared to natural pasture. The same authors further concluded that less CH_4 production in forage sorghum is possibly due to the tannin content found in forage sorghum, which inhibits methanogens. Carulla et al. (2005) reported that inhibition of methanogens by CT was primarily the result of suppressed fibre degradation that limits hydrogen gas (H_2) derived from synthesis of acetate. Results of the present study revealed that tannin contents in sweet thorn leaf meal inclusions were not adequate for suppressing CH_4 production and emission by Boer goats.

Conclusions and recommendations

It is concluded that nutrient composition of sweet thorn leaves in this study appeared adequate for ruminant growth. The species contained more than 12% of crude protein. This is quite high and ideal for protein supplementation in animal nutrition. In general, it is advisable to use sweet thorn leaves as a source of protein. Additionally, the low tannin contents in sweet thorn leaves indicate that sweet thorn can be safe to use in animal nutrition if used sparingly. With regard to methane emission, sweet thorn leaf meal inclusion levels used in the present study did not have a significant reduction on methane emission. However, there is need to determine levels of inclusion for optimal methane emission reduction in goats.

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