South African Journal of Animal Science 2022, 52 (No. 1)

Partial replacement of maize meal with high-tannin sorghum meal affects finishing and methane emissions of Pedi goats

N.O. Mavasa, J.W. Ng'ambi & T. Chitura#
Department of Agricultural Economics and Animal Production, University of Limpopo, Private Bag X1106, Sovenga 0727, South Africa

(Submitted 16 June 2021; Accepted 10 August 2021; Published 22 January 2022)

Abstract

This study was conducted to determine the effect of replacing maize meal with *Sorghum vulgare* meal, a high-tannin sorghum meal, in fattening diets on bodyweight and methane emissions by yearling male Pedi goats. A total of 12 yearling male Pedi goats with an average initial liveweight of 14 ± 1 kg were randomly assigned to a complete randomized design with four treatments, which were formulated such that 0%, 10%, 20% and 30% of the maize meal was replaced with *Sorghum vulgare* meal. The experiment was conducted over 28 days, with 21 days adaptation, followed by seven days for sample collection. Replacing maize meal with sorghum did not produce detectable (P >0.05) effects on bodyweight and live weight gain. The various replacement levels of sorghum meal had no detectable effects on the blood cell profile of Pedi goats either. However, they reduced methane emission and improved feed conversion ratio (P <0.05), which allowed for an approximation of the feed required by growing goats. These findings may assist farmers in selecting and utilizing the right feeds to maximize profitability in the small-stock farming sector.

Keywords: blood cells, feed intake, live weight, *Sorghum vulgare*
#Corresponding author: teedzai.chitura@ul.ac.za

Introduction

In South Africa, indigenous goats are more common in communal areas, where they play an important socioeconomic role, whereas improved breeds such as the Boer goat are kept mostly on commercial farms (Webb & Mamabolo, 2004). Goats are generally reared on pasture. Hence, pasture and grazing management can affect forage nutritive value and total intake by the animals (Meister *et al*., 2021). The major constraints to the improvement of livestock productivity in Limpopo are the low quantity and quality of forage during the dry season, which cannot meet the nutrient requirements of the animals (Matlebyane, 2005). Forage quality affects methane production significantly. If the feed quality is poor, the production of methane gas increases (Saha *et al*., 2014). The enteric methane produced by ruminants is a loss of feed energy from the diet, and represents inefficient utilization of the feed, which could have been converted into animal products (Chagunda *et al*., 2009; Van Wyngaard *et al*., 2018). Thus, in addition to adverse environmental implications, ruminant methanogenesis represents a loss of 2% to 12% of the gross energy intake (Van Haarlem *et al*., 2008). Therefore, minimizing enteric methane emission from ruminant production while enhancing feed conversion efficiency and dietary nutrient utilization is a major goal for sustainable livestock production (Min *et al*., 2020). Naumann *et al*. (2017) indicated that feeding tannins and other approaches could reduce enteric methane emission.

Tannins can be divided into hydrolysable and condensed tannins (CT), which have different chemical structures (Goel *et al*., 2012). Tannins can be beneficial or detrimental to ruminants, depending on which and how much is consumed, the compound's structure, its molecular weight, and the physiology of the consuming species ((Hagerman & Butler, 1991). Tannins, particularly CT, bind predominantly via hydrogen bonds with dietary protein in the rumen, preventing enzymatic hydrolysis. Additionally, tannins inhibit methanogens and protozoa and generally affect the rumen microbiota (Verma *et al*., 2021). Therefore, they can reduce enteric methane production. Tannins are present in the neutral detergent fibre (NDF) and acid detergent fibre (ADF) of the tree leaves, and are bound to the cell wall and cell protein, and decrease

URL: http://www.sasas.co.za
ISSN 0375-1589 (print), ISSN 2221-4062 (online)
Publisher: South African Society for Animal Science http://dx.doi.org/10.4314/sajas.v52i1.2

digestibility. They can also cause decreased palatability, feed intake, growth rate, nutrient utilization and iron absorption (Lata, 2021).

Sorghum, the fifth most important grain crop after wheat, maize, rice and barley (FAO, 2003), contains tannins (Hatmi *et al.*, 2021) and is characterized by high energy and feeding values (Berenji & Dahlberg, 2004), making it a suitable replacement for maize in animal feeding. Sorghum is transitioning from a mere food and fodder crop to a valued raw material for animal feed all over the world, because numerous animal feed studies showed that it was a good source of energy and protein (Venkateswarlu *et al.*, 2019). Similarly, Dicko *et al.* (2006) indicated that the nutrient composition of sorghum proved that it was a good source of energy, proteins, carbohydrates, vitamins and minerals, including trace elements, particularly iron and zinc. When processed correctly and balanced with other feed ingredients, sorghum can serve as the primary grain source in animal diets (Kimberly *et al.*, 2019). To improve its feeding value, greater understanding is needed of importnat antinutritive properties, including kafirin, phenolic compounds, and phytate. In addition, the growing ethanol industry has increased the amount of sorghum distiller's grains for use in animal sectors (Kimberly *et al.*, 2019).

This study therefore focused on the effect of partial replacement of maize meal with sorghum meal in fattening diets on performance and methane emissions by yearling male Pedi goats.

Materials and methods

The study was conducted at the University of Limpopo Livestock Unit, Limpopo, South Africa, during the autumn season of 2019. The University of Limpopo Farm lies at latitude 27.55 °S and longitude 24.77 °E. The mean ambient temperatures around the study area are 28 ° in winter and 36 °C in summer (Shiringani, 2007). The mean annual rainfall ranges between 446.8 and 468.4 mm. The dry season occurs between April and October and the rainy season between November and March (Kutu & Asiwe, 2010).

The experimental diets consisted of yellow maize meal and tef grass (*Eragrostis tef*) as a basal diet mixed with *Sorghum vulgare* meal (henceforth sorghum meal) (Table 1). The diet mixture supplied the animals with adequate amounts of dry matter (DM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), fat, energy, minerals, vitamins and tannins, which inhibited detrimental effects. Ground yellow maize meal, lamb and ewe pellets and sorghum meal were purchased at Polokwane NTK store, South Africa. Tef grass was bought from a local animal feeds producer. The grass was then cut into small pieces with a lasher and ground into smaller pieces (using a 3 mm sieve) with a milling machine at the Aquaculture Research Unit, University of Limpopo. Sorghum seeds were ground into smaller amounts (100 g). Each feed sample was stored in an airtight bag and kept until needed for chemical analysis.

Table 1 Dietary treatments containing various levels of maize meal and *Sorghum vulgare* meal fed ad libitum to fattening yearling male Pedi goats

Treatment code	Treatment description
$M_{100}S_0$	Maize meal-based fattening diet containing no *Sorghum vulgare* meal
$M_{90}S_{10}$	Maize meal-based diet in which *Sorghum vulgare* meal replaced 10% of maize meal
$M_{80}S_{20}$	Maize meal-based diet in which *Sorghum vulgare* meal replaced 20% of maize meal
$M_{70}S_{30}$	Maize meal-based diet in which *Sorghum vulgare* meal replaced 30% of maize meal

The first objective of the study was to analyse the nutrient and tannin contents in the four diets. The second was to determine the replacement effect of maize meal with sorghum meal on growth performance and methane emission in the yearling male Pedi goats. A comparative analysis of maize and *Sorghum vulgare* (Nyamambi *et al.*, 2007) is presented in Table 2. The goats were randomly assigned to the four treatments. Each treatment had three replications, and one animal per replicate. The study lasted for 28 days (21 days preliminary and seven days' collection). The goats were housed in well-ventilated individual metabolic pens with clean water and a mineral lick being provided ad libitum. The lick contained a minimum of 200 g/kg protein, a maximum of 22 g/kg urea, 100 g/kg crude fibre, at least 10 g/kg and not more than 35 g/kg calcium, at least 4 g/kg phosphorus, 8 g/kg sulphur, 12 g/kg potassium, 15 mg/kg copper, 100 mg/kg manganese, 120 mg/kg zinc, 0.5 mg/kg cobalt, 3 mg/kg iodine, 75 mg/kg iron, 0.5 mg/kg selenium, and 88 IU vitamin A, and provided 8.8 MJ ME/kg.

Table 2 Comparative nutritive analyses of yellow maize and *Sorghum vulgare*

	Yellow maize	*Sorghum vulgare*
Dry matter (DM), %	88.98	90.64
Ash, % DM	1.49	1.74
Crude protein, % DM	10.08	10.24
Fat, % DM	4.40	3.79
Neutral detergent fibre, % DM	11.50	12.58
Acid detergent fibre, % DM	3.58	6.74
Energy, kcal/kg dm	3.32	4.57
Tannins, % DM	ND	6.23

ND: not detectable
Source**:** Nyamambi *et al.,* 2007

The goats were weighed with an electronic weighing scale at the beginning of the experiment and then weekly. These weights were used to calculate the growth rates. Feed intake was measured daily by subtracting the weight of the orts from the feed offered. Feed conversion ratio was calculated as the total amount of feed consumed divided by weight gain (McDonald *et al.*, 2010).

Dry matter of the feeds, feed refusals and faecal material was determined by drying the samples in the oven for 24 hours at 105 °C. Ash contents of feeds, feed refusals and faecal samples were assessed by ashing the sample at 600 °C in a muffle furnace overnight. Ash was analysed for calcium, phosphorus, potassium and sodium. Nitrogen contents of feed and faecal samples were calculated by the Kjeldahl method). Gross energy values of feed and faecal samples were determined with a bomb calorimeter (AOAC, 2012).

The goats were housed in specially designed metabolic cages fitted with a urine bottle, and separate troughs for water and feed. Faecal bags were used to collect faeces, which were collected from each goat for seven days, weighed, dried, weighed again and stored for chemical analysis. Water and a mineral lick were provided ad libitum. Apparent digestibility (AD) of nutrients was calculated with this formula (Khan *et al*., 2003):

$$\mathrm{AD} = \frac{(Amount\ of\ nutrients\ ingested - Amount\ of\ nutrient\ excreted)}{Amount\ of\ nutrient\ ingested}$$

Methane emissions were measured with a hand-held methane detector (Chagunda *et al*., 2009). The laser beam of the detector was pointed 1 m away from the goat to identify atmospheric methane and onto the nasal area to sense the methane expired by the goat. Measurements were taken on individual goats that were at least 6 m away from any other animal. The laser beam was easy to see, since the goats were kept in an enclosed building. The measurements were taken two hours after feeding when the goats were ruminating. All measurements were taken at the same time of the day, at around 08h00. The measurements for each goat were taken within 60 seconds daily and repeated for seven consecutive days. Methane was then read and reported as parts per million-metre (ppm-m) (Chagunda *et al.*, 2009).

Blood was collected at the end of the experiment. Twelve millilitres were collected from each animal via jugular venepuncture. Five mL and 2 mL of blood samples were placed in labelled bottles containing ethylene diamine tetra acetic acid (EDTA) or sodium oxalate fluoride for haematological analysis and measurement of glucose. An additional 5 mL was collected in an anticoagulant-free plastic tube, allowed to clot at room temperature, and centrifuged at 1500 x g for 10 minutes. The supernatant was collected and stored at -20 °C for biochemical analysis.

The nutrient and tannin contents of the diets were subjected to analysis of variance (ANOVA) using SAS software (SAS Institute Inc., Cary North Carolina, USA). Data that were obtained from the animals were subjected to one-way ANOVA with sorghum inclusion level as the main effect using the GLM procedure of SAS version 9.1.3. When a significant (P <0.05) treatment effect was detected, the least significant difference test was used for mean separation.

Results and Discussion

Results of replacing maize meal with sorghum meal performance of the yearling male Pedi goats are presented in Table 3. There was no detectable effect (P >0.05) of the treatments on the nutrient intake of the goats or on the estimates of digestibility.

Brown and Ng'ambi (2019) reported that inclusion of Vachellia karroo, which contains CT, did not affect daily amounts of OM, CP, NDF and ADF consumed by Pedi bucks. Bhatta et al. (2012) also reported that the dietary treatments of goats fed two concentrations of tannin from mimosa species had no effect on the consumption of DM, energy and CP. However, Mathobela (2018) reported a linear increase in DM, OM, CP, NDF, ADF, fat and energy intakes as *A. tortilis* leaf meal levels increased from 10% to 30%.

Table 3 Effects of replacing maize meal with *Sorghum vulgare* meal on diet intake, digestibility, metabolizable energy, methane emission, bodyweight, weight gain, and feed conversion ratio of yearling male Pedi goats

	Diet			
Variable	$M_{100}S_0$	$M_{90}S_{10}$	$M_{80}S_{20}$	$M_{70}S_{30}$
DM intake, g/day	$273^a \pm 4.1$	$409^a \pm 14.0$	$395^a \pm 19.3$	$335^a \pm 78.9$
OM intake, g/day	$254^a \pm 3.8$	$381^a \pm 11.8$	$365^a \pm 17.9$	$311^a \pm 73.4$
CP intake, g/day	$37^a \pm 0.5$	$55^a \pm 1.9$	$53^a \pm 2.6$	$46^a \pm 10.8$
NDF intake, g/day	$128^a \pm 1.9$	$202^a \pm 6.9$	$191^a \pm 9.9$	$155^a \pm 36.5$
ADF intake, g/day	$87^a \pm 1.2$	$131^a \pm 4.5$	$122^a \pm 6.0$	$104^a \pm 24.6$
Fat intake, g/day	$7^a \pm 0.1$	$9^a \pm 0.3$	$11^a \pm 0.5$	$10^a \pm 2.2$
Energy intake, MJ/day	$3^a \pm 0.1$	$6^a \pm 0.5$	$5^a \pm 0.6$	$5^a \pm 1.2$
DM intake, g/kg $W^{0.75}$	$35^a \pm 0.5$	$53^a \pm 1.8$	$55^a \pm 2.7$	$46^a \pm 10.8$
OM intake, g/kg $W^{0.75}$	$33^a \pm 0.5$	$49^a \pm 1.5$	$50^a \pm 2.5$	$43^a \pm 10.0$
CP intake, g/kg $W^{0.75}$	$4.70^a \pm 0.1$	$7^a \pm 0.2$	$7^a \pm 0.4$	$6^a \pm 1.5$
NDF intake, g/kg $W^{0.75}$	$16^a \pm 0.2$	$26^a \pm 0.9$	$26^a \pm 1.3$	$21^a \pm 5.0$
ADF intake, g/kg $W^{0.75}$	$11^a \pm 0.2$	$17^a \pm 0.6$	$17^a \pm 0.8$	$14^a \pm 3.4$
Fat intake, g/kg $W^{0.75}$	$1^a \pm 0.01$	$1^a \pm 0.04$	$2^a \pm 0.01$	$1^a \pm 0.21$
Energy intake (MJ/kg $W^{0.75}$)	$0^a \pm 0.02$	$1^a \pm 0.06$	$1^a \pm 0.01$	$1^a \pm 0.17$
DM digestibility, %	$61^a \pm 1.0$	$63^a \pm 1.6$	$62^a \pm 0.3$	$63^a \pm 1.2$
OM digestibility, %	$59^a \pm 0.6$	$63^a \pm 1.7$	$62^a \pm 0.5$	$64^a \pm 0.9$
CP digestibility, %	$72^a \pm 0.5$	$73^a \pm 0.5$	$70^a \pm 1.1$	$69^a \pm 3.8$
NDF digestibility, %	$50^a \pm 2.5$	$52^a \pm 2.9$	$62^a \pm 11.6$	$58^a \pm 4.7$
ADF digestibility, %	$38^a \pm 0.8$	$43^a \pm 2.5$	$48^a \pm 8.2$	$45^a \pm 3.9$
Fat digestibility, %	$57^a \pm 3.1$	$39^a \pm 8.7$	$53^a \pm 0.7$	$50^a \pm 2.7$
Energy digestibility, %	$63^a \pm 2.7$	$63^a \pm 1.5$	$60^a \pm 2.7$	$63^a \pm 1.2$
Methane emitted, ppm-m	$15.67^a \pm 0.9$	$10.67^b \pm 0.7$	$12.33^{ab} \pm 0.7$	$12.00^{ab} \pm 1.5$
Initial weight, kg	$14.0^a \pm 0.6$	$14.3^a \pm 0.9$	$13.0^a \pm 1.2$	$13.3^a \pm 1.2$
Final weight, kg	$15.5^a \pm 0.6$	$15.3^a \pm 0.9$	$14.0^a \pm 1.2$	$14.2^a \pm 1.6$
Weight gain, g/day	$71.0^a \pm 51.4$	$143.0^a \pm 103.7$	$143.0^a \pm 103.7$	$119.3^a \pm 86.3$
Feed conversion ratio	$3.9^a \pm 0.1$	$2.9^b \pm 0.1$	$2.8^b \pm 0.2$	$2.8^b \pm 0.1$

$M_{100}S_0$: maize meal-based diet without sorghum meal, $M_{90}S_{10}$: maize meal-based diet with 10% sorghum meal, $M_{80}S_{20}$:maize meal-based diet with 20% sorghum meal, $M_{70}S_{30}$: maize meal-based diet with 30% sorghum meal, DM: dry matter, OM: organic matter, CP: crude protein, NDF: neutral detergent fibre, ADF: acid detergent fibre
[a,b,c] Within a row, values with a common superscript did not differ with probability P =0.05

Dey and De (2014) reported that inclusion of CT at 1.5% did not seem to interfere with rumen microbial fermentation and digestion, resulting in similar digestibility values for various nutrients. Nascimento *et al*. (2021) also reported that no differences were observed in DM and nutrient intake among levels of CT-amended cassava silage blend fed to goats. Non-significant nutrient digestibility differences were probably because of a low to moderate amount of tannins in the diet (Pathak *et al.*, 2014; Dey & De, 2014). However, Salem *et al.* (2006) reported that ingestion by ruminants of feed containing tannin may reduce nutrient digestibility. In other studies, digestibilities of OM, CP, NDF, and ADF in sheep were decreased by adding *A. mearnsii,* which contained CT, to grass-based diets (Carulla *et al.*, 2005).

Finally, including various levels of sorghum meal in the diet provided to the goats in the current study did not produce detectable effects on their bodyweight and live weight gain. Mathobela (2018) also reported that the inclusion of *A. nilotica* leaf meal did not affect live weight changes in yearling male Boer goats fed an *Avena sativa* hay-based diet. The absence of detectable adverse effects on the performance of the goats suggested that tannins in the diets did not alter growth of the goats. Ng'ambu *et al.* (2013) reported improved growth performance when Xhosa lop-eared goats were supplemented with 200 g fresh *Vachellia karroo* leaves. The findings of Ng'ambu *et al.* (2013) might be associated with the observation that moderate level of tannins in the diet can precipitate with soluble proteins and thereby increase protein available to small ruminants (Min & Solaiman, 2018). However, Dludla (2010) indicated that the bodyweight gains of goats decreased with increasing CT concentrations in the diet, which might have been because of reductions in voluntary feed intake and in digestibility of organic matter and fibrous components of the rations (Priolo *et al.*, 2000)

Sorghum meal replacement levels in the current study did affect methane emission. Pedi goats on 10% sorghum meal had lower methane emissions than those that were not fed sorghum meal. These results are in line with several studies that reported lower methane production and emission as the levels of forage containing CT increased (Hariadi *et al*., 2010; Guglielmelli *et al.*, 2011). Similarly, Bhatta *et al*. (2009) reported that *Quebracho* tannins inhibited methane production linearly by 13 - 45% with increasing doses of 5–25% substrates. However, goats on diets containing 0%, 20%, and 30% sorghum meal replacement levels had similar (P >0.05) methane emission values.

Mathobela (2018) reported that a decrease in methane production in Boer goats fed a diet with *A. tortilis* leaf meal might be because of a reduction in fibre digestion (Van Dorland *et al.,* 2007). This resulted in less hydrogen production, which reduced methanogenesis because there was less substrate available for the production of methane (Carulla *et al*., 2005).

In the current study, food conversion ratio (FCR) improved with the level of sorghum meal in the diet. Goats fed the diets that contained 10%, 20% and 30% of sorghum meal had improved FCR compared with those that contained no sorghum meal. The results were in line with the findings of Mathobela (2018), who reported that FCR improved linearly with increased *A. karroo* leaf meal in the diets of Boer goats. The results from the current study are in contrast to those of Al-Dobaib (2009), who found that a diet treated with quebracho tannins at the levels of 1% and 3% of DM did not affect the FCR of lambs, but perhaps tannin levels in their study were too low to have beneficial effects. Likewise, Obeidat *et al.* (2011) observed that replacement of part of barley grain with tannin-rich carob pods did not affect the FCR of Awassi lambs.

Replacing maize meal with sorghum meal did not affect the haematological indices and blood bio-chemical components of male Pedi goats (Table 4). The findings of the current study were in line with the work of Terry *et al.* (2016). These authors reported no differences in blood metabolites among the lambs that were fed diets with various tanniniferous browse levels, suggesting no effect on proteolysis in the rumen. The values of the red blood cells (RBC) reported in the present study were not affected by the replacement levels of sorghum meal. The results, irrespective of replacement level, were consistent with the findings of Solaiman *et al*. (2010), who reported no differences in RBC when Kiko crossbred male kids were fed a *S. lespedeza*-based diet containing varying levels of CT. In the current study, haematocrit (HCT) values were not affected. This agrees with the findings of Brown *et al.* (2016), who reported that HCT was unaffected by various levels of *Vachellia Karroo*. Indices such as mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH) and mean corpuscular haemoglobin concentration (MCHC) could give significant information about the anaemia, dehydration and infection status of an animal (Campbell, 1995). The findings of the present study were similar to the results of Solaiman *et al.* (2010), who reported no differences in MCHC values of goats fed varying levels of tannin-rich *Sericea lespedeza*. Contrary to the current study, Brown *et al.* (2016) reported lower MCHC values of goats fed 50% *A. Karroo* leaf meal and suggested that this might have been caused by the relatively higher levels of CT in that diet.

Table 4 Effect of replacing maize meal with sorghum meal on haematological indices and blood biochemical components of yearling male Pedi goats

	Diet			
Red blood cells	$M_{100}S_0$	$M_{90}S_{10}$	$M_{80}S_{20}$	$M_{70}S_{30}$
Erythrocyte count, x10[12]/l	3[a] ± 0.3	2[a] ± 0.8	3[a] ± 0.1	3[a] ± 0.1
Haemoglobin, g/dl	9[a] ± 0.7	7[a] ± 3.4	11[a] ± 0.3	10[a] ± 0.2
Haematocrit, l/l	0[a] ± 0.0	0[a] ± 0.0	0[a] ± 0.0	0[a] ± 0.1
Mean corpuscular volume, F/l	33[a] ± 1.0	20[a] ± 10.2	32[a] ± 0.3	32[a] ± 0.7
Mean corpuscular haemoglobin, p/g	35[a] ± 35.4	31[a] ± 16.1	34[a] ± 0.5	35[a] ± 1.7
Mean corpuscular haemoglobin, g/dl	108[a] ± 1.1	100[a] ± 52.5	104[a] ± 2.3	110[a] ± 7.2
Red cell distribution width, %	12[a] ± 0.3	7[a] ± 3.6	12[a] ± 0.1	12[a] ± 0.7
White blood cells				
Leucocyte count, 10[9]/l	23[a] ± 6.4	9[a] ± 4.8	21[a] ± 1.0	18[a] ± 1.8
Neutrophils, 10[9]/l	4[a] ± 0.6	3[a] ± 1.7	7[a] ± 1.2	8[a] ± 1.9
Lymphocytes, 10[9]/l	17[a] ± 6.3	5[a] ± 2.9	13[a] ± 2.1	9[a] ± 0.3
Monocytes, 10[9]/l	1[a] ± 1.0	0[a] ± 0.2	1[a] ± 0.0	1[a] ± 0.3
Eosinophils, 10[9]/l	1[a] ± 0.6	1[a] ± 0.4	1[a] ± 0.3	1[a] ± 0.2
Blood glucose, mol/l	3[a] ± 0.2	3[a] ± 0.1	3[a] ± 0.1	3[a] ± 0.0
Blood urea nitrogen, mol/l	5[a] ± 0.7	5[a] ± 0.2	3[a] ± 0.8	3[a] ± 0.6

$M_{100}S_0$: maize meal-based diet without sorghum meal, $M_{90}S_{10}$: maize meal-based diet with 10% sorghum meal, $M_{80}S_{20}$:maize meal-based diet with 20% sorghum meal, $M_{70}S_{30}$: maize meal-based diet with 30% sorghum meal
[a,b,c] Within a row, values with a common superscript did not differ with probability *P* =0.05

The current study failed to reveal significant differences in the white blood cell count of the goats fed various levels of sorghum meal. The results were similar to those of Mathobela (2018), who found that no significant variation in white blood cell counts of Boer goats fed diets with various levels of *A. karroo* leaf meal. Brown *et al.* (2016) also reported no differences in white blood cell counts of indigenous Pedi goats fed varying levels of *Vachellia karroo* leaf meal in *Setaria verticillata* hay-based diets. In the current study, replacing maize meal with sorghum meal did not affect blood urea nitrogen values, which indicated that the quality of dietary protein was satisfactory (Roy, 1970). These results, irrespective of replacement level, were comparable with those of Mathobela (2018), who reported no significant variations in the blood urea nitrogen values of Boer goats with various levels of *A. karroo* leaf meal. The results of the current study were contrary to those of Leibholz (1970), who reported high blood urea nitrogen levels in the control diet, although the low weight gain suggested some level of body protein catabolism in the control group. However, Olafadehan (2011) observed that goats fed a sole diet of *Pterocarpus erinaceous* or *Andropogon gayanus* grass had depressed serum glucose compared with animals on mixed forage diets. Goats fed maize meal diets with various levels of sorghum meal showed no significant variations in blood glucose values. These results agreed with those of Solaiman *et al.* (2010), who reported that serum glucose was unaffected as *Sericea lespedeza* inclusion increased in the diet of Kiko crossbred male kids. Other studies noted variations in blood glucose levels when CT were incorporated in ruminant diets. Olafadehan (2011) stated that inclusion of tannin-rich diets improved glucose levels.

Conclusions

Replacing 10% of the maize meal with sorghum meal in the diet of goats resulted in better feed conversion and lowered methane emissions than the unaugmented diet. However, analysis of the productive performance, haematological indices and blood biochemical components did not result in significant differences among the treatments. It was concluded that a high tannin sorghum meal may be used to replace up to 30% of maize meal in goat fattening diets without apparent deleterious consequences. However, further studies should be conducted to validate the present findings.

Acknowledgements

The authors would like to acknowledge the financial assistance from the Department of Agricultural Economics and Animal Production, University of Limpopo.

Authors' Contributions

NOM collected the data for this study, analysed the data and wrote the initial draft of this manuscript. JWN collaborated in the interpretation of the results and drafting the manuscript. TC interpreted the results and finalized the manuscript. All the authors approved the final version of the manuscript.

Conflict of Interest Declaration

All the authors do not have any conflicts of interest to declare.

References

Al-Dobaib, S.N., 2009. Effect of different levels of quebracho tannin on nitrogen utilization and growth performance of Najdi sheep fed alfalfa *(Medicago sativa)* hay as a sole diet. J. Anim. Sci. 80, 532-541. DOI: 10.1111/j.1740-0929.2009.00662.x

AOAC, 2012. Official methods of analysis. Association of Official Analytical Chemists International. 17th ed. AOAC, Washington DC.

Berenji, J. & Dahlberg J., 2004. Perspectives of sorghum in Europe. J. Agron. Crop Sci. 190(5), 332-338. DOI: 10.1111/j.1439-037X.2004.00102.x

Bhatta, R., Uyeno, Y., Tajima, K., Takenaka, A., Yabumoto, Y., Nonaka, I., Enishi, O. & Kurihara, M., 2009. Difference in the nature of tannins on in vitro ruminal methane and volatile fatty acid production and on methanogenic archaea and protozoal populations. J. Dairy Sci. 92, 5512-5522. DOI: 10.3168/jds.2008-1441

Bhatta, R.O., Enishi, Y., Yabumoto, I., Nonaka, N., Takusari, K, Higuchi, K, Tajima, Takenaka, A. & Kurihara, M., 2012. Methane reduction and energy partitioning in goats fed two concentrations of tannin from Mimosa spp. J. Agric. Sci. 151, 119-128. DOI: 10.1017/S0021859612000299

Brown, D. & Ng'ambi, J.W., 2019. The effects of dietary *Vachelia Karroo* leaf meal inclusion on meat quality and histological parameters in Pedi bucks fed *Setaria verticillata* hay-based diet. J. Appl. Ecol. Environ. Res. 17(2), 2893-2909. DOI: 10.15666/aeer/1702_28932909

Brown, D., Ng'ambi, J.W., Norris D. & Mbajiorgu, F.E., 2016. Blood profiles of indigenous Pedi goats fed varying levels of Vachellia Karroo leaf meal *in Setaria verticillata* hay-based diet. S. Afr. J. Anim. Sci. 46, 433-439. DOI: 10.4314/sajas.v46i4.11

Dicko, M.H., Gruppen, H., Traoré, A.S., Voragen, A.G. & Van Berkel, W.J., 2006. Sorghum grain as human food in Africa: relevance of content of starch and amylase activities. African J. Biotech. 5(5), 384-395. https://tspace.library.utoronto.ca/bitstream/1807/6695/1/jb06065.pdf

Campbell, T.W., 1995. Avian haematology and cytology. Iowa State University Press, Ames, , USA.

Chagunda, M.G.G., Römer, D.A.M. & Roberts, D.J., 2009. Effect of genotype and feeding regime on enteric methane, non-milk nitrogen and performance of dairy cows during the winter-feeding period. Livest. Sci. 122, 323-332. https://www.cabdirect.org/cabdirect/abstract/20093148326

Carulla, J.E., Kreuzer, M., Machmuller, A. & Hess, H.D., 2005. Supplementation of *Acacia mearnsii* tannins decreases methanogenesis and urinary nitrogen in forage-fed sheep. Austr. J. Agric. Res. 56, 961-970. https://doi.org/10.1071/AR05022

Dey, A. & De, P.S., 2014. Influence of condensed tannins from *Ficus bengalensis* leaves on feed utilization, milk production and antioxidant status of crossbred cows. Asian-Australas. J. Anim. Sci. 27 (3), 342-348. DOI: 10.5713/ajas.2013.13295

Dludla, S.P., 2010. The effect of condensed tannins on goat's body weight. MSc thesis. Department of Agricuture, Faculty of Science and Agriculture, University of Zululand, South Africa.

Food and Agriculture Organization of the United Nations, 2003. FAOSTAT database. FAO, Rome, Italy. https://www.fao.org/faostat/en/#home

Goel, G. & Makkar, H.P.S., 2012. Methane mitigation from ruminants using tannins and saponins. Trop. Anim. Health Prod. 44, 729-739. DOI: 10.1007/s11250-011-9966-2

Guglielmelli, A., Calabrò, S., Primi, R., Carone, F., Cutrignelli, M.I., Tudisco, R., Piccolo, G., Ronchi, B. & Danieli, P.P. 2011. In vitro fermentation patterns and methane production of sainfoin hay with different condensed tannin contents. Grass Forage Sci. 66, 488-500. DOI: 10.1111/j.1365-2494.2011.00805.x

Hagerman A.E. & Butler L.G., 1991. Tannins and lignins. In: G.A. Rosenthal. & M.R. Berenbaum (eds). Herbivores, their interactions with secondary plant metabolites. Vol I: The chemical participants. Academic Press, NY. Pp. 355-388.

Hariadi, B.T. & Santoso, B., 2010. Evaluation of tropical plants containing tannin on in vitro methanogenesis and fermentation parameters using rumen fluid. J. Sci. Food Agric. 90, 456-461. DOI: 10.1002/jsfa.3839

Hatmi, R.U., Wirabhuana, A., Wanita, Y.P. & Tando, E., 2021. The effect of the polishing process and sorghum type (brown and white) on the content of crackers nutrition. IOP Conference Series, Earth and Environmental Science 759(1), 012037.

McCuistion, K.C., Selle, P.H., Liu, S.Y. & Goodband, R.D., 2019. Sorghum as a feed grain for animal production. Sorghum and Millets (2nd Edition), AACC International Press, Pg. 355-391 DOI: 10.1016/B978-0-12-811527-5.00012-5

Khan, M.A., Nisa M.U. & Sarwar, M., 2003. Techniques measuring digestibility for the nutritional evaluation of feeds. Intern. J. Agric. Biol. 5(1), 91-94. http://www.fspublishers.org/published_papers/33580_..pdf

Kutu, F.R. & Asiwe, J.A.N., 2010. Assessment of maize and dry bean productivity under different intercrops system and fertilization regimes. African J. Agric. Res. 15, 1627-1631. DOI: 10.5897/AJAR09.147

Lata, M., 2021. Anti-nutritional factors: Its impacts in animal nutrition. J. Trop. Anim. Res. 1(3), 128-131. https://aavpublisher.com/cuploads/POPULAR%20ARITCLE%201.pdf

Leibholz, J., 1970. The effect of starvation and low nitrogen intakes on the concentration of free amino acids in the blood plasma and on the nitrogen metabolism in sheep. Austr. J. Agric. Res. 23, 723-734. https://doi.org/10.1071/AR9700723

Mathobela, R.M., 2018. Effect of dietary tanniniferous *Acacia nilotica* leaf meal inclusion level on productivity methane emission and productivity in yearling Boer bucks. MSc thesis. Department of Agricultural Economics and Animal Production, Faculty of Science and Agriculture, University of Limpopo, South Africa.

Matlebyane, M.M., 2005. Relationship between chemical composition, in vitro digestibility and locally based feeding value rankings and medicinal use of some common forages for ruminant livestock in three chief areas of Capricorn Region of Limpopo Province, South Africa. MSc dissertation. Department of Animal Production, University of Limpopo, South Africa.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D., Morgan, C.A., Sinclair, L.A. & Wilkinson, R.G., 2010. Nutrient digestion and the environment. In: Animal nutrition. 7th ed. Blackwell, London, UK. Pp. 188-189.

Meister, N.C., da Silva Cardoso, A., Alari, F.O., Lemos, N.L.S., Frighetto R.T.S., Malheiros E.B., Reis R.A. & Ruggieri A.C., 2021. Effect of pasture management on enteric methane emissions from goats. Trop. Anim. Health Prod. 53(1), 94. DOI: 10.1007/s11250-020-02507-z

Min, B.R. & Solaiman S., 2018. Comparative aspects of plant tannins on digestive physiology, nutrition and microbial community changes in sheep and goats: A review. J. Anim. Physiol. Anim. Nutr. (Berl.)102(5).1181-1193. DOI: 10.1111/jpn.12938.

Min, B.R.,Solaman, S., Waldrip, H.M., Parker, D., Todd, R.W. & Brauer, D., 2020. Dietary mitigation of enteric methane emissions from ruminants. A review of plant tannins mitigation options. Anim. Nutr. 6, 231-246. DOI: 10.1016/j.aninu.2020.05.002

Naumann, H.D., Tedeschi, L.O., , W.E. & Huntley, N.F., 2017. The role of condensed tannins in ruminant animal production, advances, limitations and future directions. Revista Brasileira de Zootecnia. 46, 929-949. DOI: 10.1590/s1806-92902017001200009

Nascimento, T.V.C., Oliveira, R.L., Menezes, D.R., de Lucena, A.R.F., Queiroz, M.A.Á., Lima, A.G.V.O., Ribeiro, R.D.X. & Bezerra, L.R., 2021. Effects of condensed tannin-amended cassava silage blend diets on feeding behavior, digestibility, nitrogen balance, milk yield and milk composition in dairy goats. Animal 15(1), 100015. https://doi.org/10.1016/j.animal.2020.100015

Ng'ambu, S., Muchenje, V. & Marume, U., 2013. Effect of *Acacia Karroo* supplementation on growth, ultimate pH, colour and cooking loses of meat from indigenous Xhosa lop-eared goats. Asian-Austr. J. Anim. Sci. 26, 128-133. DOI: 10.5713/ajas.2012.12046

Nyamambi, B., Ndlovu, L.R., Naik, Y.S. & Kock, N., 2007. Intestinal growth and function of broiler chicks fed sorghum-based diets differing in condensed tannin levels. S. Afr. J. Anim. Sci. 37, 202-214. DOI: 10.4314/sajas.v37i3.4092

Obeidat, R.S., Alrababah, M.A., Abdullah, A.Y., Alhamad, M.N., Gharaibeh, M.A., Rababah, T.M. & Abu Ishmais, M.A., 2011. Growth performance and carcass characteristics of Awassi lambs fed diets containing carob pods (*Ceratonia siliqua* L.). Small Ruminant Res. 96, 149-154. DOI: 10.1016/j.smallrumres.2010.12.001

Olafadehan, O.A., 2011. Change in haematological and biochemical diagnostic parameters of Red Sokoto goats fed tannin-rich *Pterocarpus erinaceus* forage diets. Veterinarski Arhiv 81, 471-483. http://vetarhiv.vef.unizg.hr/papers/2011-81-4-5.pdf

Pathak, A.K., Dutta, N., Banerjee, P.S., Goswami, T.K. & Sharma, K., 2014., Effect of condensed tannins supplementation through leaf meal mixture on voluntary feed intake, immune response and worm burden in Haemonchus contortus infected sheep. J. Parasitic Diseases 40, 100-105. DOI: 10.1007/s12639-014-0455-1

Priolo, A., Waghorn, G.C., Lanza, M., Biondi, L. & Pennisi. P., 2000. Polyethylene glycol as a means for reducing the impact of condensed tannins in carob pulp: Effects on lamb growth, performance and meat quality. J. Anim. Sci. 78, 810-816. DOI: 10.2527/2000.784810x

Roy, A.V., 1970. Rapid method for determining alkaline phosphatase activity in serum with thymolphthalein monophosphate. Clin. Chem. 16, 431-436. https://doi.org/10.1093/clinchem/16.5.431

Saha, C.K., Ammon, C., Berg, W. & Fiedler M., 2014. Seasonal and diel variations of ammonia and methane emissions from a naturally ventilated dairy building and the associated factors influencing emissions. Sci. Total Environ. 468-469, 53-62. DOI: 10.1016/j.scitotenv.2013.08.015

Salem, A.Z.M., Salem, M.Z.M., El-Adawy, M.M. & Robinson, P.H., 2006. Nutritive evaluations of some browse tree foliages during the dry season: Secondary compounds, feed intake and in vivo digestibility in sheep and goats. Anim. Feed Sci. Technol. 127(3-4), 251-267. DOI:10.1016/J.ANIFEEDSCI.2005.09.005

Shiringani, R.P., 2007. Effects of planting date and location on phenology, yield and yield components among selected cowpea varieties. MSc thesis. School of Agriculture, University of Limpopo, South Africa.

Solaiman, S., Thomas, J., Dupre, Y., Min, B.R., Gurung, N., Terril, T.H. & Haenlein, G.F.W., 2010. Effect of feeding *Sericea lespedeza (Lespedeza cuneata)* on growth performance, blood metabolites, and carcass characteristics of Kiko crossbred male kids. Small Ruminant Res. 93, 149-156. DOI: 10.1016/j.smallrumres.2010.05.015

Terry, A., Wilkinson, R. & Dei, H.K., 2016. Effects of tanniferous browse plant supplementation on the nutrient digestibility and growth of Djallonké rams. Intern. J. Livest. Prod. 7, 122-127. DOI: 10.5897/IJLP2016.0314

Van Dorland, H.A., Wettstein, H.R., Leuenberger, H. & Kreuzer, M., 2007. Effect of supplementation of fresh and ensiled clovers to ryegrass on nitrogen loss and methane emissions in dairy cows. Livest. Sci. 111, 57-69. DOI: 10.1016/j.livsci.2006.11.015
Van Haarlem, R.P., Desjardins, R.L., Gao, Z., Flesch, T.K. & Li, X., 2008. Methane and ammonia emissions from a beef feedlot in western Canada for a twelve-day period in the fall. Can. J. Anim. Sci. 88, 641-649. https://doi.org/10.4141/CJAS08034
Van Wyngaard, J.D.V., Meeske, R. & Erasmus, L.J., 2018. Technical note: A simple back-mounted harness for grazing dairy cows to facilitate the sulfur hexafluoride tracer gas technique. J. of Dairy Sci. 101, 2655-2658. https://doi.org/10.3168/jds.2017-13821
Venkateswarlu R., Aruna, C., Visarada, K.B.R.S. & Venkatesh Bhat, B., 2019. Chapter 14 - Sorghum for animal feed. In: C. Aruna, K.B.R.S. Visarada, B. Venkatesh Bhat, & Vilas A. Tonapi (editors). Woodhead Publishing Series in Food Science, Technology and Nutrition, Breeding Sorghum for Diverse End Uses, Woodhead Publishing, Pg. 229-238.
Verma, S., Taube, F. & Malisch, C.S., 2021. Examining the variables leading to apparent incongruity between anti-methanogenic potential of tannins and their observed effects in ruminants – A review. Sustainability 13(5), 2743. https://doi.org/10.3390/su13052743
Webb, E.C. & Mamabolo, M.J., 2004. Production and reproduction characteristics of South African indigenous goats in communal farming systems. S. Afr. J. Anim. Sci. 34 (Suppl. 1), 236-239.