Blood profiles of indigenous Pedi goats fed varying levels of *Vachellia karroo* leaf meal in *Setaria verticillata* hay-based diet

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(Received 21 November 2015; Accepted 8 November 2016; First published online 1 December 2016)

Abstract

Vachellia karroo (*Acacia karroo*) is promising fodder for goats in the critical dry season in communal rangelands. The only limitation to the use of this fodder tree is the presence of phenolic compounds, such as condensed tannins. A study was conducted to investigate the effects of tanniniferous *V. karroo* leaf meal feeding on blood profiles of indigenous Pedi goats fed a basal diet of *Setaria verticillata* grass hay. Twenty indigenous Pedi goats, weighing 18 ± 2 kg, were allocated in a completely randomized design to five dietary treatments containing *V. karroo* leaf meal at 20% ($S_{80}A_{20}$), 25% ($S_{75}A_{25}$), 30% ($S_{70}A_{30}$), 40% ($S_{60}A_{40}$) and 50% ($S_{50}A_{50}$) of the total diet in a 22-day trial. Twelve ml of blood were collected from the jugular vein from each goat before and after the experiment for haematological and serum biochemical assays. Daily dry matter intake (DMI) was similar across treatments, ranging from 633 g to 765 g per goat per day. There was no difference in initial and final bodyweights of goats consuming various experimental diets. However, bodyweight gains were significantly higher in goats fed a diet with 50% leaf meal as compared with other treatment groups. There were no differences in haematological indices of Pedi goats except for mean corpuscular haemoglobin (Hb) concentration. Goats fed 50% leaf meal had significantly lower mean corpuscular haemoglobin concentration (MCHC) values as compared with other treatment groups. Similarly, there were no differences in the blood serum chemistry of goats that consumed various inclusion levels of *V. karroo*, except for serum total protein (TP) and alanine aminotransferase (ALT). Goats fed 50% leaf meal had depressed serum TP, while serum enzyme Alanine aminotransferase (ALT) concentration decreased significantly in goats fed 25% leaf meal as compared with those on the 20% dietary treatment. Tannin concentration of 8.2 g/kg dry matter (DM) had no toxic effect on experimental animals. A 40 % inclusion of *V. karroo* in a *Setaria verticillata* hay-based diet may be fed to indigenous Pedi goats without compromising the immunity system and health of the animals.

Keywords: Condensed tannin, fodder, haematology, serum
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Introduction

Indigenous Pedi goats are important domestic animals in Limpopo, South Africa. They contribute immensely to the economy and food security of many smallholder farmers in this area (Motubatse *et al*., 2008). However, their productivity is constrained by shortage of good-quality feed, especially during the long dry season (Brown *et al*., 2016). There is insufficient plant biomass to support the production of goats in this period, resulting in poor reproductive performance and slow attainment of market weight. Alternative feed resources may alleviate this nutritional fluctuation. Fodder tree and shrub legumes have high potential values as sources of feed for ruminant livestock during the austere period (Mapiye *et al*., 2011).

Vachellia karroo (*Acacia karroo*) is one of the most widespread and abundant indigenous tree legume species in southern Africa, especially in communal rangelands (Mapiye *et al*., 2011). It is adapted to free draining acid infertile soils, shows excellent drought tolerance, is resistant to wide temperature variations, and retains green leaves during long dry seasons (Barnes *et al*., 1996). *V. karroo* leaves contain high levels of crude protein (CP) (100–160 g/kg DM) and essential amino acids (Chepape *et al*., 2011), and have potential as a protein supplement for goats fed low-quality roughage. However, their use is constrained by

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.v46i4.11

the presence of phenolic compounds, such as condensed tannin (CT) (Mokoboki *et al*., 2005). According to Min *et al*. (2003), CTs are the most common type of tannin in forage legumes, trees and shrubs. Feeding relatively high CT forages to ruminants and pseudo ruminants has been reported to produce adverse effects such as reduction in feed intake and animal performance, inhibition of digestive enzymes, depressed blood Hb, elevated serum creatinine, and mortality (Silanikove *et al*., 1994; Bhat *et al*., 2013). *Setaria verticillata* (L.) P. Beauv. is a perennial grass of the tribe Paniceae and is grown widely by commercial farmers in Limpopo, South Africa (Shaheen *et al*., 2011; Brown *et al*., 2016). The grass is well grazed in summer and is suitable for hay making (Oudtshoorn, 1992). Mixing shrubs with grass hay-based diets has been hypothesized as an efficient way of diluting the negative effects of undesirable secondary compounds, such as tannins (Bhat *et al*., 2013), because the secondary metabolites, particularly CT, in tree fodders could produce intoxication if consumed in excess (Olafadehan *et al*., 2014).

Blood is an important medium in assessing the health status of animals. The physiological and the pathological conditions of animals can be assessed by haematological and biochemical analyses of the blood (Khan *et al*., 2011). Adverse effects of tannin-rich *Pterocarpus erinaceus* have been reported in the blood of goats (Olafadehan, 2011). However, there is a dearth of information on the haematological and biochemical profiles of indigenous Pedi goats fed tanniniferous *V. karroo* leaf meal. The objective of this study was therefore to determine certain haematological and biochemical parameters of indigenous Pedi goats fed a basal diet of *Setaria verticillata* grass hay supplemented with various levels of *V. karroo* leaf meal.

Materials and Methods

The experiment was conducted at the Goat Unit of the University of Limpopo Experimental farm. The farm is located about 10 km north west of Turfloop Campus, which lies at latitude 27.55 °S and longitude 24.77 °E. The ambient temperature at the study site ranges between 20 and 36 °C in summer (November to January) and between 5 and 25 °C in winter (May to July). It receives mean annual rainfall of less than 400 mm. The vegetation is a mixture of shrubs (mainly *Vechellia* species), trees and grass. This experiment was conducted in compliance with the Turfloop Research Ethics Committee (TREC/12/2014:IR).

Twenty yearling indigenous Pedi goats with an average initial live weight of 18 ± 2 kg were used in the study. The goats were randomly divided into five groups consisting of four animals per group. The groups were allocated to five treatments in a completely randomized design. Before the experiment, the pens and surrounding environment were cleaned thoroughly and disinfected with antiseptic (Jeyes Fluid manufactured by Tiger Brands (Pty) Ltd South Africa). The goats were given a prophylactic treatment consisting of intramuscular injections of antibiotics (oxytetracycline LA) at the rate of 1 ml/10 kg BW (Inversa Spain), drenched with anthelmintic (Valbazen® broad-spectrum dewormer, Pfizer Inc, NY, USA), and sprayed against ectoparasites with diazintol. The goats were housed in individual holding pens (1 x 3 m^2). The pens were installed in a well-ventilated shed with one side open to natural light, and roofed to protect goats against sun and rain. The goats were weighed three times, at the beginning, middle, and end of the study. Weighing was carried out before morning feeding to avoid feed effect (Sarwatt *et al*., 2003). Average live weight gain was determined as the difference between initial and final weights divided by the total number of the experimental days.

Vachellia karroo fodder was hand harvested at the University of Limpopo Experimental Farm with long scissors in summer (November to January). The branches with the leaves were air-dried for three days under the shade to minimize nutrient losses to ultraviolet rays. After drying, leaves were separated from the branches by shaking them off gently with a long stick. Thorns were also removed, leaving the twigs behind. *Setaria verticillata* (bristle grass) grass hay was bought from the local farmer (Flourie Boerdery Farm, Polokwane, RSA). Botanical authentication of the plant materials was done at Larry Leach Herbarium, Department of Biodiversity, University of Limpopo. The adaptation period lasted for two weeks, during which goats were maintained solely on *Setaria verticillata* grass hay. At the end of the adaptation period, goats were introduced to the dietary treatments (Table 1) for three weeks. The grass and *V. karroo* leaves were chopped into smaller sizes of 13 mm and mixed according to the dietary treatments in Table 1, to avoid diet selection. The goats were fed *ad libitum*, allowing a 15 % refusal of each diet, as suggested by Kaitho *et al*. (1996). Water was provided *ad libitum.* Feeding was done at 08:00 h daily. The amount of feed offered and refusals were measured during the collection period. The collection period lasted 22 days.

Table 1 Feed composition of the experimental diets

Diet code	Diet description
$S_{80}A_{20}$	80% *Setaria verticillata* hay and 20% *Vachellia karroo* leaves
$S_{75}A_{25}$	75% *Setaria verticillata* hay and 25% *Vachellia karroo* leaves
$S_{70}A_{30}$	70% *Setaria verticillata* hay and 30% *Vachellia karroo* leaves
$S_{60}A_{40}$	60% *Setaria verticillata* hay and 40% *Vachellia karroo* leaves
$S_{50}A_{50}$	50% *Setaria verticillata* hay and 50% *Vachellia karroo* leaves

Blood samples were collected from each animal via the jugular vein with hypodermic syringes at the start and end of the experiment. Blood samples (5 ml) were collected into labelled sterile bottles containing ethylenediaminetetraacetic acid (EDTA) as anticoagulant to determine haematological parameters. Blood samples for serum analysis were collected into anticoagulant free bottles, allowed to coagulate at room temperature, and centrifuged at 1500 x g for 10 minutes. The supernatant sera were collected and stored at -20 ºC prior to biochemical analysis. Blood samples (2 ml) were collected in sodium oxalate fluoride bottles for serum glucose analysis.

Composite samples of the experimental diets were analysed for DM, organic matter (OM), CP, ash and fat (AOAC, 1990). Fibre components of the diets were analysed according to the methods of Van Soest *et al*. (1994). Total phenolics were determined using Folin-Ciocalteu methods, and expressed as tannic acid equivalent (% DM) (Makkar *et al*., 1993). CTs were determined using the Butanol-HCl method, and expressed as leucocyanidin equivalent (% DM). Determination of haematocrit (HCT) and Hb concentration followed the procedures outlined by Dacie & Lewis (2001). Red blood cells (RBC) and total white blood cells (WBC) were determined with the Neubauer haemocytometer after appropriate dilution. Mean corpuscular haemoglobin concentrations (MCHC), mean corpuscular haemoglobin (MCH) and mean corpuscular volume (MCV) were calculated from RBC, Hb and HCT values, as described by Dacie & Lewis (2001). Serum total protein and its components were obtained by the biuret method. Sodium oxalate fluoride was used for glucose preservation, while the blood glucose was determined by enzymatic colorimetric test (Quimica Clinica Applicada, SA). Mineral elements were estimated with an atomic absorption spectrophotometer, Model 490 (Gallenkamp & Co. Ltd., London). The activities of the enzymes ALT and aspartate transaminase (AST) were measured according to the method of Reitman & Frankel (1957).

Data were scrutinised by analysis of covariance (ANCOVA) using blood baseline values as the covariate to control statistically for differences in baseline values. Where the covariate showed no significant effect, the data were analysed with analysis of variance (ANOVA) in a completely randomized design at 5% level of significance with diet as a fixed factor (SAS, 2008). Where significant treatment effects were detected, means were separated by Fisher's least significant difference.

Results

Nutrient composition and tannin contents of *V. karroo* and *Setaria verticillata* are presented in Table 2. *Vachellia karroo* had higher CP content than *Setaria verticillata* grass hay. However, neutral detergent fibre (NDF) and acid detergent fibre (ADF) contents were higher in *Setaria verticillata* grass hay. *Vachellia karroo* contained moderate levels of CTs and total phenolics. Tannins were not detected in *Setaria verticillata* grass hay. The nutritive values of dietary mixtures of *Setaria verticillata* and *V. karroo* are presented in Table 3. Diet containing 50% leaf meal had higher CP, CTs and total phenolic contents.

Table 2 Chemical composition of the experimental forages (%, dry matter basis)

Nutrient	*Vachellia karroo* leaves	*Setaria verticillata* hay
Dry matter	97.01	96.23
Organic matter	92.14	91.37
Crude protein	12.65	7.97
Fat	2.44	0.79
Ash	7.86	8.63
Acid detergent fibre	32.47	50.68
Neutral detergent fibre	38.01	77.88
Condensed tannins*	2.0	ND
Total phenolics**	1.95	ND

* Condensed tannins as percentage dry matter leucocyanidin equivalent
** Expressed at tannic acid equivalent (%)
ND: not detected

Table 3 Nutritive values of dietary mixtures of *Setaria verticillata* grass hay and *Vachellia karroo* leaves

Nutrient	Treatment				
	$S_{80}A_{20}$	$S_{75}A_{25}$	$S_{70}A_{30}$	$S_{60}A_{40}$	$S_{50}A_{50}$
Dry matter	95.24	95.86	94.05	95.21	97.01
Organic matter	91.52	91.56	91.60	91.67	91.75
Crude protein	8.90	9.16	9.34	9.84	10.37
Ash	8.47	8.43	8.39	8.32	8.24
Fat	1.12	1.20	1.28	1.45	1.61
Acid detergent fibre	47.03	46.12	45.21	43.39	41.57
Neutral detergent fibre	69.90	67.91	65.91	61.93	57.94
Condensed tannins*	0.41	0.51	0.61	0.82	1.02
Total phenolics**	0.39	0.49	0.58	0.78	0.98

* Condensed tannins as percentage dry matter leucocyanidin equivalent
** Expressed as tannic acid equivalent (%)

Intake and growth performance of indigenous Pedi goats fed diets with various inclusion levels of *V. karroo* are presented in Table 4. Daily DM intakes were similar (*P* >0.05) across the treatments, ranging from 633 g to 765 g per goat per day. Similarly, goats consumed the same (*P* >0.05) amounts of dietary organic matter, CP, NDF and ADF contents. There was no difference (*P* >0.05) in initial and final bodyweights of goats. However, bodyweight gain (BWG) was higher (*P* <0.05) in goats fed a diet with 50% leaf meal as compared with other groups. Similarly, goats on diets with 30% or 40% leaf meal had higher (P <0.05) BWG than those on diets of 20% or 25% leaf meal.

Table 4 Intake and live weight gain of goats fed various inclusion levels of *Vachellia karroo* leaves and *Setaria verticillata* grass hay

Variable	Treatment (%)					SEM
	$S_{80}A_{20}$	$S_{75}A_{25}$	$S_{70}A_{30}$	$S_{60}A_{40}$	$S_{50}A_{50}$	
Intake (g/day)						
DM	679	633	642	633	617	56.6
OM	621	580	588	581	566	51.9
CP	60	58	60	62	64	5.38
NDF	475	430	423	392	358	36.6
ADF	319	292	290	274	256	31.0
Initial BW (kg)	17.6	18.6	17.0	19.0	17.4	4.84
Final BW (kg)	17.7	18.7	17.2	19.2	17.8	4.61
BWG (g/day)	20^c	23^c	34^b	36^b	60^a	10.37

[abc] Means with different superscripts in the same row are significantly different (*P* <0.05); SEM: standard error of mean; DM: dry matter; OM: organic matter; CP: crude protein; NDF: neutral detergent fibre: ADF: acid detergent fibre.

Tables 5 and 6 present the haematological and blood serum chemistry of goats fed various inclusion levels of *V. karroo* leaf meal and *Setaria verticillata* grass hay. There were no differences (*P* >0.05) in the haematological indices of the goats except for MCHC. Goats fed 50% leaf meal had lower (*P* <0.05) MCHC values compared with other treatment groups. Similarly, there were no differences (*P* >0.05) in blood serum chemistry of goats consuming various inclusion levels of *V. karroo* leaves except for serum total protein (TP) and ALT. Serum TP decreased (*P* <0.05) in goats fed 50% leaf meal compared with other treatment groups. ALT concentration decreased (*P* <0.05) in goats fed 25% leaf meal compared with those on 20% treatment.

Table 5 Haematological parameters of goats fed various inclusion levels of *Vachellia karroo* leaves and *Setaria verticillata* grass hay

Parameter	Treatment					SEM
	$S_{80}A_{20}$	$S_{75}A_{25}$	$S_{70}A_{30}$	$S_{60}A_{40}$	$S_{50}A_{50}$	
WBC $(x10)^3$ μL	17.77	24.67	17.16	21.59	17.16	3.808
RBC $(x10)^6$ μL	17.11	17.74	18.36	17.09	20.05	1.036
HB (g/dL)	9.10	9.55	9.60	9.45	9.82	0.868
HCT (L/L)	0.66	0.68	0.68	0.65	1.01	0.092
MCV (fL)	38.40	38.45	37.00	38.27	48.70	5.850
MCH (pg)	5.40	5.40	5.27	5.55	4.97	0.105
MCHC (g/dL)	14.40^a	14.02^a	14.30^a	14.60^a	11.20^b	0.979

WBC: white blood cell; RBC: red blood cell; HB: haemoglobin; HCT: haematocrit; MCV: mean corpuscular volume; MCH: mean corpuscular haemoglobin; MCHC: mean corpuscular haemoglobin concentration

Table 6 Blood serum chemistry of goats fed various inclusion levels of *Vachellia karroo* leaves and *Setaria verticillata* grass hay

Parameter	Treatment					SEM
	$S_{80}A_{20}$	$S_{75}A_{25}$	$S_{70}A_{30}$	$S_{60}A_{40}$	$S_{50}A_{50}$	
Glucose (mmol/L)	2.92	2.77	2.82	2.86	2.92	0.177
Total protein (g/L)	76.50[ab]	80.00[a]	73.50[b]	64.00[c]	58.00[d]	2.571
Albumin (g/dL)	15.75	16.50	17.50	16.50	15.25	1.578
Chol (mmol/L)	0.86	1.28	1.02	0.72	0.98	0.805
ALT (IU/L)	43.00[a]	25.75[b]	34.50[ab]	34.50[ab]	36.75[ab]	5.161
AST (IU/L)	84.00	83.00	79.00	101.75	85.25	13.787
K (mmol/L)	9.75	11.28	10.41	10.63	10.28	1.785
Ca (mmol/L)	2.22	2.30	2.32	2.32	2.23	0.106
Mg (mmol/L)	1.13	1.09	1.15	1.13	1.18	0.037
Na (mmol/L)	138.40	136.65	140.47	139.55	138.35	1.009

[abcd] means in the same row with different superscripts are significantly different (P <0.05)
Chol: cholesterol; ALT: alanine aminotransferase; AST: aspartate aminotransferase; K: potassium; Ca: calcium; mg: magnesium; Na: sodium

Discussion

The observed high CP content in *V. karroo* leaves is consistent with values reported by Mapiye *et al*. (2011). *Vachellia karroo* leaves are thus a potential CP supplement for ruminants in the tropics. Levels of CT in the leaves in this experiment were similar to the values reported by Aganga *et al*. (2000). The NDF, ADF and TP contents of *V. karroo* in the present study were lower than those reported by Mokoboki *et al*. (2005). The discrepancy in the nutrient contents of the browse can be attributed to differences in tree populations, soils, climatic conditions, seasons, stage of growth, browsing pressure, assay methods and plant secondary compounds (Aganga *et al*., 2000). The diets containing 40% and 50% leaf meal had 9.84% and 10.37% CP contents, respectively. The high CP contents in these diets were because of the higher levels of the *V. karroo* in these diets. The CP contents of all the experimental diets were above the minimum level of 8%, required for optimal rumen microbial function (Norton, 2003), suggesting that all the diets could support maintenance requirements and some production levels in ruminants (Van Soest, 1994). Utilization of fodder trees as supplements for goats on poor-quality basal diets such as hays would improve the performance of the animals.

In agreement with the current study, Dludla (2010) did not find differences in DMI when goats were fed *Acacia caffra* and *Euclea crispa* (high CT concentrations), *Rhus lancea* (moderate CT concentrations) and *Ziziphus mucronata* (low CT concentration). Nuňez-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 DMI of forage legumes by decreasing palatability (Reed, 1995). Consumption of plant species with high CT contents (generally > 50 g/kg DM) in the diet would depress feed palatability, reduce feed intake and slow down digestion (Waghorn *et al*., 1994a; Reed, 1995). The reduction in palatability and intake is associated with astringency in the mouths of the animals (Lamy *et al*., 2011). However, the present results indicate that CT concentration in the diets did not affect feed intake of goats. The concentrations of CT in the experimental diets which range from 4.1 g/kg DM to 8.2 g/kg DM were below the level that could cause adverse effects in animals. Reduced DMI in tannin-rich plants may be related to the type rather than the amount of tannins in browse species. Generally, animals consuming tannin-rich feeds develop defensive mechanisms by secreting proline-rich proteins in their saliva (Makkar, 1993). The presence of microorganisms that are resistant to high levels of CTs has been reported in ruminants that consume tannin-rich feeds (Makkar, 2003).

Goats fed *V. karroo* leaves had improved daily weight gain. This observation might be associated with efficient protein utilization by goats fed higher *V. karroo* leaf meal (Makkar, 1993). Solaiman *et al.* (2010)

reported an increase in daily weight gain of goats fed *Sericea* lespedeza by 2.22% CT, compared with those that consumed 0.72 CT and 1.46 CT contents, respectively.

Utilization of blood metabolite provides an immediate indication of an animal's nutritional status, and is recommended when assessing the effects of a diet on the performance of animal in the short to medium term (Pambu-Gollah *et al*., 2000). In the current study, the experimental goats did not show clinical signs of ill health or of tannin toxicity, such as head pressing, generalized depression, grinding teeth, foaming at the mouth and twitching and jerking (Odenyo *et al*., 1997). The mean WBC counts were similar across the treatments, indicating that the concentration of CT in the diets of the current study was below the level that could cause adverse effects. In another study, goats fed a sole diet of tannin-rich *Pterocarpus erinaceus* forage with 60 g/kg CT had significantly lower WBC count (7.31 x 10^9/L,) which implies that the animals might have ingested a considerable amount of tannins in their diets (Olafadehan, 2011). As indicated by Belewu and Ojo-Alokomaro (2007), indigenous goats possess a protective system that provides a rapid potent defence against infectious agents. The insignificant RBC values obtained in this study were similar to the findings of Solaiman *et al*. (2010), who reported no differences in RBC numbers when Kiko crossbred male kids were fed a *Sericea lespedeza* diet containing varying levels of CT. Red blood cell indices help in the characterization of anaemia. Thus, the RBC values obtained in the current study indicate the absence of haemolytic anaemia and depression of erythrogenesis (Olafadehan *et al*., 2011). Haemoglobin concentration is an indication of the oxygen-carrying capacity of the blood. The values reported in this study were within the range of 7–15 g/dL for clinically healthy goats (Daramola *et al*., 2005). Previous research reported that goats fed tanniniferous *Ficus polita* had similar Hb concentration values (Olafadehan *et al*., 2014). The implication of the result in the present study is that the experimental diets were capable of supporting high oxygen-carrying capacity without depressing the respiratory capability of the goats. The Hb values in the present study also indicate the absence of microcytic hypochromic anaemia owing to iron deficiency (Olafadehan *et al.,* 2014). Haematocrit or packed cell volume, is the percentage of blood volume filled by erythrocytes and, thus, a measure of the oxygen-carrying capacity of the blood. In the current study, HCT was unaffected by the dietary treatments. This is in agreement with the findings of Solaiman *et al*. (2010), who reported no differences in HCT values when goats consumed various levels of tannin-rich *Sericea lespedeza* diets. This implies that RBC production was adequate, and there was no loss or breakdown of the cells. Erythrocyte indices such as MCV, MCH and MCHC are useful in diagnosis of certain forms of anaemia (Pratt, 1985). The lower MCHC values of goats fed 50% leaf meal might be because of the relatively higher CT in that diet. This finding is in contrast with that of Solaiman *et al*. (2010), who reported no differences in MCHC values of goats fed varying levels of tannin-rich *Sericea lespedeza*. Olafadehan (2011) reported lack of treatment effects on MCHC values of goats fed tannin-rich forage diets. Further investigation is needed to determine the effects of CT in the diet on MCHC values of growing goats.

Serum biochemistry parameters indicate pathophysiological states that help in identifying pathogenesis and causes of disease (Solaiman *et al*., 2010). Serum glucose levels for all the diets in the current study were within the normal range of 2.78-4.16 mmol/l for healthy goats (Kaneko, 1997). Previous studies indicated that serum glucose was unaffected as tannin-rich *Sericea lespedeza* inclusion level increased in the diet of Kiko crossbred male kids (Solaiman *et al*., 2010). However, Olafadehan (2011) observed that goats fed a sole diet of tannin-rich *Pterocarpus erinaceus* or *Andropogon gayanus* grass had depressed serum glucose compared with animals on mixed forage diets. Serum total protein of goats in the current study decreased as the level of *V. karroo* leaves increased in the diets. Goats fed 50% leaf meal had depressed serum TP, although this diet had the highest CP content. This observation may be an indication of underutilization of protein owing to the tannin level in the diet. Adverse effects of dietary tannins in ruminant nutrition have been reported (Zhu *et al.,* 1992). Consumption of plant species with high CT contents (> 50 g/kg DM) is considered detrimental to ruminants (Frutos *et al*., 2004). However, these recommendations originated from feeding trials with *Lotus* species and may not be applicable to other feeds (Mueller-Harvey, 2006).

Albumin is a protein that is made by the liver. Serum albumin gives an indication of the nutritional status of animals (Solaiman *et al*., 2010). Serum albumin was unaffected as *V. karroo* leaves increased in the diet. This result is similar to those reported by others (Olafadehan *et al*., 2014; Solaiman *et al*., 2010). In contrast, Olafedehan (2011) reported significantly higher serum albumin levels in goats fed mixed forage diets consisting of tannin-rich *Pterocarpus erinaceus* and *Andropogon gayanus*. These discrepancies could be due to the amount of tannins ingested (1.40 g/kg CT intake by goats fed *Pterocarpus erinaceus* forage), chemical structure or molecular weight of the tannins, and the physiology of the animals (Frutos *et al.,* 2004). Cholesterol is used to diagnose hepatic damage in domestic animals (Kaneko, 1997). Increased cholesterol levels are risk factors for heart disease, while a reduction in serum cholesterol indicates inadequate liver function, malnutrition, stress, decreased nutrient intake, and hormonal insufficiency (Kaneko, 1997). Similar cholesterol levels of the experimental animals in the present study indicate absence of dyslipidaemia, also known as hypercholesterolemia (Olafadehan *et al*., 2014). Similar findings were reported by Olafedehan (2011) and Olafadehan *et al.* (2014) when goats were fed tannin-rich forage.

Apart from AST, which was similar across treatments, goats fed 25% leaf meal had depressed ALT compared with goats on 20% inclusion level. Earlier studies reported non-significant differences in AST and ALT of goats fed tannin-rich forage (Olafadehan, 2011; Olafadehan *et al*., 2014). The discrepancy in ALT values of goats in the current study merits further investigation. However, ruminants such as goats that consume tannin-rich plants have developed defensive mechanisms so that they tolerate the negative effects of condensed tannins without showing signs of tannin toxicity (Lamy *et al*., 2011). These mechanisms include secreting proline-rich protein in the parotid saliva, increasing the number of tannin-resistant organisms in the rumen, and increasing intestinal mucus production as a defence against intestinal damage (Makkar, 2003; Lamy, 2011).

Blood serum mineral and electrolyte values in the current study were unaffected by the dietary treatments. This is similar to the findings of Olafadehan *et al*. (2014), who reported non-significant differences in goat serum minerals and electrolyte when fed tannin-containing forage in varying proportions. These results indicate that there was no mineral depletion and that their absorption from the gastrointestinal tract was not hindered by the dietary treatments.

Conclusions

Dietary mixtures of *V. karroo* and *Setaria verticillata* grass hay had no effect on nutrient intake and final weight of goats. However, an increase in the inclusion level of *V. karroo* leaf meal resulted in improved daily weight gain of goats. A condensed tannin concentration of 8.2 g/kg DM had no adverse effects on haematological and biochemical indices of indigenous Pedi goats. A 40% inclusion of *V. karroo* to a *Setaria verticillata* hay-based diet may be added to the diet of indigenous Pedi goats. It is therefore concluded that *V. karroo* could be used safely as a protein supplement during the critical dry period of the year to enhance productivity when fed low-quality roughages. Optimization of productivity would improve the economic, nutritional and social status of Pedi goat farmers.

Acknowledgements

The authors acknowledge the financial contribution for this project from the National Research Foundation.

Authors' contributions

DB carried out the experiment and wrote the manuscript,JWN coordinated the design and edited the manuscript. DN was involved in data analysis and FEM assisted with layout of the experiment. All authors read and approved the final manuscript.

Conflict of Interest Declaration

The authors declare that they have no competing interests.

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