

Partial substitution of concentrate with *Parkia biglobosa* foliage improves feed utilisation and performance of goats

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ABSTRACT

This study investigated the response of intake, ruminal fermentation, digestibility, N utilisation and growth performance in goats fed concentrate partially substituted with *Parkia biglobosa* foliage (PBF). Fifteen goats were randomly assigned to a control concentrate diet (PBF0) which was partially substituted with 25% PBF (PBF25) or 50% PBF (PBF50) on dry matter (DM) basis. Concentrate, TST and non-fibre carbohydrates intakes (linear and quadratic, $P < 0.001$), digestible organic matter (DOM; linear, $P = 0.001$) and urinary N (linear, $P = 0.039$) decreased with increased PBF level. Condensed tannins intake, fibre fractions and cellulose digestibility, faecal N (linear and quadratic, $P < 0.05$) and ruminal pH (quadratic, $P = 0.001$) increased with increasing PBF level. Average daily gain, DM and crude protein (CP) digestibility, N intake and retention (quadratic, $P < 0.05$), organic matter and hemicellulose digestibility, DM and nutrient intakes, energy concentration, ruminally-fermented DOM and microbial protein synthesis (linear and quadratic, $P < 0.05$), and digestible CP and volatile fatty acids (linear, $P < 0.05$) increased as PBF level increased. Feed:gain ratio and total N excretion (quadratic, $P < 0.05$), and ruminal total N and ammonia N (linear and quadratic, $P < 0.05$) decreased in PBF25. It is concluded that PBF is a cost-effective

alternative supplement which could reduce the quantity of concentrate for goat feeding by 50%.

Keywords: concentrate substitution, condensed tannins, goat, *Parkia biglobosa*, nutritive value

INTRODUCTION

In developing countries, ruminant production depends almost absolutely on grazing and crop residues, which are fibrous, low in nutrient and energy density, confer little or no nutritional benefits and limit the expression of the genetic potentials of the animals (Olafadehan and Adewumi, 2009). This scenario makes feeding of concentrates, as supplements, inevitable but, nowadays, the shortage, scarcity and soaring cost of conventional feeds are well recognized, limiting their use by resource-poor smallholder farmers. The quest for readily available and affordable alternatives to expensive concentrate feeds thus becomes imperative.

In most tropical countries, shrub or tree leaves have invariably found their place in ruminant diet due to their availability, appreciable nutrient density and effective utilisation by the animals. They are thus an important component of ruminant diets that are well relished by the animals. Foliage of browse or tree species containing moderate concentration of secondary compounds, particularly condensed tannins (CT), as feed supplement for ruminants are increasingly used in many parts of the tropics to improve animal performance due to their ability to mitigate methane production and divert energy loss through methane towards production (Abdulrazak et al., 2000; Waghorn and McNabb, 2003; Olafadehan, 2013). African locust bean (*Parkia biglobosa*), is a leguminous, perennial, evergreen, uncultivated, copiously available and phytochemical containing multipurpose tree legume. It is also a medicinal and nutritive plant with low to moderate concentration of secondary metabolites, particularly condensed tannins and saponins (Ladipo and Akinfemi, 2014).

Medicinal plants have been shown to possess anthelmintic, antibacterial and insecticidal properties (Salem et al. 2017). As a tannin-containing and nutritive plant, *Parkia biglobosa* foliage (PBF) could be an alternative protein source to the expensive supplementary concentrate used for ruminant feeding, thus making production sustainable in the developing countries. Foliage of tannin-containing multipurpose trees, such as *Pterocarpus erinaceus* (Olafadehan, 2013), *Moringa oleifera* (Kholif et al., 2018) and *Daniellia oliveri* (Olafadehan et al., 2020), have been used in goat diets to improve the animal performance, nitrogen utilisation efficiency and amino acid absorption. Previous studies (Wada et al., 2014) on the partial replacement of PBF for groundnut cake in total mixed rations fed to sheep elucidated its nutritive

value. However, there are no literature reports on the replacement value of PBF for a concentrate feed for goats. We hypothesised that concentrate feed replacement with PBF could improve the feed utilisation and performance of growing goats. The current assay investigated the effect of partial substitution of a concentrate diet with PBF on the intake, ruminal fermentation, nutrient digestibility, N utilisation and growth performance of Red Sokoto bucklings.

MATERIALS AND METHODS

Animals and diets

The experiment was carried out at the University of Abuja Teaching and Research Farm. Fifteen Red Sokoto bucklings (about 8-mo-old; 13.7 ± 0.52 kg LW), housed in individual slatted cage (1.2 m^2) equipped with facilities for urine and faeces collection, were used in a 70-d study designed as a completely randomized design with 3 dietary treatments. Goats were quarantined, given prophylactic treatment and adjusted to the experimental diets and cages for 2 weeks. They were weighed prior to the start of the experiment, stratified by mean LW to equalize the initial LW among treatments and randomly allocated to the 3 treatments. Goats in treatment I (PBF0) were fed a concentrate mixture (g/kg): 250 maize, 270 corn bran, 300 brewer's dried grain 120 groundnut cake, 10 urea, 20 limestone, 20 salt and 10 vitamin-mineral premix. Concentrate was offered at 5% LW of goats on DM basis and the amount offered was adjusted every week to ensure daily collection of 10% orts. In treatments II and III, 25 (PBF25) and 50% (PBF50) of the control concentrate diet were replaced with PBF respectively on DM basis. PBF were carefully plucked from the lumped branches of mature stands at pre-anthesis stage, sun-cured, weighed and fed twice daily at 08.00 and 15.00h in equal portions. Threshed sorghum tops (TST; basal diet) and water were provided free choice. Goats were weighed weekly before morning feeding.

Faecal and urinary samples collection

Daily faecal and urinary outputs were collected respectively for a 7-d collection period, starting from d 64 of the experiment. About 10% of the daily collections of faeces and urine were saved, pooled for the 7-day and another 10% subsampled for each goat. Feeds and faeces were dried in a forced-air oven to determine the DM, ground using a Willey mill to pass a 1-mm sieve and kept pending analysis. Before frozen, concentrated H_2SO_4 was added to the urinary samples to prevent N losses.

Rumen fluid collection

On the 70th day of the experiment, rumen liquor was collected before morning feeding by aspiration using stomach tube, and pH was taken immediately with a digital pH meter. The rumen fluid was strained through 4

layers of cheese cloth, preserved by adding 5 ml of 1 M H₂SO₄ to 45 ml of the fluid and frozen pending analysis.

Chemical analysis

Dried feed and faecal samples were analysed for proximate constituents according to AOAC (AOAC, 1997). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were determined according to Van Soest et al. (1991). Hemicellulose and cellulose were calculated as the differences between NDF and ADF and ADF and ADL respectively. Ruminal ammonia samples were analysed for Kjeldahl-N according to AOAC (AOAC, 1997). Ruminal volatile fatty acids (VFA) concentrations were analysed by gas chromatography and auto-analyser as described by Zijlstra et al. (1977). Condensed tannins were determined using the methods of Makkar (2003).

Statistical analysis

Data were subjected to analysis of variance using SPSS Base 17 (SPSS software products, USA). Linear and quadratic polynomial contrasts were used to examine responses to increasing level of PBF. Significant variation was measured at $P < 0.05$.

RESULTS

Chemical composition of feed

Relative to the concentrate, the PBF had lower crude protein (CP), organic matter (OM), ether extract (EE) and non-fibre carbohydrates (NFC) contents but higher NDF, ADF hemicellulose and cellulose concentrations (Table 1). Both the TST and PBF were tannin-containing feeds.

Table 1. Chemical composition of the experimental diets (g/kg DM unless stated otherwise)

	TST ¹	Concentrate	<i>P. biglobosa</i> foliage
Dry matter (g/kg of fresh matter)	935.8	936.2	931.2
Crude protein	72.1	186	167.5
Organic matter	871.6	935.9	902.5
Ether extract	64.5	99.9	64.7
Ash	128.4	64.1	97.5
Neutral detergent fibre	603	238.2	523.2
Acid detergent fibre	427.2	124.2	400.1
Acid detergent lignin	92.4	39.8	93
Non-fibre carbohydrate	132	411.8	147.1
Cellulose	334.8	84.4	317.1
Hemicellulose	175.8	114	123.1
Condensed tannins	1.9	ND ²	25

¹TST, threshed sorghum tops. ²ND, not detected.

Voluntary intake and growth performance

Intakes of TST, concentrate and NFC decreased linearly and quadratically ($P<0.001$), while CT intake increased with increasing replacement of PBF for concentrate (Table 2). Intakes of DM and all nutrients increased (linearly ($P<0.05$); and quadratically ($P<0.001$) in PB25 relative to other treatments. Whereas Average daily gain (ADG) and feed:gain ratio were quadratically higher and lower ($P=0.006$) respectively for PBF25 compared to PBF0 and PBF50.

Table 2. Voluntary intake and growth performance (g/kg $W^{0.75}$ /d) unless stated otherwise) of goats fed concentrate substituted with *Parkia* foliage

Variable	Treatment ¹			SEM	P value	
	PBF0	PBF25	PBF50		Linear	Quadratic
Intake (g/d)						
Threshed sorghum tops	197.9	193.7	94.2	7.53	<0.001	<0.001
<i>P. biglobosa</i> foliage		139.2	240.1	4.27	<0.001	
Concentrate	397.3	338	238.4	0.91	<0.001	<0.001
Total	594.4	670.9	572.7	11.2	0.019	<0.001
Dry matter (g/kg BW)	36.9	38.9	35.9	0.70	0.048	<0.001
Dry matter	73.92	79.3	71.77	1.39	0.046	<0.001
Crude protein	10.96	11.84	11.38	0.11	0.001	<0.001
Organic matter	67.18	74.6	64.28	1.55	0.022	<0.001
Neutral detergent fibre	26.61	31.93	29.35	0.64	<0.001	<0.001
Acid detergent fibre	16.65	21.33	20.35	0.46	<0.001	<0.001
Hemicellulose	9.96	10.61	9.00	0.19	<0.001	<0.001
Cellulose	12.41	16.25	15.67	0.36	<0.001	<0.001
Non-fibre carbohydrate	23.6	21.9	18.15	0.48	<0.001	<0.001
Condensed tannins (g/kg BW)	0.02	0.22	0.39	0.00	<0.001	0.004
Condensed tannins	0.05	0.46	0.78	0.00	<0.001	0.001
Average daily gain (g/d)	77.14	92.86	71.43	8.00	0.309	0.006
Feed: gain ratio	7.75	7.24	8.09	0.28	0.111	0.006

P value is the observed significance level of the F-test for the equally spaced treatment.

¹Concentrate diet replaced with *Parkia biglobosa* foliage at 0% (PBF0), 25% (PBF25) or 50% (PBF50) on dry matter basis.

Nutrient digestibility and nutritive indices

Digestibility of DM ($P=0.004$) and CP ($P=0.025$) displayed a quadratic trend (Table 3). Digestibility of OM was linearly ($P=0.0211$) and quadratically ($P=0.001$) increased in PBF25 treatment. Digestibility of NDF, ADF and cellulose linearly ($P<0.01$) and quadratically ($P<0.05$) increased as the PBF level increased in the diets. Digestibility of hemicellulose (linear and quadratic, $P<0.01$), DCP ($P=0.044$) and ME (linear, $P=0.021$; quadratic, $P=0.001$) increased for PBF25 treatment compared with PBF0 and PBF50

treatments. A negative linear ($P=0.039$) effect was noticed for DOM as the PBF level increased.

Table 3. Nutrient digestibility and nutritive indices of goats fed concentrate substituted with *Parkia* foliage

Variable	Treatment			SEM	<i>P</i> value	
	PBF0	PBF25	PBF50		Linear	Quadratic
Nutrient digestibility (g/kg)						
Dry matter	654.4	682.8	643.9	11.4	0.273	0.004
Crude protein	663.0	693.9	679.6	11.6	0.108	0.025
Organic matter	675.4	706.9	645.0	12.9	0.0211	0.001
Neutral detergent fibre	467.8	538.5	543.4	15.2	0.001	0.016
Acid detergent fibre	417.3	504.0	524.0	19.7	<0.001	0.042
Hemicellulose	524.5	587.5	575.5	12.6	0.002	0.004
Cellulose	500.8	565.7	576.7	16.0	0.001	0.043
Nutritive indices (g/kg W ^{0.75})						
Digestible crude protein	1.17	1.21	1.16	0.00	0.044	0.096
Digestible organic matter	7.53	7.49	7.25	0.14	0.039	0.316
Digestible energy (MJ/kg) ²	11.59	12.13	11.07	0.17	0.021	0.001
Metabolisable energy (MJ/kg) ³	9.76	10.22	9.32	0.19	0.021	0.001

P value is the observed significance level of the F-test for the equally spaced treatment.

¹Concentrate diet replaced with *Parkia biglobosa* foliage at 0% (PBF0), 25% (PBF25) or 50% (PBF50) on dry matter basis.

²Calculated according to McDonald et al. (2002): digestible energy (MJ/kg) = digestible organic matter x 0.19.

³Calculated according to McDonald et al. (2002): metabolisable energy (MJ/kg) = digestible organic matter x 0.16.

Nitrogen utilisation

While N intake and N retention were quadratically ($P=0.001$) increased in PBF25 treatment, total N excretion was quadratically ($P=0.01$) reduced relative to PBF0 and PBF50 treatments (Table 4).

Table 4. Nitrogen utilisation of goats fed concentrate substituted with *Parkia* foliage

Variable (g/d)	Treatment ¹			SEM	P value	
	PBF0	PBF25	PBF50		Linear	Quadratic
N intake	14.1	16.03	14.53	0.42	0.227	0.001
Faecal N	1.74	2.06	2.67	0.08	<0.001	0.023
Urinary	5.10	4.40	4.15	0.14	<0.001	0.057
Total N excretion	6.84	6.46	6.82	0.15	0.089	0.01
N retention						
g/d	7.26	9.57	7.70	0.51	0.304	0.001
g/kg of N intake	514.9	596.8	530	19.1	0.338	0.001

P value is the observed significance level of the F-test for the equally spaced treatment.

¹Concentrate diet replaced with *Parkia biglobosa* foliage at 0% (PBF0), 25% (PBF25) or 50% (PBF50) on dry matter basis.

Faecal and urinary N excretions were linearly and quadratically ($P<0.05$) increased, and linearly ($P<0.001$) decreased respectively in PBF0 treatment.

Ruminal fermentation and microbial protein synthesis

PBF0 treatment reduced (quadratic, $P=0.001$) ruminal pH and increased $\text{NH}_3\text{-N}$ and total N (linear and quadratic, $P<0.05$) (Table 5). PBF25 treatment increased VFA (linear, $P<0.001$) and DOMR and MPS (linear and quadratic, $P<0.05$).

Table 5. Rumen fermentation characteristics and microbial protein synthesis in goats fed concentrate substituted with *Parkia* foliage

Variable			Treatment ¹			SEM		P value	
			PBF0	PBF25	PBF50			Linear	Quadratic
pH			6.30	6.71	6.85	0.15		0.227	0.001
Ammonia	nitrogen		193.4	174	176	5.94		0.011	0.028
Volatile	fatty	acid	120.7	139.7	125.1	5.68		<0.001	0.057
(mmol/L)									
Total nitrogen (mg/L)			2102	1961	1984	33.9		0.002	0.005
DOMR ² (g/d)			235.6	278.5	217	4.56		0.002	<0.001
MPS ³ (g/d)			47.11	55.7	43.4	0.91		0.002	<0.001

P value is the observed significance level of the F-test for the equally spaced treatment.

¹Concentrate diet replaced with *Parkia biglobosa* foliage at 0% (PBF0), 25% (PBF25) or 50% (PBF50) on dry matter basis.

²DOMR, digestible organic matter fermented in the rumen = DM intake x DOM x 0.65.

³MPS, Microbial protein supply, = 32 g/kg x DOMR x 6.25 (Chen and Gomes 1992).

DISCUSSION

Chemical composition

With relatively high CP and moderate fibre fractions (Table 1), PBF can be regarded as a good quality fodder. The CP is above the range of 11-13% required for the maintenance and growth of small ruminants (NRC, 2007). The chemical composition compares with the previous reports (Njidda et al., 2017). The CT concentration of PBF is moderate and within the threshold level of 2-4% DM that improves rumen escape value of fodders and ruminant performance (Terrill et al., 1992; Turner et al., 2005). The chemical composition of the basal TST is parallel with previous findings (Okunade et al., 2016).

Voluntary intake and growth performance

PBF demonstrate the nutritive value and acceptability or preference of the *Parkia* foliage by the experimental goats, resulting in displacement of the both the basal and concentrate control diets. The linear and quadratic increases in DM intake of PBF25 treatment compared to PBF0 and PBF50 treatments could be related to enhanced ruminal fermentation and outflow rate, fibre digestion and supply of degradable OM. PBF50 treatment caused a marginal decline in DM intake relative to the control, indicating 25% concentrate replacement with *Parkia* foliage (PBF25) as the optimum substitution level for improved feed intake. The result contradicts previous reports where DM intake increased with increasing concentrate replacement with *Daniellia oliveri* foliage up to 50% (Olafadehan et al., 2020) or was not affected by concentrate replacement with *Piliostigma thonningii* leaves (Olafadehan et al., 2018). Variation in results may be explained by differences in the soil type and quality (chemical composition and concentration of secondary metabolites), age and season of harvest of foliage and the quality of the partially substituted concentrate in different experiments. The increased DM intake of PBF25 fed goats also suggests that the diet gave the optimum level of fibre for improved ruminal fermentation and a favourable combination of roughage to concentrate ratio that enhanced palatability. Whereas NFC intake was linearly and quadratically enhanced in PBF0 treatment, intake of other nutrients was linearly and quadratically increased in PBF25 treatment, reflecting either the trend of the DM intake or the concentration of the nutrients in the feeds.

In response to the enhanced feed intake and nutrient digestion, ruminal fermentation, MPS, energy concentration and N utilisation, ADG was quadratically increased in PBF25 treatment. Previous studies (Balehegn et al., 2014; Olafadehan et al., 2020) reported increased in ADG of goats with concentrate replacement with other fodder trees. Reduced feed:gain ratio of PBF25 treatment confirms the superior feed value of the diet, as it optimised the efficiency of feed, energy and nutrient utilisation for body accretion. Plant secondary metabolites, such as tannins at moderate concentration, have been reported to modulate ruminal fermentation and improve nutrient utilisation in ruminants (Olafadehan et al., 2020). The improved performance of goats fed PBF25 diet indicates that optimum medicinal and nutritional benefits of the CT of the *Parkia* foliage can be harnessed when the foliage replaced 25% of concentrate feed in a practical goat ration. Earlier reports (Hrckova and Velebny, 2013) indicated that tannins at moderate concentration possessed a combination of immunomodulatory action and direct anthelmintic effects. This could have further enhanced the health of the goats for efficient ruminal fermentation, feed utilisation and improved weight gain, in confirmation of previous reports (Cedillo et al., 2015) that CT suppressed or stimulated microbial growth, mitigated nutritional stress such as bloat and/or enhanced animal health and productivity in terms of voluntary feed intake, daily gain

and milk production. Concentrate substitution with *Parkia* foliage, especially at 25% substitution, may be advocated in goat nutrition for enhanced nutritional status and improved dietary constituents' conversion efficiency to LW gain for increased meat and sustainable ruminant production.

Nutrient digestibility and nutritive indices

The linearly and quadratically increased DM and OM digestibility of the PBF25 treatment may be attributed to its enhanced ruminal fermentation and MPS, which must have invariably promoted rumen microbiota growth and multiplication and hence enhanced feed degradation. The linearly and quadratically improved CP digestibility of the PBF diets is obviously the result of increased digesta protein bound CT, which perhaps reduced ruminal CP degradation and promoted enzymatic digestion in the lower gut and dietary amino acids availability (Olafadehan et al., 2020). This supposition was confirmed by the decreased ruminal total N and faecal N, and increased urinary N of the treatment. Fibre digestibility is a function of ruminal cellulolytic activity, which is affected by ruminal pH. Therefore, the linear and quadratic increases of the fibre digestibility indicate increased ruminal cellulolytic activities. It is apt to say that the proportion of basal roughage consumed by PBF0 fed goats was below 35% of the total DM intake. It, therefore, plausibly appears that the high amount of concentrate consumed by PBF0 fed goats reduced ruminal cellulolytic activity and fibrolytic enzymes secretion, with reduced fibre digestion as the fallout (Ben Salem and Znaidi, 2008; Olafadehan et al., 2020).

PBF25 treatment increased DCP and DOM relative to PBF0 and PBF50 treatments, which had marginally varied values. The increased DCP, DOM and ME of PBF25 treatment further confirmed its superior nutritive value relative to PBF0 and PBF50 treatments. Since energy is perhaps the most critical factor affecting feed utilisation, and productive and reproductive performance of ruminants, the increased ME is, therefore, nutritionally beneficial and indicates enhanced dietary energetic efficiency due to reduced dietary energy loss in faeces and urine, and as methane. Methane production represents a loss of dietary energy, but tree fodders and leguminous tree seeds have been reported to suppress ruminal methanogenesis and thus mitigate methane production and emissions (Olafadehan, 2013; Okunade et al., 2014, 2022).

N utilisation

Due to invaluable roles of N in ruminants' productive and reproductive performance and the consequences of its excessive excretion on environmental degradation, ruminant scientists prioritise improving N utilisation efficiency. Increased N retention of PBF25 treatment is obviously attributable to the increased N intake and CP digestibility, and reduced ruminal $\text{NH}_3\text{-N}$ concentration and total N excretion due to the moderate and

beneficial concentration of the CT of *Parkia* foliage. Earlier studies (Pathak et al., 2013) in goats fed moderate tannin-containing feeds reported increased N retention due to reduced N excretion. Increased post-ruminal CP digestion of the PBF diets and availability at the lower gut were evidenced by the linearly lower urinary N, and linearly and quadratically higher faecal N outputs which escaped ruminal degradation due to the formation tannin-protein complexes. Abated ruminal ammonia N production and urinary N excretion have been associated with CT (Merkel et al., 1999; Mui et al., 2002), thereby increasing N retention.

Ruminal fermentation and microbial protein synthesis

Ruminal pH is a major determinant of the profile of nutrients available for absorption (Beauchemin, 1991). Therefore, the quadratically reduced ruminal pH of PBF0 diet confirmed the speculated reduced growth/activity of cellulolytic microbial populations and hence reduced feed degradation and nutrient availability for absorption. The linearly and quadratically reduced ruminal NH₃-N and quadratically increased CP digestibility of the PBF25 diet are the consequences of reduced solubility and ruminal proteolysis of the dietary CP, which must have formed complexes with the CT of the *Parkia* foliage. Increased VFA concentration of PBF25 treatment may be related to its improved feed intake and enhanced ruminal fermentation. It may as well be attributed to the increased OM and fibre digestibility (Kholif et al., 2018).

Though MPS can be affected by many factors, energy remains the most important requisite for MPS (Olafadehan et al., 2018). Therefore, higher ME level of PBF25 treatment is responsible for the improved MPS. The increased MPS is also likely the results of increased ruminal growth/activity of the cellulolytic microbiome populations (Uyeno et al., 2015) and DOMR (Okunade and Olafadehan, 2019), another critical determinant of MPS.

CONCLUSION

Results show that *Parkia biglobosa* foliage at 25% concentrate replacement had a better nutritive value and improved goat performance, while 50% concentrate replacement had equivalent feed value as the partially substituted concentrate. *Parkia biglobosa* foliage can thus be used as a novel, cost-effective alternative protein source to ameliorate the problem associated with the use of expensive and irregularly available concentrate feeds, particularly in developing countries. However, partial substitution of concentrate with 25% PBF foliage optimised feed utilisation and performance.

REFERENCES

- Abdulrazak, S.A., Fujihara, T., Ondiek, J.K., Ørskov, E.R., 2000. Nutritive evaluation of some Acacia tree leaves from Kenya. *Anim Feed Sci Technol.* 85(1–2), 89–98.
- AOAC. 1997. Official Methods of Analysis. Sixteenth ed., Association of Official Analytical Chemists., Washington, DC, USA.
- Balehegn, M., Eik, L.O., Tesfay, Y., 2014. Replacing commercial concentrate by *Ficus thonningii* improved productivity of goats in Ethiopia. *Trop Anim Health Prod.* 46(5), 889–894.
- Beauchemin KA. 1991. Effects of dietary neutral detergent fiber concentration and Alfalfa hay quality on chewing, rumen function, and milk production of dairy cows. *J Dairy Sci.* 74(9):3140–3151.
- Ben Salem, H., Znaidi, I.A., 2008. Partial replacement of concentrate with tomato pulp and olive cake-based feed blocks as supplements for lambs fed wheat straw. *Anim Feed Sci Technol.* 147(1–3), 206–222.
- Cedillo, J., Kholif, A.E., Salem, A.Z.M., Elghandour, M.M.Y., Vázquez, J.F., Alonso, M.U., Barbabosa, A., Chagoyán, J.C.V., Reyna, A.G., 2015. Oral administration of Sauce llorón extract to growing lambs to control gastrointestinal nematodes and *Moniezia* spp. *Asian Pac J Trop Med.* 8(7), 520–525.
- Chen, X.B., Gomes, M.J., 1992. Estimation of microbial protein supply to sheep and cattle based on urinary excretion of purine derivatives - an overview of the technical details. Rowett Research Institute, Bucksburnd Aberdeen, Scotland.
- Hrckova G, Velebny S. 2013. Parasitic helminths of humans and animals: Health impact and control, in: Hrckova, G., Velebny, S. (Eds.), *Pharmacological Potential Selected Natural Compound in the Control of Parasitology Disease*. SpringerBriefs in Pharmaceutical Science Drug Development, Springer Nature, Switzerland AG, pp. 29–99. DOI: 10.1007/978-3-7091-1325-7_2
- Kholif, A.E., Kassab, A.Y., Azzaz, H.H., Matloup, O.H., Hamdon, H.A., Olafadehan, O.A., Morsy, T.A., 2018. Essential oils blend with a newly developed enzyme cocktail works synergistically to enhance feed utilization and milk production of Farafra ewes in the subtropics. *Small Rumin Res.* 161, 43–50.
- Kholif, A.E., Gouda, G.A., Olafadehan, O.A., Abdo, M.M., 2018. Effects of replacement of *Moringa oleifera* for berseem clover in the diets of Nubian goats on feed utilisation, and milk yield, composition and fatty acid profile. *Animal.* 12(5), 964–972.
- Ladipo, M.K., Akinfemi, A., 2014. Evaluation of some selected browse plants as ruminant feed using in vitro production technique. *Int J AgriScience.* 4(5):260–266.

- Makkar, H.P.S., 2003. Quantification of Tannins in Tree and Shrub Foliage. Dordrecht: Kluwer Academic. <http://link.springer.com/10.1007/978-94-017-0273-7>
- McDonald, P., Edwards, R.A., Greenhalgh, J.F.D., Morgan, C.A., Sinclair, L.A., 2002. Animal Nutrition. Sixth ed., Prentice Hall, Essex, UK.
- Merkel, R.C., Pond, K.R., Burns, J.C., Fisher, D.S., 1999. Intake, digestibility and nitrogen utilization of three tropical tree legumes II. As protein supplements. Anim Feed Sci Technol. 82(1-2),107-120.
- Mui, N.T., Ledin, I., Uden, P., Binh, D.V., 2002. Nitrogen balance in goats fed Flemingia (Flemingia macrophylla) and jack fruit (Artocarpus heterophylla) foliage based diets and effects of a daily supplementation of polyethylene glycol (PEG) on intake and digestion. Asian-Australasian J Anim Sci. 15, 699-707.
- Njidda, A.A., Olafadehan, O.A., Alkali, H.A., 2017. Potential nutritive value of selected leguminous browse forage species from Nigeria using in vitro gas production technique. Iran J Appl Anim Sci. 7, 567-575.
- NRC. 2007. Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World camelids. National Academy Press, Washington, DC, USA.
- Okunade, S.A., Isah, O.A., Aderinboye, R.Y., Olafadehan, O.A., 2014. Assessment of chemical composition and *in vitro* degradation profile of some Guinea savanna browse plants of Nigeria. Trop Subtrop Agroecosystems. 17, 529-538.
- Okunade, S.A., Isah, O.A., Oyekunle, M.A., Olafadehan, O.A., Makinde, O.J., 2016. Effects of supplementation of threshed sorghum top with selected browse plant foliage on haematology and serum biochemical parameters of Red Sokoto goats. Trop Anim Health Prod. 48(5), 979-984. DOI 10.1007/s11250-016-1045-2
- Okunade, S.A., Olafadehan, O.A., 2019. Rolfe (Daniellia oliveri) seed meal as a protein source in locally produced concentrates for lambs fed low quality basal diet. J Saudi Soc Agric Sci. 18(1), 83-88.
- Okunade, S.A., Olafadehan, O.A., Umunna, M.O., Makinde, O.J., 2022. Chemical composition and its relationship with in vitro methane mitigation potential of selected wild legume seeds. Trop Subtrop Agroecosystems. 25.
- Olafadehan, O.A., 2013. Feeding value of Pterocarpus erinaceus for growing goats. Anim Feed Sci Technol. 185(1-2), 1-8. <http://dx.doi.org/10.1016/j.anifeedsci.2013.05.014>.
- Olafadehan, O.A., Adewumi, M.K., 2009. Productive and reproductive performance of strategically supplemented free grazing prepartum Bunaji cows in the agropastoral farming system. Trop Anim Health Prod. 41(7), 1275-1281. DOI 10.1007/s11250-009-9312-0.

- Olafadehan, O.A., Okunade, S.A., 2018. Fodder value of three browse forage species for growing goats. *J Saudi Soc Agric Sci.* 17(1), 43–50.
- Olafadehan, O.A., Njidda, A.A., Okunade, S.A., Salihu, S.O., Balogun, D.O., Salem, A.Z.M., 2018. Performance and hemtochemical parameters of buck-kids fed concentrate partially replaced with tropical *Piliostigma thonningii* foliage. *Anim Sci J.* 89(2), 340–347. <http://doi.wiley.com/10.1111/asj.12814>.
- Olafadehan, O.A., Okunade, S.A., Njidda, A.A., Kholif, A.E., Kolo, S.G., Alagbe, J.O., 2020. Concentrate replacement with *Daniellia oliveri* foliage in goat diets. *Trop Anim Health Prod.* 52(1), 227–233.
- Pathak, A.K., Dutta, N., Banerjee, P.S., Pattanaik, A.K., Sharma, K., 2013. Influence of dietary supplementation of condensed tannins through leaf meal mixture on intake, nutrient utilization and performance of *haemonchus contortus* infected sheep. *Asian-Australasian J Anim Sci.* 26(10), 1446–1458.
- Salem, A.Z.M., Elghandour, M.M.Y., Kholif, A.E., López, S., Pliego, A.B., Cipriano-Salazar, M., Chagoyán, J.C.V., de Oca Jiménez R.M., Alonso, M.U., 2017. Tree leaves of *Salix babylonica* extract as a natural anthelmintic for small-ruminant farms in a semiarid region in Mexico. *Agrofor Syst.* 91(1), 111–122.
- Terrill, T.H., Rowan, A.M., Douglas, G.B., Barry, T.N., 1992. Determination of extractable and bound condensed tannin concentrations in forage plants, protein concentrate meals and cereal grains. *J Sci Food Agric.* 58(3), 321–329. <http://doi.wiley.com/10.1002/jsfa.2740580306>
- Turner, K.E., Wildeus, S., Collins, J.R., 2005. Intake, performance, and blood parameters in young goats offered high forage diets of lespedeza or alfalfa hay. *Small Rumin Res.* 59(1), 15–23.
- Uyeno, Y., Shigemori, S., Shimosato, T., 2015. Effect of probiotics/prebiotics on cattle health and productivity. *Microbes Environ.* 30(2):126–132.
- Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J Dairy Sci.* 74(10), 3583–3597.
- Wada, N.I., Njidda, A.A., Olafadehan, O.A., Bello, B., 2014. Effect of graded levels of *Parkia biglobosa* in concentrate diets on the growth performance, digestibility and nitrogen utilization of Yankasa rams Nig J Anim Prod. 43, 231–237
- Waghorn, G.C., McNabb, W.C., 2003. Consequences of plant phenolic compounds for productivity and health of ruminants. *Proc Nutr Soc.* 62(2), 383–392.
- Zijlstra, J.B., Beukema, J., Wolthers, B.G., Byrne, B.M., Groen, A., Ankert, J.D., 1977. Pretreatment methods prior to gaschromatographic analysis of volatile fatty acids from faecal samples. *Clin Chim Acta.* 78(2), 243–250.