



## ***In vitro* and Ruminal Characteristics of the Three Selected Nigerian Herbs: *Phyllanthus amarus*, *Ocimum gratissimum* and *Lactuca taraxacifolia* as Feed Additives in Ruminant Production**

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### ABSTRACT

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This study evaluated the effects of selected herbal feed additives on *in vitro* fermentation and ruminal characteristics of West African Dwarf (WAD) goats. Twenty goats (4 per treatment) were assigned to five dietary treatments in a 12-week completely randomised design: basal diet only (T1, control), diet + *Ocimum gratissimum* leaf meal (T2), diet + *Phyllanthus amarus* leaf meal (T3), diet + *Lactuca taraxacifolia* leaf meal (T4), and diet + a mixture of the three herbs (T5). Phytochemical screening confirmed the presence of saponins, tannins, and alkaloids in the herbs. The additives, incorporated at 3 g/kg feed, were offered at 5% of body weight. Feed samples were incubated for 24 h, with gas volume measured every 3 h, and methane subsequently estimated. Gas data were used to derive metabolizable energy (ME), organic matter digestibility (OMD), and short-chain fatty acid (SCFA) concentrations. At the end of the feeding trial, the rumen liquor was analysed for its fermentation characteristics and microbial populations. The herbs were rich in crude protein (CP) and moderate in carbohydrate content. The mixture diet (T5) contained the highest CP, while T2 had the greatest crude fibre. *In vitro* fermentation showed increasing gas production with incubation time, with T1 and T4 yielding the highest gas volumes. Methane production was lower in T3 and T5 compared with other treatments. Similarly, T1 and T4 recorded the highest ME, OMD, and SCFA values. However, T3 and T5 markedly improved ruminal fermentation and beneficially modified microbial populations. In conclusion, *P. amarus* (T3) and the combined herbal treatment (T5) demonstrated potential as natural feed additives for mitigating methane emissions and enhancing rumen ecology, thereby improving ruminant productivity.

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## Introduction

Methane emissions from ruminants are a major contributor to global greenhouse gases, accounting for 15 – 24% of total anthropogenic emissions, equivalent to 4.1 – 7.1 billion tonnes CO<sub>2</sub> annually (Goodland & Anhang, 2009; Wanapat et al., 2013). These losses represent not only an environmental concern but also a reduction in feed energy efficiency and overall livestock productivity (Gebrehiwot, 2014). Thus, developing nutritional strategies that mitigate methane and reduce ruminal ammonia is essential for improving feed conversion efficiency, enhancing productivity, and reducing the environmental footprint of animal agriculture.

Phytogenics bioactive plant compounds used as feed additives have gained attention as alternatives to synthetic antibiotics, which raise concerns about antimicrobial resistance (Benchaar et al., 2008). Several studies have

demonstrated their potential to manipulate rumen fermentation and suppress methane production. For example, thyme extract reduced soybean meal degradability *in vitro* (Rezaei & Pour, 2012), while spices such as coriander, turmeric, cumin, clove, and cinnamon acted as natural antibiotics against methanogens, thereby reducing methane formation (Chaudhry & Khan, 2012). Similarly, the inclusion of *Artemisia annua* extract and mixed herbal medicines in goat diets lowered methane, increased propionate, and reduced protozoa numbers (Dong et al., 2010).

Other herbs and spices, including ginger and garlic, have shown positive effects on fermentation. Ginger supplementation reduced methane, ammonia, and the acetate: propionate ratio while enhancing fermentation efficiency (Mohammad & Moeini, 2015). Garlic juice and

ginger improved gas production and reduced methane emissions (Tag El-Din et al., 2012), and garlic oil altered fermentation similarly to monensin (Busquet et al., 2005). Furthermore, plant extracts have been reported to reduce methanogen populations and increase fibrolytic bacteria (Kim et al., 2012). However, not all essential oil blends are effective, as some studies reported no significant impact on gas production or fermentation (Mariam et al., 2014). In contrast, others found reductions in methane and ammonia concentrations (Arhab et al., 2013).

Beyond methane mitigation, phytonutrients can improve nutrient utilisation and animal performance. Plantain herb and garlic leaf supplementation enhanced protein intake, feed conversion, and weight gain in goats (Redoy et al., 2020). *Andrographis paniculata* increased feed intake and growth performance (Yusuf, 2015), *Nigella sativa* and *Rosmarinus officinalis* improved digestibility in lambs (Odhaib et al., 2018), while *N. sativa* leaf meal enhanced feed utilization in sheep (Abdullah & Farghaly, 2019).

Given their dual potential to reduce greenhouse gas emissions and improve productivity, phytonutrient feed additives offer a promising strategy for sustainable ruminant production. However, research efforts have not been geared towards the utilization of scent leaf (*Ocimum gratissimum*), Indian gooseberry (*Phyllanthus amarus*) and wild lettuce (*Launaea taraxacifolia*) in ruminant feeding for reduction of methane production.

Scent leaf (*Ocimum gratissimum*), Indian gooseberry (*Phyllanthus amarus*) and Wild lettuce (*Launaea taraxacifolia*) are rich in nutrients and phyto-energy sources which are readily available, cheap and can be included in ruminant feeding. The scent leaf (*Ocimum gratissimum*) belongs to the family “*Lamiaceae*”, which is also called the “mint family” (Winifred and Alexander, 2018). It is called “*Efirin*” in Yoruba, which is a good source of alkaloids, tannins, flavonoids, phytates and oligosaccharides. The leaf is a good source of volatile aromatic compounds such as thymol, eugenol, xanthenes, terpenes and lactones (Nte et al., 2016). Indian gooseberry (*Phyllanthus amarus*) is widely found in all tropical and subtropical regions of the planet (Edeoga et al., 2006). Locally, it is called “*Oyomokeisoamank edem*” in Efik, “*Eyin Olobe*” in Yoruba and “*Ebebenizo*” in Bini. It is also a good source of alkaloids, flavonoids, hydrolysable tannins, major lignans, sterols, tetracyclic, triterpenoids volatile oil, polyphenols (Verma et al., 2014). Wild Lettuce (*Launaea taraxacifolia*) belongs to the family *Asteraceae* (*Compositae*), which is a leafy vegetable that can be found in several African countries including Ghana, Senegal, Benin and Nigeria (Bello et al., 2018). It is regarded as “*Efo Yarin*” in Yoruba, and it is ranked among the most important ten (10) less utilized plants in Benin and constitutes a high priority for research (Dansie et al., 2012). Several studies show that wild lettuce is rich in vitamins, minerals, proteins, essential fatty acids and fibre contents (Namrata et al., 2010; Arawande et al., 2013).

The aim of this work is to determine the effect of the feed enriched with dried phytobiotic bearing matter from *Phyllanthus amarus*, *Ocimum basilicum* and *Lactuca taraxacifolia* on the methane level, growth performance of African dwarf goat.

## Materials and Methods

### Experimental Site

The study was carried out at the Small Ruminant Unit, Teaching and Research Farm, Kwara State University, Malete, Kwara State, Nigeria, located at Latitude 8.71°N and Longitude 4.44°E in the southern Guinea Savannah zone (Ogunbosoye et al., 2015).

### Experimental Animals

Twenty (20) growing West African Dwarf (WAD) goats were sourced within Ilorin metropolis. The goats were neck-tagged for identification, quarantined, vaccinated against *peste des petits ruminants* (1 mL/animal), dewormed with Albendazole (12.5 mg/kg BW), treated with oxytetracycline HCl, and dusted with ectoraid before the trial. They were housed in pens with ad libitum access to clean water.

### Herbs Procurement and Preparation

*Phyllanthus amarus*, *Ocimum gratissimum*, and *Lactuca taraxacifolia* were harvested from the school farm, air-dried for 3 – 5 days on mesh racks, milled, sieved (1 mm), and stored in airtight containers until use.

### Experimental Design and Diets

Goats were randomly assigned to five dietary treatments in a completely randomised design (CRD) with four animals per treatment:

T1: Feed only (control); T2: Feed + *O. gratissimum* ; T3: Feed + *P. amarus* ; T4: Feed + *L. taraxacifolia* and T5: Feed + *O. gratissimum* + *P. amarus* + *L. taraxacifolia*

Herbs were incorporated at 3 g/kg feed (Abdelhamid et al., 2011) and offered at 08:00 and 16:00 h daily.

### Chemical Analysis

Dietary samples were analyzed for proximate composition (AOAC, 2012). Carbohydrate content was estimated by difference. Fibre fractions (NDF, ADF, ADL, hemicellulose, cellulose) were determined following Van Soest et al. (1994).

### In vitro Fermentation

Rumen fluid was collected from five donor WAD goats before feeding, strained through four-layer cheesecloth, and flushed with CO<sub>2</sub>. Incubations were conducted in 120 mL calibrated syringes using 200 mg substrate and 30 mL inoculum (Menke & Steingass, 1988). Gas production was recorded at 3 h intervals up to 24 h. Metabolizable energy (ME), organic matter digestibility (OMD), and short-chain fatty acids (SCFA) were estimated using standard equations (Menke & Steingass, 1988; Getachew et al., 1999). Methane was determined by NaOH absorption (Fievez et al., 2005).

### Rumen Fermentation Parameters

At the end of the feeding trial, rumen liquor was collected by stomach tube. pH was measured immediately, while ammonia-N (AOAC, 2012) and total volatile fatty acids (TVFA) (Samuel et al., 1997) were determined from centrifuged samples. Individual VFA profiles (acetic, propionic, butyric acids) were analysed by HPLC (Filipek & Dvořák, 2009).

**Microbial Counts**

Rumen fluid was used for total bacterial, protozoa, and fungal counts using a haemocytometer (Galyean, 1989). Formalin-preserved samples (1:9 v/v) were used for protozoa and fungi, while viable bacterial counts were determined using roll tubes (Aberu et al., 2004).

**Statistical Analysis**

Data were analysed using Analysis of Variance (ANOVA), and treatment means were separated by Least Significant Difference (LSD) test.

**Results**

**Phytochemical Qualitative Abundance of Leaves**

The phytochemical screening of *Lactuca taraxacifolia*, *Phyllanthus amarus*, and *Ocimum gratissimum* is presented in Table 1. Saponin was highly abundant (+++) in *L. taraxacifolia* and *O. gratissimum*, but moderately present (++) in *P. amarus*. Steroids were detected (+) in *L. taraxacifolia* and *P. amarus* but absent in *O. gratissimum*. Tannin was moderately present (++) in *O. gratissimum* and relatively present (+) in both *L. taraxacifolia* and *P. amarus*. Terpenoids were observed only in *L. taraxacifolia*, while flavonoids were moderately present (++) in *L. taraxacifolia*, slightly present (+) in *O. gratissimum*, and absent in *P. amarus*. Glycosides were detected only in *L. taraxacifolia*. Phenols were present (+) in *L. taraxacifolia* and *O. gratissimum* but absent in *P. amarus*. Oxalates were absent in all three plants, while phytate was detected only in *O. gratissimum*.

**Proximate Composition of Leaves**

The proximate composition of the three herbs is presented in Table 2. Crude protein (CP) ranged from 15.87% (*P. amarus*) to 19.44% (*L. taraxacifolia*). Ash content was highest in *L. taraxacifolia* (20.34%) and lowest in *O. gratissimum* (2.55%). Crude fibre was also highest in *L. taraxacifolia* (14.27%), while carbohydrates were highest in *O. gratissimum* (61.21%).

**Chemical Composition of Experimental Diets**

The chemical composition of diets containing the herbs is presented in Table 3. Significant differences (P<0.05) were observed across treatments. Crude protein ranged from 13.47% (T3) to 17.27% (T5), crude fibre from 4.89%

(T1) to 5.94% (T2), and ash from 4.90% (T1) to 6.69% (T3). Carbohydrate content was highest in T3 (63.51%) and lowest in the control (42.76%). Neutral detergent fibre (NDF) ranged between 61.94% (T1) and 69.88% (T4).

**In vitro Gas Production**

Gas production increased progressively with incubation time across all treatments (Table 4). At 24 h, values ranged from 26.33 ml/200 mg DM (T5) to 36.33 ml/200 mg DM (T1). The control (T1) and *L. taraxacifolia* (T4) diets produced more gas compared to other treatments.

**Methane Production**

Methane production varied significantly (P<0.05) among treatments (Figure 1). The highest value was recorded in the control diet (12.67 ml/200 mg DM), while the lowest occurred in the combined herbal diet (T5: 7.67 ml/200 mg DM).

**Digestibility, Energy, and Fermentation Products**

Organic matter digestibility (OMD), metabolizable energy (ME), and short-chain fatty acids (SCFA) were significantly influenced by treatments (Figures 2–4). OMD ranged from 48.56% (T5) to 57.45% (T1), ME from 6.99 MJ/kg (T5) to 8.35 MJ/kg (T1), and SCFA from 0.57 µmol (T5) to 0.81 µmol (T1).

**Ruminal Characteristics**

The effects of herbal supplementation on ruminal parameters are shown in Table 5. Significant differences (P<0.05) were observed in acetic, propionic, and butyric acid concentrations, while rumen pH, NH<sub>3</sub>-N, and A/P ratio were not significantly affected. Acetic acid was highest in goats fed *P. amarus* (36.45 mm/100 mL), while butyric acid was highest in goats fed *L. taraxacifolia* (8.39 mm/100 mL).

**Rumen Microbial Population**

Herbal supplementation significantly influenced microbial populations (Table 6). The highest bacterial (190 × 10<sup>4</sup> cfu/mL) and fungal counts (11.00 sfu/mL) were recorded in goats fed the combined herbal diet (T5). Protozoa were reduced in most herb-supplemented diets, with the lowest count observed in *P. amarus* (T3).

Table 1. Phytochemical Screening of leaves of *Lactuca taraxacifolia* (LT), *Phyllanthus amarus* (PA) and *Ocimum gratissimum* (OG)

Phytoconstituents	LT	PA	OG
Saponin	+++	++	+++
Steroid	+	+	-
Tannin	+	+	++
Alkaloid	+	+	++
Terpenoid	+	-	-
Flavonoid	++	-	+
Glycoside	++	-	-
Phenol	+	-	+
Oxalate	-	-	-
Phytate	-	-	+

Key: present (+), moderately present (++), highly present (+++), not present (-)

Table 2. Proximate Composition (%) of *Lactuca taraxacifolia*, *Phyllanthus amarus* and *Ocimum gratissimum*

Parameters	LT	PA	OG
Dry Matter	7.44	10.43	7.96
Crude Protein	19.44	15.87	15.98
Total Ash	20.34	5.73	2.55
Crude Fibre	14.27	7.83	9.85
Crude Fat	0.49	7.02	2.45
Carbohydrate	37.90	53.12	61.21

Table 3. Chemical Composition (%) of Experimental Diets with the Inclusion of Herbs

Parameters	T1	T2	T3	T4	T5	SEM
Dry matter	92.85 <sup>a</sup>	93.11 <sup>c</sup>	92.99 <sup>b</sup>	93.11 <sup>c</sup>	93.00 <sup>b</sup>	0.0006
Crude Protein	15.75 <sup>ab</sup>	16.08 <sup>ab</sup>	13.47 <sup>c</sup>	15.20 <sup>b</sup>	17.27 <sup>a</sup>	0.6884
Crude Fibre	4.89 <sup>d</sup>	5.94 <sup>a</sup>	5.51 <sup>c</sup>	5.64 <sup>b</sup>	5.67 <sup>b</sup>	0.0008
Ash	4.90 <sup>d</sup>	6.03 <sup>c</sup>	6.69 <sup>a</sup>	6.69 <sup>a</sup>	6.52 <sup>b</sup>	0.0011
Ether Extract	8.51 <sup>a</sup>	7.91 <sup>b</sup>	6.79 <sup>d</sup>	7.06 <sup>c</sup>	7.14 <sup>c</sup>	0.0436
CHO	42.76 <sup>c</sup>	57.15 <sup>c</sup>	63.51 <sup>a</sup>	58.53 <sup>b</sup>	56.41 <sup>d</sup>	0.0780
Neutral Detergent Soluble	11.41 <sup>a</sup>	10.53 <sup>b</sup>	10.82 <sup>b</sup>	9.57 <sup>c</sup>	10.36 <sup>b</sup>	0.0698
Acid Detergent Fibre	39.08 <sup>b</sup>	39.98 <sup>a</sup>	39.94 <sup>a</sup>	38.67 <sup>c</sup>	37.83 <sup>d</sup>	0.0329
Acid Detergent Lignin	30.18 <sup>b</sup>	30.90 <sup>a</sup>	29.43 <sup>c</sup>	29.01 <sup>d</sup>	29.90 <sup>b</sup>	0.0822
Hemicellulose	8.90 <sup>c</sup>	9.09 <sup>b</sup>	10.15 <sup>a</sup>	9.83 <sup>a</sup>	7.93 <sup>c</sup>	0.0822
Cellulose	22.86 <sup>d</sup>	28.31 <sup>c</sup>	29.97 <sup>b</sup>	31.05 <sup>a</sup>	31.11 <sup>a</sup>	0.0102
Neutral Detergent Fibre	61.94 <sup>c</sup>	68.29 <sup>c</sup>	67.93 <sup>d</sup>	69.88 <sup>a</sup>	68.94 <sup>b</sup>	0.0123

<sup>abcde</sup> Means along the same row with different superscripts are significantly different (P<0.05), SEM = Standard Error of Mean, CHO = carbohydrate, T1 = No herbs (Control), T2 = *Ocimum gratissimum*, T3 = *Phyllanthus amarus*, T4 = *Lactuca taraxacifolia*, T5 = *P. amarus* + *O. gratissimum* + *L. taraxacifolia*

Table 4. *In vitro* Gas Production Volume of the Experimental Diets at Different Incubation Hours

Incubation hours	Treatments						SEM	p-value
	T1	T2	T3	T4	T5			
3	8.00	9.33	7.33	9.33	7.33	1.30	0.6678	
6	15.33	14.00	12.00	16.67	13.33	1.79	0.4452	
9	20.67	20.67	16.66	23.33	18.67	2.04	0.2771	
12	24.67	24.00	21.33	27.33	22.00	1.63	0.1533	
15	26.67	26.00	22.67	29.33	23.33	1.96	0.1878	
18	28.67	28.00	26.33	31.33	25.33	2.01	0.3237	
21	32.00	28.67	28.00	31.33	25.33	1.55	0.0712	
24	36.33	31.33	29.67	34.00	26.33	1.27	0.0022	

<sup>abcde</sup> Means along the same row with different superscripts are significantly different (p<0.05), SEM = Standard error mean, T1 = No herbs (Control), T2 = *Ocimum gratissimum*, T3 = *Phyllanthus amarus*, T4 = *Lactuca taraxacifolia*, T5 = *P. amarus* + *O. gratissimum* + *L. taraxacifolia*

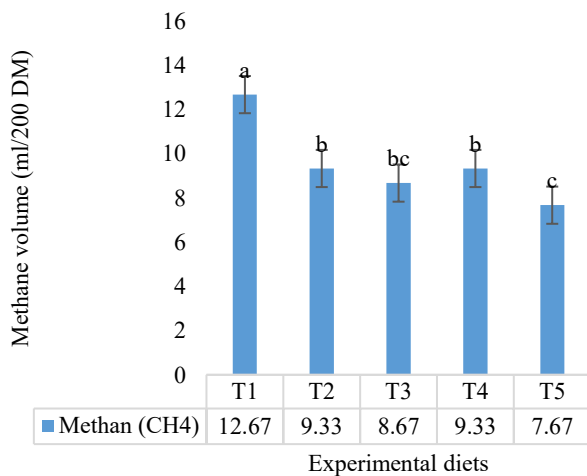


Figure 1. The methane (CH<sub>4</sub>) production of experimental diets

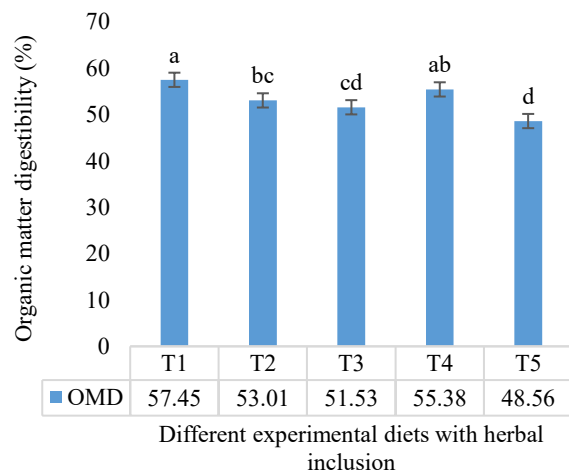


Figure 2. The Organic Matter Digestibility of the Experimental Diet (%)  
 T1 = No herbs (Control), T2 = *Ocimum gratissimum*, T3 = *Phyllanthus amarus*, T4 = *Lactuca taraxacifolia*, T5 = *P. amarus* + *O. gratissimum* + *L. taraxacifolia*

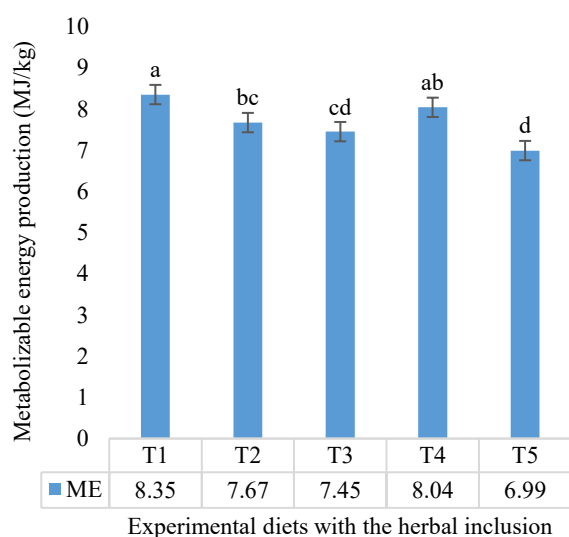


Figure 3. The Metabolisable Energy of the Experimental Diet (MJ/kg)

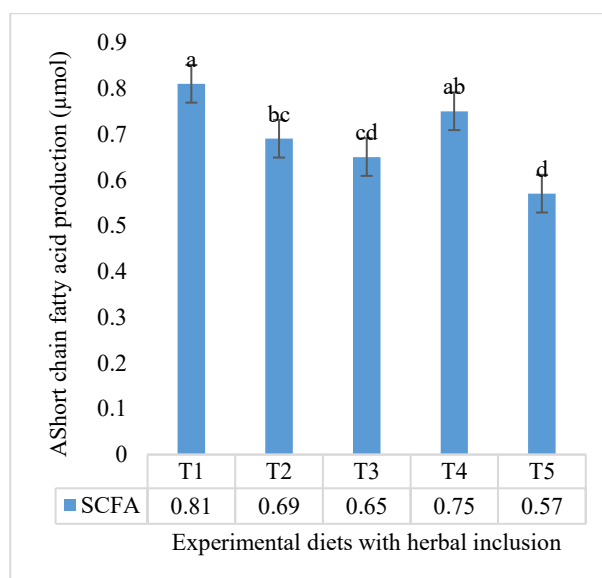


Figure 4. The Short Chain Fatty Acid of the Experimental Diet (µmol)

Table 5. Effect of Different Herbal Supplementation on Ruminal Characteristics of West African dwarf goats

Parameters	T1	T2	T3	T4	T5	SEM
pH	5.02	5.06	4.48	5.05	4.80	0.10
Acetic acid (mm/100mL)	27.65 <sup>b</sup>	28.72 <sup>b</sup>	36.45 <sup>a</sup>	27.00 <sup>b</sup>	33.41 <sup>ab</sup>	1.32
Butyric acid (mm/100mL)	5.98 <sup>b</sup>	7.29 <sup>ab</sup>	7.85 <sup>ab</sup>	8.39 <sup>a</sup>	7.56 <sup>ab</sup>	0.33
Propionic acid (mm/100mL)	6.69 <sup>ab</sup>	6.90 <sup>ab</sup>	10.42 <sup>a</sup>	6.52 <sup>b</sup>	8.47 <sup>ab</sup>	0.58
TVFA (mm/100mL)	64.59 <sup>a</sup>	64.32 <sup>a</sup>	58.43 <sup>b</sup>	64.45 <sup>a</sup>	61.00 <sup>ab</sup>	0.92
A/P	4.40	4.18	3.56	4.22	4.08	0.18
NH <sub>3</sub> -N(mg/100mL)	5.30	5.06	4.48	5.05	4.80	0.10

<sup>ab</sup> Means along the same row with different superscripts are significantly different (P<0.05), SEM = Standard Error of Mean, TVFA= Total Volatile Fatty Acids, A/P= Acetic acid: Propionic acid, NH<sub>3</sub>-N= Rumen ammonia Nitrogen, T1 = No herbs (Control), T2 = *Occimum gratissimum*, T3 = *Phyllantus amarus*, T4 = *Lactuca taraxacifolia*, T5 = *P. amarus* + *O. gratissimum* + *L. taraxacifolia*

Table 6. Effect of Different Herbal Supplementation on Rumen Microbial Count of West African Dwarf Goats

Parameters	T1	T2	T3	T4	T5	SEM
Total bacterial count (x10 <sup>-4</sup> cfu/mL)	65.33 <sup>d</sup>	71.67 <sup>cd</sup>	93.33 <sup>b</sup>	75.00 <sup>c</sup>	190.00 <sup>a</sup>	2.83
Total fungal count (sfu/mL)	5.67 <sup>b</sup>	5.83 <sup>b</sup>	9.50 <sup>a</sup>	6.67 <sup>b</sup>	11.00 <sup>a</sup>	0.51
Protozoan (x10 <sup>-2</sup> /mL)	19.00 <sup>b</sup>	13.33 <sup>c</sup>	12.67 <sup>c</sup>	28.67 <sup>a</sup>	17.50 <sup>b</sup>	0.90

SEM = Standard Error of Mean, T1 = No herbs (Control), T2 = *Occimum gratissimum*, T3 = *Phyllantus amarus*, T4 = *Lactuca taraxacifolia*, T5 = *P. amarus* + *O. gratissimum* + *L. taraxacifolia*

## Discussion

The presence of secondary metabolites such as saponins, tannins, flavonoids, glycosides, and phenols in the leaves studied confirms their phytochemical richness. These compounds are known to play important roles in animal health, including antimicrobial, antioxidant, and antiprotozoal activities, thereby reducing overall methane and carbon dioxide gases production during fermentation in the ruminant digestive tract (Ladipo et al., 2010). Previous studies similarly reported the occurrence of tannins, flavonoids, steroids, and glycosides in *L. taraxacifolia* (Adinortey et al., 2012; Rosine et al., 2022) and *O. gratissimum* (Mgbeje et al., 2019). The absence of oxalates across the three herbs suggests a reduced risk of oxalate-induced mineral imbalance and additional gases production especially from methane and carbon dioxide. Oxalate induction of gas production in ruminant digestive tract is influenced by concentration of oxalate and the adaptation level of the animal's microbiota in the rumen.

The high crude protein contents (>15%) observed in all three herbs indicate their potential as protein supplements for small ruminants. These values surpass the 7% threshold required for optimal rumen microbial activity (Norton, 2003). Notably, the combination of herbs (T5) yielded the highest dietary CP, suggesting a possible synergistic effect, as also reported by Amany et al. (2022). Similarly, the high carbohydrate content in *O. gratissimum* corroborates findings by Gideon et al. (2018), highlighting its role as an energy-rich feed resource.

Gas and methane production trends reflect the degradability of dietary carbohydrates and fibre. Higher gas output in *L. taraxacifolia* diets is likely due to its higher crude fibre and cellulose content. The reduced methane observed in herb-supplemented diets, particularly in T5, is consistent with earlier reports that secondary metabolites such as saponins suppress methanogenesis (Babayemi & Bamikole, 2009; Anantasook & Wanapat, 2012).

Digestibility and energy indices further emphasise the nutritional value of these herbs. Although the control diet recorded the highest OMD and ME, the herbal diets-maintained values within ranges previously reported for ruminant diets (Tag-El-Din et al., 2012). The lower SCFA in T5 reflects its reduced gas production but still indicates energy availability, particularly in *L. taraxacifolia*-based diets (Akinfemi & Ladipo, 2014).

Ruminal fermentation profiles showed increased production of volatile fatty acids (VFA) in herb-supplemented diets, with acetic acid predominating, consistent with fibre-rich diets supporting cellulolytic activity. However, total VFA values were lower than some earlier reports (Wang et al., 2023), possibly due to differences in herb quality and harvest stage.

Importantly, microbial enumeration revealed that herbal mixtures enhanced bacterial and fungal populations while suppressing protozoa. This supports previous findings that saponins reduce protozoal counts, thereby lowering methane emissions and improving nutrient utilisation (Sirohi et al., 2009; Lila et al., 2003). The elevated microbial population in T5 underscores the potential of herbal combinations to enhance rumen ecology and feed utilization efficiency.

## Conclusion

The inclusion of *Phyllanthus amarus*, *Ocimum gratissimum*, and *Lactuca taraxacifolia* as feed additives influenced rumen fermentation, methane production, and microbial populations in West African Dwarf goats. Among the treatments, *P. amarus* and the combined herbal mixture were most effective in lowering methane emissions while improving rumen ecology. These findings highlight the potential of herbal feed additives as sustainable alternatives for enhancing ruminant productivity and mitigating environmental impacts.

## Declarations

This study was presented at the IV. International Congress of the Turkish Journal of Agriculture - Food Science and Technology (Niğde, TURJAF 2025).

### Ethical Approval

The research was approved by the Kwara State University Ethical Committee: KWASU/CRIT/REA/2023/023

### Author Contribution Statement

**Dupe Olufunke Ogunbosoye:** Conceptualization, methodology, supervision, project administration, review, and editing.

**Ade Isaac Afe:** Data collection, investigation and formal analysis.

**Akeem Raji:** Data collection, laboratory analysis, and investigation.

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## Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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