International Journal of Academic and Applied Research (IJAAR)
ISSN: 2643-9603
Vol. 9 Issue 9 September - 2025, Pages: 9-20

Growth Performance, Nutrient Digestibility, Hematology, and Rumen Characteristics of West African Dwarf Goat Fed Plantain Pseudo-Stem Supplemented with Groundnut Foliage.

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Abstract: *The study evaluated the effects of four dietary treatments on the nutritional digestibility, rumen fermentation, hematological changes, growth performance, and economic returns of West African Dwarf (WAD) goats fed with different treatment level of groundnut foliage and plantain pseudo-stem: T1 (control), T2 (75% groundnut foliage + 25% plantain pseudo-stem), T3 (50% groundnut foliage + 50% plantain pseudo-stem), and T4 (25% groundnut foliage + 75% plantain pseudo-stem). T2 had the most significant crude protein content (13.57%) and dry matter content (32.72%) of all the formulated diets, which greatly improved nutritional digestibility and growth parameters. T2 goats had the highest final body weight (16.18 kg), average daily gain (101.63 g/day), and crude protein and fiber digestibility. Better erythropoiesis, immunological response, and microbial activity were indicated by T2's optimized rumen fermentation properties and hematological indices. A diet consisting of 75% groundnut leaf silage and 25% plantain pseudo-stem maximizes nutrient absorption, development, and financial gains, making it a suitable feeding strategy for small ruminant breeding. The economic study findings showed that T2 was the most cost-effective diet, with the lowest cost per kilogram of weight gain ($1.36) and the highest benefit-cost ratio (3.24). In contrast, the over-inclusion of plantain pseudo-stem (T4) resulted in weight gain, less protein digestibility, higher fiber content, and lower economic efficiency.*

Keywords: *Hematological, Groundnut foliage, Nutrient digestibility, Plantain pseudo-stem, Rumen characteristics, and West African dwarf goats.*

1. NTRODUCTION

In Nigeria and West Africa, the West African Dwarf (WAD) goat is one of the most well-liked small ruminant breeds (Daramola *et al.* 2021). Rural farmers depend on this native breed, which has adapted well to a range of climates, including humid and sub-humid zones (Hoffmann, 2013). Although raised mainly for their meat, some tribes also use WAD goats for their milk and skin. According to current livestock population estimates, WAD goats make up a large percentage of Nigeria's small ruminant population and are a vital part of small-scale farming systems because of their ability to thrive in environments with limited resources and input (Ofori and Hagan, 2021). Their short gestation period, high productivity, and capacity to adapt to harsh environmental circumstances make them the preferred choice of farmers. According to Mwaba (2011), these goats also provide a financial buffer against economic downturns by dramatically increasing household income and food security. Inadequate nutrition often lowers their productivity, especially during dry seasons when fodder is limited (Salem and Smith, 2008; Ade *et al.* 2024).

WAD goats' growth performance is significantly impacted by the quality of their feed (Abegunde *et al.* 2021). Natural pasture is mostly used in traditional feeding methods, although this is usually insufficient for the best possible development, reproduction, and general health (Makkar, 2016). Suboptimal weight gain, poor reproductive outcomes, and increased susceptibility to health problems can all be caused by certain dietary inadequacies (Kiani *et al.* 2022). According to Saha and Pathak (2021), digestibility has significant effects on an animal's general performance and nutrient usage. Although they may be potential sources of fiber and protein, it essential to evaluate the digestibility of plantain pseudo-stem and other feed components to make sure they align with ruminant nutritional needs (Palai, 2010). Integrating plantain pseudo-stem with other unconventional feed ingredients, including groundnut leaf silage, can enhance digestibility and performance (Abiola-Olagunju, 2016, Dubale, 2017).

Hematological indicators are essential for determining the physiological and health status of animals (Ajay *et al.* 2023). Blood profiles, such as packed cell volume, hemoglobin concentration, white blood cell count, and red blood cell count, can be used to determine the impact of different diets on an animal's health (Etim *et al.* 2014). Hematological evaluations must be incorporated into feeding experiments to guarantee the safety and efficacy of groundnut foliage and plantain pseudo-stem in preserving normal physiological functioning (Flynn, 2023). In ruminants, microbial fermentation and digestion occur primarily in the rumen (Owens and Basalan, 2016). The pH balance, VFA level, and microbial population have a direct influence on feed efficiency and nutrient absorption.

The plantain pseudo-stem is made up of tightly wrapped 14–18 leaf sheaths and a soft core (Okoli, 2020). These leaf sheaths separate from the stem and develop into plantain leaves as the plant matures. Course fiber makes up the outermost 4–6 leaf sheaths, while soft, glossy fiber makes up the following 6–8 sheaths (Okoli, 2020). Soft fiber makes up the remaining sheaths, and depending on the maturation stage, the stem may also have a core. Each sheath is composed of three layers as well: an inner layer of soft cellular tissue, a middle layer of vascular tissue that transports water, and an outer layer of epidermis with bundles arranged in a soft tissue background. The middle layer has a high cellulose and starch content, which makes it a good candidate for animal feed production. Once more, it contains certain proteins that may have antibacterial properties, and the plant wastes primarily consist of stems and leaves. Farmers harvest plantains all at a time, and the pseudo-stems are available in bulk, which cannot be stored for long due to their high moisture content. Plantain plant wastes have good digestibility, fermentable energy, and crude protein (Anusha *et al.,* 2022).

Groundnut foliage is a high-protein legume forage that serves as a complementary feed to low-protein fibrous materials like plantain pseudo-stem. A study reported by Bala and Hassan (2023), that groundnut foliage contains 18–22% CP, making it a valuable protein source for small ruminants. Groundnut foliage's high digestibility enhances nitrogen balance and microbial protein synthesis, both of which are necessary for WAD goat development and milk production (Adewuyi, 2021). Groundnut foliage includes protein as well as important minerals such as calcium, phosphorus, and magnesium, which aid in bone-building and metabolic function (Aremu and Ibrahim, 2014).
This study will look at how supplementing plantain pseudo-stem (PS) with groundnut foliage (GF) affects the growth performance, nutrient digestibility, hematological parameters, rumen features, and economic viability of West African dwarf (WAD) goats.

2.0 MATERIALS AND METHODS

2.1. Experimental Site

The research was carried out at the Goat and Sheep Research Unit of the Teaching and Research Farm of Dennis Osadebay University, Asaba; situated in the equatorial rainforest zone of Nigeria. It is located at latitude 6º 12'N and longitude 6º 12' N. The climate of the site is hot and humid with maximum day temperatures ranging from 27^0C to 30^0C. From March to November, the region experiences a rainy season every year. Rainfall varies from 1800 to 300 mm every year.

2.2. Experimental animals

Forty-eight (48) West African Dwarf goats aged less than a year old and weighing between 6.57±0.6kg were used for this study. The animals were obtained from the open market and randomly assigned to four dietary treatments, with three replicates per treatment, in a completely randomized design. A quarantine period of 14 days was also implemented. The goats were housed in an open-sided, well-lighted, and adequately ventilated building with concrete floors that had been previously disinfected with germicide. The concrete floor was covered with 4 cm layers of grass straws to absorb urine and for easy removal of faeces. The animals were fed the experimental diets early in the morning (8.00 am), grass was given in the afternoon (2.00 pm), and cool, fresh drinkable water was supplied. Leftover feed was weighed each morning. Animals' weights were taken using a hanging scale at the start of the study, and weekly, throughout the experimental period, and the growth study lasted for forty-nine (49) days. The goats were then transferred to metabolic cages with facilities for the separate collection of urine and faeces for the digestibility trial. Faeces and urine were collected daily before morning feeding. The urine was collected into a plaque bucket placed under each cage, and which few drops of 25% HSO were introduced to curtail volatilization of the ammonia from the sample. The daily volume of urine output per goat for a period of 7days was determined, and 10% of the daily output was saved in stopper plastic bottles, numbered and stored in a refrigerator at -5 °C. Samples of feed and faeces were analyzed for proximate and fibre compositions using the method described by AOAC (1990)
The animals were vaccinated against Peste des Petits Ruminants (PPR). The animals were also given long-acting antibiotics, dewormed, and dipped in acaricide against ectoparasites.

2.3. Experimental design and procedure

The animals were randomly allotted to four groups of twelve (12) goats per dietary treatment and four (4) goats per replicate to receive:
Diet 1: 100% conventional feed (maize + grass hay).
Diet 2: 75% groundnut foliage + 25% plantain pseudo-stem.
Diet 3: 50% groundnut foliage + 50% plantain pseudo-stem
Diet 4:25% groundnut foliage + 75% plantain pseudo-stem

Table 1. Preparation of experimental diets

Diet	GF (%)	PS (%)	Maize + Hay (%)
1 (0%)	0	0	100 (50% maize + 50% hay)
2	75	25	0
3	50	50	0
4	25	75	0

2.4. Collection and Processing

Groundnut Foliage: Harvest after pod removal. Dry under shade to retain nutrients. Chop to 2–3 cm in size.
Plantain Pseudo-stem: Cut fresh pseudo-stems. Chop into small pieces (2–3 cm), sun-dry partially to reduce moisture content.
Maize + Hay (Control group): Use commercially available maize and sun-dried grass hay. Mix at the desired ratio (at 1:1 by weight for energy and fiber balance).
Mixing: Weigh dry matter-equivalent portions of each component based on the diet ratio, the diet was mix thoroughly to ensure even distribution.
For Diet 2: Mix 750 g groundnut foliage with 250 g plantain pseudo-stem per kg of feed.
For Diet 3: Mix 500 g each of groundnut foliage and pseudo-stem per kg.
For Diet 4: Mix 250 g groundnut foliage with 750 g pseudo-stem per kg.
Step 3: Feeding and Allocation
During each feeding time, the animals were offered the experimental diet and access to clean water *ad libitum*. After an initial adjustment of 14 days, body weights were taken fortnightly for 98 days, and the quantity of the experimental diets offered was adjusted according to their body weight. The initial and final weight of the animals was taken at the beginning and end of the experiment, respectively, and refusals were collected daily to determine feed intake.

2.5. Statistical Analysis

Collected data was subjected to a one-way analysis of variance (ANOVA) using R-statistics (version 4.5.1). The Mean separations will be compared using Duncan's Multiple Range Test. The analysis was evaluated with the following model.

$Xij = \mu + T_i + E_{ij}$

Where:
X_{ij} = The observed value of any response (growth rate, feed intake, feed efficiency, digestibility trial, etc.)
μ = the overall population mean common to all treatments
T_i = Treatment effects
e_{ij} = random residual error due to the experimentation

3. RESULTS AND DISCUSSION

Dietary nutrient composition

Particularly in terms of crude protein and metabolizable energy content, the composition of the formed silages differed significantly between treatments. The maximum energy value (10.16 MJ/kg) and crude protein (13.57%) were found in T2 (25% PS + 75% GF), indicating the ideal nutritional profile for WAD goat growth. These findings align with earlier research that emphasized the importance of striking a balance between forages high in calories and protein-rich components (Oluwadele et al. 2025). The control had the highest proportion of crude fiber (26.10%), whereas T2 had the lowest (23.76%), confirming that a moderate amount of PS could improve digestibility. The highest dry matter percentage, 32.72%, was also found in T2, which may have improved feed intake and nutrient absorption. Ether extract, a measure of energy density and fat content, was likewise highest in T2 (3.67%), which may have contributed to the enhanced energy availability for metabolic processes. The ash concentration varied slightly between treatments, but T3 (50% PS + 50% GF) had the highest value (7.65%), suggesting sufficient mineral retention. PS's lower nitrogen content than GF may have contributed to the decrease in CP in T4 (10.88%) observed when plantain pseudo-stem integration increased. In order to meet the nutritional needs of growth and development of goats, it is imperative to maintain an appropriate ratio of forage components, as this pattern implies.

Fig. 1: Feed composition of supplements with plantain pseudo-stem and groundnut foliage silage for growing West African dwarf goat

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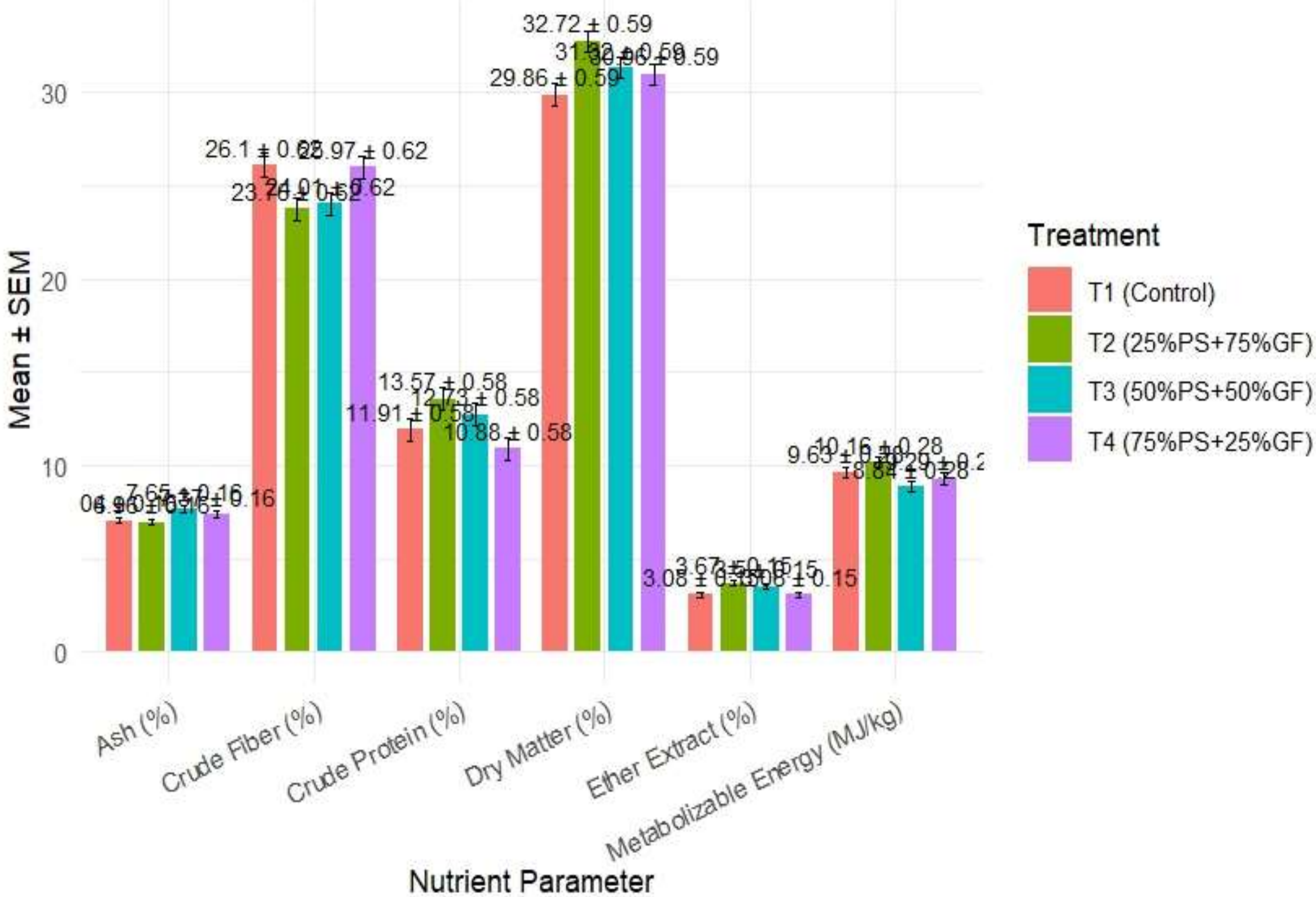
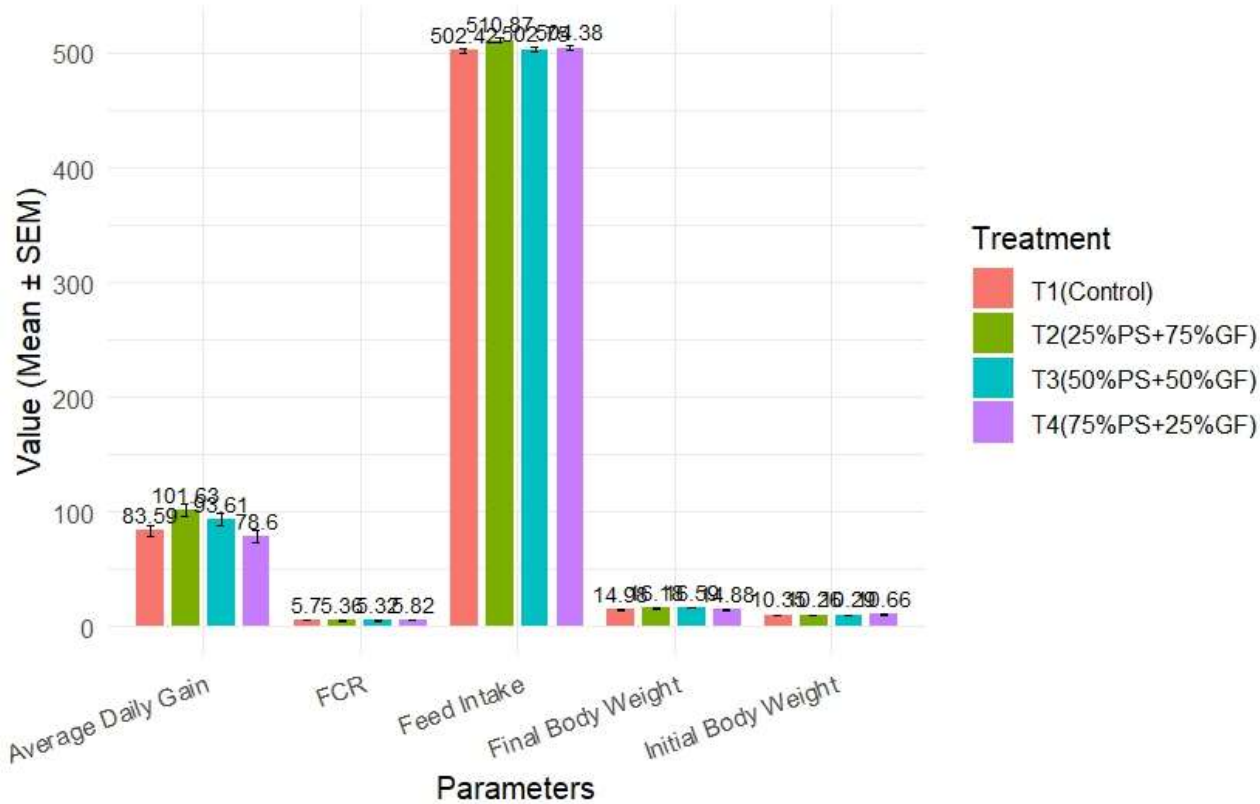


The treatments had strong alignment with body weights ranging from 10.26 kg (T2) to 10.66 kg (T4). Baseline homogeneity is necessary to reduce variance caused by genetic and physiological differences, as this shows. In ruminant feeding trials, baseline homogeneity allows for a more accurate assessment of dietary effects, as González et al. (2018) observed. In comparison to goats fed T1 (14.98 kg) and T4 (14.88 kg), goats fed T2 (16.18 kg) and T3 (16.59 kg) had much greater final body weights. These results show how supplementing GF, a protein-rich feed (13.57% CP in T2 silage; see Table 1), improves animal growth performance. Final body weights of 15.90–16.50 kg were likewise noted by Odeyinka et al. (2024) in WAD goats offered protein-enriched silage blends for 8–10 weeks. At 101.63 g/day, T2 had the highest average daily gain (ADG), followed by T3 (93.61 g/day). The control and T4 treatments came in second and third, respectively, at 83.59 g/day and 78.60 g/day. The effectiveness of the silage formulations examined here is demonstrated by the fact that these values surpass the benchmark ADG of 70–80 g/day for WAD goats fed traditional forages as reported by Bélanger-Naud et al. (2024). The high ADG in T2 is likely due to the superior nutrient profile and especially the high crude protein and digestibility of GF and which aligns with Abegunde *et al*. (2021), who found ADG improvements up to 105 g/day in goats fed ensiled leguminous diets. Feed intake ranged from 502.42 to 510.87 g/day, showing minimal variation among treatments, indicating that the silage was well accepted among treatment groups. Van (2006) noted that goats maintain relatively stable intake when feed palatability and moisture content are not drastically altered. However, even with comparable intake, growth outcomes were probably influenced more by nutrient density and balance than by intake volume. The lowest feed conversion ratio (FCR), as an indicator of feed efficiency, was found in T3 (5.32) and T2 (5.36), as in contrast to T1 (5.70) and T4 (5.82). These values suggest that diets with higher GF proportions improve feed utilization. Similar findings by Shegun *et al*. (2017) emphasized that legumes like GF improve nitrogen retention and rumen microbial efficiency, thereby reducing FCR values. The optimal FCR range for goats on forage-based diets is typically 5.0–6.0, according to the same authors, placing T2 and T3 within the ideal efficiency bracket.

Fig. 2: Growth of WAD fed with plantain pseudo-stem with groundnut foliage silage



Goats fed the T2 diet (25% plantain pseudo-stem and 75% groundnut foliage) recorded the highest dry matter digestibility (69.86%), followed by T3 (68.60%) and T1 (67.60%), while the least value was observed in T4 (61.96%). The superior digestibility in T2 may be attributed to the higher groundnut foliage content, which is known for its high palatability and digestible nutrient profile (Muhammad and Muhammad, 2020). Comparable DMD values ranging between 65% and 70% were also reported by Rusdy *et al*. (2020) for goats fed forage-based diets, confirming the present results. Crude protein digestibility followed a similar trend, peaking at 78.43% in T2, which reflects the protein-rich nature of groundnut foliage. According to Finangwai *et al.* (2018), groundnut haulms contribute significantly to CP availability in small ruminant diets. The values obtained here compare favorably with the CPD range (70–80%) reported for WAD goats fed legume-supplemented diets (Ikyume *et al.* 2018). The drop in CP digestibility at higher plantain pseudo-stem levels (T4) could be linked to its relatively lower nitrogen content and higher fiber complexity. Fiber digestibility improved with moderate inclusion of plantain pseudo-stem, with T2 (60.12%) outperforming the control (54.42%). This aligns with findings by Silva *et al.* (2018), who observed that balanced roughage-legume silage can enhance fiber digestibility due to improved microbial activity in the rumen. However, a further increase in pseudo-stem content (T4) did not sustain this trend, likely due to lignin buildup, which limits fiber breakdown (Van, 2006). NDF and ADF digestibility were highest in T2, 54.53% and 48.54%, respectively, followed closely by T3. These values agree with those reported by Abubakar and Ibrahim (2022), who found that the inclusion of legumes in silage, improves fiber solubility and digestibility. The decline in T4 could be attributed to the fibrous, less digestible composition of pseudo-stem at higher proportions, which affects cell wall degradation (Abegunde *et al*. 2021).

Fig. 3: Nutrient Digestibility (%) of WAD fed with plantain pseudo-stem with groundnut foliage silage

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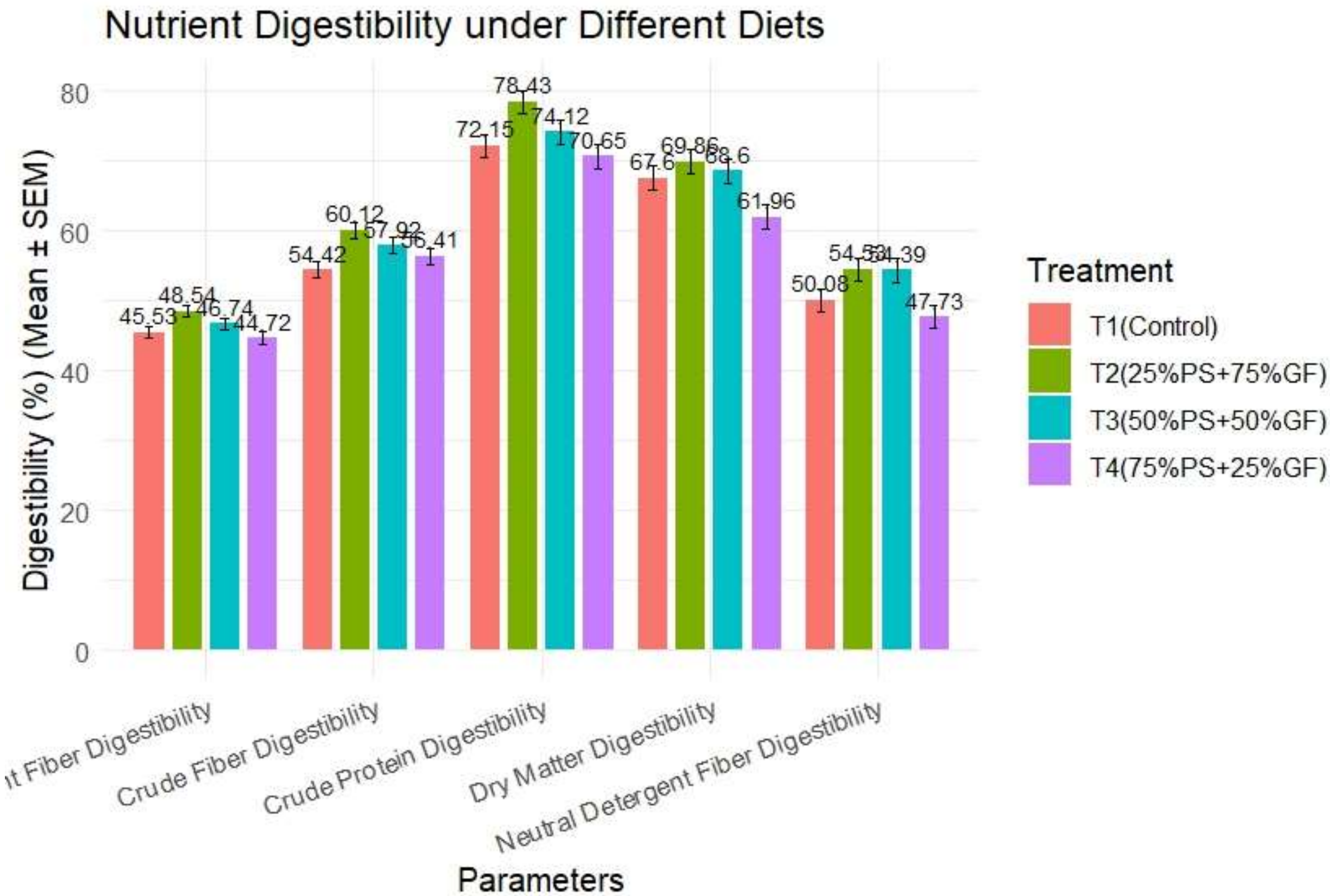
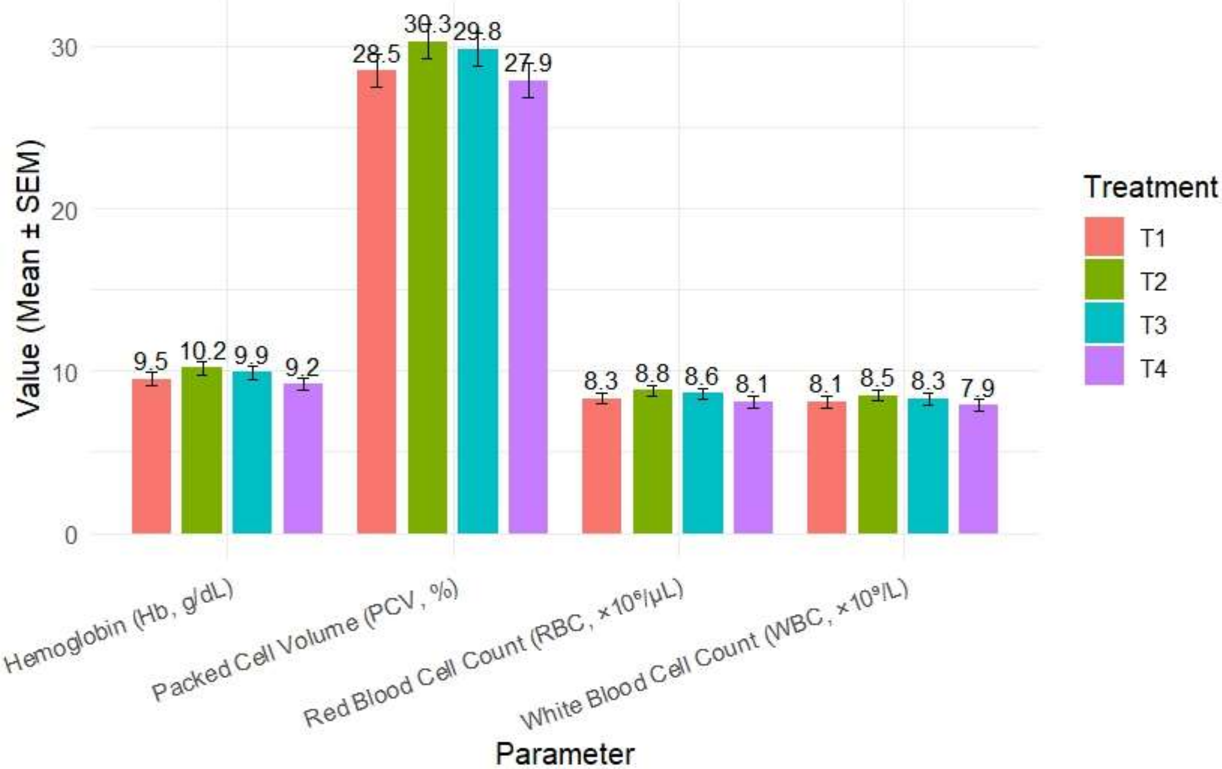


In T4, the PCV was 27.90%, while in T2, it was 30.30%. Goats fed 75% groundnut foliage and 25% plantain pseudo-stem (T2) had the highest PCV value, indicating better overall health and oxygen-carrying ability (Njidda et al. 2013). According to Fanta et al. (2024), there is no detrimental effect of the diets on erythropoiesis as PCV values for all treatments are within the normal physiological range of 22–38% for healthy goats. A similar pattern was seen in the concentrations of hemoglobin (Hb), with T2 exhibiting the highest value (10.20 g/dL) and T4 the lowest (9.20 g/dL). Akinrinmade and Akinrinde (2013) found that the typical ranges of hemoglobin for WAD goats were between 8.0 and 12.0 g/dL, which is in line with these results. Better protein and mineral availability from the diet is demonstrated by adequate hemoglobin levels in T2 and T3, which improve erythrocyte synthesis (Dauda et al., 2023). The highest red blood cell (RBC) counts were found in T2 (8.80 $\times10^6$/µL), closely followed by T3 (8.60 $\times10^6$/µL), and T4 (8.10 $\times10^6$/µL). These values align with the reference range of 5.0–13.0 $\times10^6$/µL for goats (Jiwuba *et al.* 2021). The elevated RBC counts in T2 may be attributed to the superior nutritional composition of the GF-dominated silage, which could enhance hematopoiesis (Daramola *et al.* 2005, Ade *et al.* 2024). White blood cell (WBC) counts, a marker of immune response, remained within normal limits (4.0–13.0 $\times10^9$/L) across treatments (Daramola *et al.* 2005). T2 again recorded the highest WBC count (8.50 $\times10^9$/L), indicating a potentially improved immune status due to better diet quality. The slight decline observed in T4 may be due to the lower protein content and digestibility of the PS-dominant silage, which might reduce immune competence (Omu *et al.* 2024).

Fig. 4: Haematology of WAD fed with plantain pseudo-stem with groundnut foliage silage



The rumen environment heavily affects all microbial activity, nutrient digestion, and general animal performance. Fig. 5 shows the total volatile fatty acid (TVFA), ammonia nitrogen content, and rumen pH of West African Dwarf (WAD) goats fed varying amounts of groundnut foliage silage and plantain pseudo-stem inclusion. With the control (T1) and T3 recording 6.40 and 6.60, respectively, the rumen pH ranged from 6.30 in T4 (75% plantain pseudo-stem + 25% groundnut foliage) to 6.70 in T2 (25% plantain pseudo-stem + 75% groundnut foliage). For cellulolytic bacterial activity and effective fiber digestion in ruminants, these levels fall within the recommended pH range of 6.0–7.0 (Zain 2024: optimal range = 6.0–7.0; Baldwin and Connor, 2017: optimal range = 6.2–7.0). The greater pH of T2 may be due to the increased production of saliva due to the higher fiber content of groundnut leaves, which enhances buffering capacity and microbiological stability. T2 (2.80 mg/dL) recorded the highest ammonia nitrogen (NH_3-N) level, followed in descending order by T3 (16.10 mg/dL), T1 (15.20 mg/dL), and T4 (14.90 mg/dL). Weakley and Owens (1983) recommend an NH_3-N range of 15–25 mg/dL, while Dewhurst and Newbold (2022) suggest 10–25 mg/dL as optimal. These findings fall within this range. The increased NH_3-N in T2 suggests that rumen microorganism for microbial proliferation and synthesis, as well as a higher degradability of dietary protein, efficiently used nitrogen from groundnut foliage. Treatment differences were observed in total volatile fatty acids (TVFA), the main source of energy for ruminants and a major consequence of rumen fermentation. TVFA concentrations were greater in T2 (95.30 mmol/L), T3 (92.70 mmol/L), T1 (90.50 mmol/L), and T4 (89.10 mmol/L). The range of 80–130 mmol/L TVFA concentrations seen in rumens that are healthy and fermenting efficiently is consistent with our findings (Mao and Wang, 2025: reference TVFA = 80–130 mmol/L). A better-balanced carbohydrate-protein interaction in T2's diet promotes appropriate microbial fermentation and energy availability, which in turn leads to superior VFA production in T2, indicating greater fermentative activity.

Fig. 5: Rumen Characteristics of WAD fed with plantain pseudo-stem with groundnut foliage silage

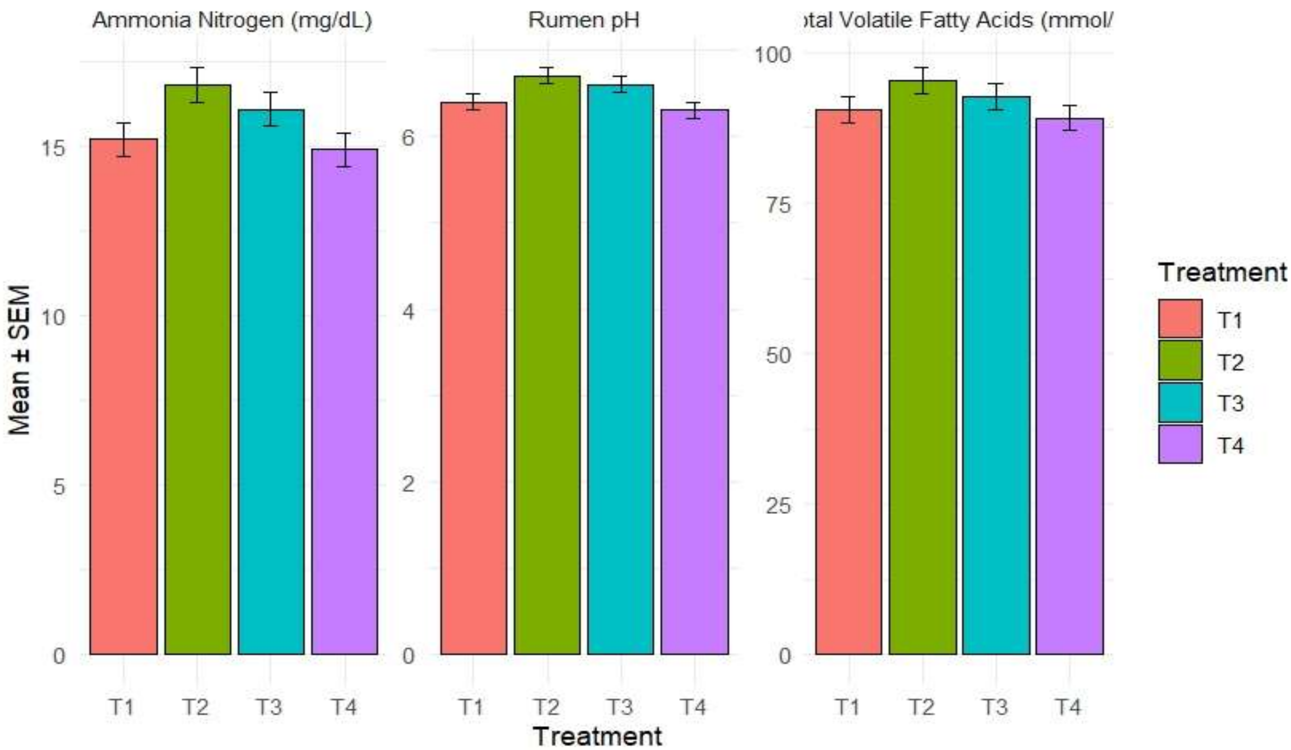


Table 6 presents the economic evaluation of feeding West African Dwarf (WAD) goats with varying inclusion levels of plantain pseudo-stem (PS) and groundnut foliage (GF) silage. Feed prices per kilogram ranged from \$0.29 to \$0.33 for each treatment. The control diet (T1) came in second at \$0.30 ± 0.01, and T3 (50% PS + 50% GF) had the lowest unit cost (\$0.29 ± 0.01). According to Jiwuba et al. (2021), employing agricultural by-products can reduce feed costs without lowering nutritional value. These results are in line with their findings. Total feed cost per animal was lowest for T2 (\$13.18 ± 0.60), followed by the control group (\$14.98 ± 0.60). The highest expenditure occurred in T4 (\$16.03 ± 0.60), which may be linked to the higher proportion of plantain pseudo-stem in the diet. This ingredient may offer lower nutrient density, leading to greater feed consumption to meet dietary requirements (Legesse et al., 2005). The reduction in feed cost in T2 could be attributed to the synergy between groundnut foliage's high protein content and the fiber-rich plantain pseudo-stem, which improved nutrient utilization. The cost per kilogram of weight gain further revealed the economic efficiency of the dietary treatments. While T2 had the lowest cost (\$1.36 ± 0.11), suggesting that it was the most cost-effective for weight increase, T1 and T4 recorded higher values at \$1.84 ± 0.11 and \$1.80 ± 0.11, respectively. This pattern is in agreement with the results of Ikyume et al. (2018), who demonstrated that feed combinations with moderate calorie content and high protein content increase feed conversion efficiency and lower cost per gain in small ruminants. The Benefit-Cost Ratio (BCR), a key indicator of profitability, was highest for T2 at 3.24 ± 0.26, yielding returns that were more than three times the investment. The BCR was lowest for T1 (2.42 ± 0.26), T3 (2.40 ± 0.26), and T4 (1.99 ± 0.26). Goat-feeding systems are profitable if the BCR is more than 1.5, report Abegunde et al. (2021). T2 thus exhibits the greatest economic advantage, presumably because of enhanced weight increase, decreased cost per unit gain, and optimal nutritional synergy.

Table 2: Economic Analysis of WAD fed with plantain pseudo-stem with groundnut foliage silage

Parameters	T1(Control)	T2(25%PS + 75% GF)	T3(50%PS + 50% GF)	T4(75%PS + 25% GF)
Feed Cost per kg (\$)	0.30 ± 0.01	0.33 ± 0.01	0.29 ± 0.01	0.33 ± 0.01
Total Feed Cost per Goat (\$)	14.98 ± 0.60	13.18 ± 0.60	15.30 ± 0.60	16.03 ± 0.60
Cost per kg Weight Gain (\$)	1.84 ± 0.11	1.36 ± 0.11	1.67 ± 0.11	1.80 ± 0.11
Benefit-Cost Ratio (BCR)	2.42 ± 0.26	3.24 ± 0.26	2.40 ± 0.26	1.99 ± 0.26

4. CONCLUSION

The feed composition, growth performance, nutritional digestibility, hematological, rumen, and economic viability of WAD goats are all deeply affected by the inclusion of a blend of plantain pseudo-stem and groundnut leaf silage in the experimental diets, according to this study. The diet that contained 75% groundnut foliage and 25% plantain pseudo-stem (T2) had the maximum digestibility, metabolizable energy, and protein content, which improved feed efficiency and growth performance. T2 enhanced microbial activity and erythropoiesis, which led to improved nutrient use, according to the rumen fermentation and hematological results. Based on economic investigation, T2 is the most profitable feeding strategy because it is cost-effective. Higher percentages of plantain pseudo-stem inclusion (T4) decreased feed costs, but because of their higher fiber content, they also had a negative effect on growth and digestibility. Consequently, it is advised to increase the productivity and profitability of WAD goat production by utilizing plantain pseudo-stem and groundnut foliage in an appropriate amount, especially at a 25:75 ratio.

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