

Growth Performance, Nutrient Digestibility, Nitrogen Utilization and Economic Efficiency of West African Dwarf Rams Fed Rice Straw, Maize Stovers or Maize Cobs

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Abstract

This study evaluated the effects of feeding rice straw, maize stovers, and maize cobs supplemented with a concentrate diet on growth performance, nutrient utilization, nitrogen balance, serum biochemical metabolites, and economic efficiency of West African Dwarf (WAD) rams. Twenty-four growing WAD rams with an average initial body weight of 18.5 ± 0.6 kg were randomly assigned to three dietary treatments in a completely randomized design and fed for 70 days. Rice straw (RS), maize stovers (MS), and maize cobs (MC) were offered ad libitum as basal roughage sources, while concentrate supplementation was provided at 2% of body weight. Dietary treatments significantly ($P < 0.05$) influenced dry matter intake, nutrient digestibility, nitrogen utilization, growth performance, and selected serum metabolites. Rams fed maize stovers recorded greater ($P < 0.05$) concentrate intake, total dry matter intake, final body weight, average daily gain, feed efficiency, nutrient digestibility coefficients, and nitrogen retention compared with those fed rice straw and maize cobs. Serum total protein, albumin, and glucose concentrations were enhanced in animals fed maize stovers, whereas urea and cholesterol values remained within physiological limits. Economic evaluation revealed that maize stovers resulted in the highest net profit and benefit–cost ratio compared with rice straw and maize cobs. The findings indicate that maize stovers provide superior nutritional value, improve biological performance, and enhance economic returns when used as a basal feed resource for WAD rams supplemented with concentrate diets.

Introduction

Small-ruminant production contributes significantly to food security, income generation, and livelihood improvement in tropical and subtropical regions, particularly among smallholder farmers operating under low-input production systems. However, productivity of these animals is often limited by seasonal variations in feed availability and quality, especially during prolonged dry periods when natural pastures become scarce and nutritionally inadequate (Anim-Jnr et al., 2023). Consequently, livestock producers increasingly depend on agricultural crop residues, including rice straw, maize stovers, and maize cobs, as alternative feed resources due to their availability, low cost, and accessibility (Shah et al., 2025).

Although widely available, crop residues generally possess poor nutritional characteristics, including low crude protein concentration, high lignocellulosic fibre content, and reduced digestibility, which negatively affect voluntary feed intake, nutrient utilization, and animal performance (Zhong et al., 2021). Efficient utilization of fibrous residues is highly dependent on adequate ruminal microbial activity; however, the low nitrogen concentration of most crop residues restricts microbial growth and reduces degradation of structural carbohydrates, thereby limiting nutrient availability to the animal (Sharma et al., 2024). Therefore, supplementation with nitrogen-rich feed resources is essential to improve rumen fermentation efficiency and enhance the feeding value of poor-quality roughages.

Protein supplements such as soybean meal and groundnut cake have traditionally been used to improve the utilization of low-quality roughages. Nevertheless, their high cost and limited availability have

encouraged the search for alternative protein sources that are economical, locally available, and environmentally sustainable (Sime and Duguma, 2025). Poultry litter represents a potential alternative feed resource because of its considerable nitrogen, mineral, and residual nutrient content. The nitrogen present mainly as uric acid and other non-protein nitrogen compounds can be utilized by rumen microorganisms for microbial protein synthesis, thereby improving fibre digestion and nutrient utilization (Kyakuwaire et al., 2019).

The efficiency of ruminal fermentation depends not only on nitrogen availability but also on the synchronization between nitrogen release and fermentable energy supply. Deoiled rice bran is an agro-industrial by-product that provides fermentable energy for rumen microorganisms (Madziga et al., 2025), while molasses supplies rapidly available carbohydrates that improve microbial activity and feed acceptability (Mordenti et al., 2021). The combination of these ingredients with processed poultry litter may provide a balanced supplementation strategy capable of improving the utilization of crop-residue-based diets.

The nutritive response of ruminants to supplementation is strongly influenced by the chemical composition of the basal roughage. Rice straw is characterized by high silica concentration and poor fibre digestibility, which restrict feed intake and nutrient availability. Similarly, maize cobs contain highly lignified structural carbohydrates and high acid detergent fibre (ADF), reducing microbial degradation. In contrast, maize stovers generally possess improved nutritive characteristics and lower fibre limitations, which may support greater feed intake, digestibility, nitrogen utilization, and animal performance (Blandino et al., 2016; Gebru et al., 2019).

Previous studies have demonstrated improvements in crop residue utilization through supplementation. Abera et al. (2018) reported improved nutrient utilization and growth performance in rams fed treated maize stover, while Abu El-Hamed et al. (2024) observed improved digestibility, ruminal fermentation, and growth performance in lambs receiving supplemented corn stover diets. However, comparative information regarding the feeding value of rice straw, maize stovers, and maize cobs supplemented with poultry-litter-based concentrates remains limited under West African production conditions.

Therefore, this study aimed to evaluate the effects of rice straw, maize stovers, and maize cobs supplemented with a poultry-litter-based concentrate on feed intake, nutrient digestibility, nitrogen utilization, growth performance, serum biochemical metabolites, and economic efficiency of West African Dwarf (WAD) rams. It was hypothesized that supplementation would improve nutrient utilization and productive performance and that differences among crop residues would influence the magnitude of animal responses according to their chemical composition.

Materials and Methods

Animal Ethics Statement

All procedures involving animals were conducted according to accepted guidelines for animal experimentation. The experimental protocol was reviewed and approved by the Odeda Farm Institute Animal Care and Use Committee (Approval No. OFI/00184/2023). All management procedures, including feeding, handling, and sample collection, were conducted to minimize stress and ensure animal welfare.

Animals, Experimental Design and Management

The experiment was conducted at the Small Ruminant Unit of the Odeda Farm Institute, Eweje, Ogun State, Nigeria. Twenty-four healthy West African Dwarf (WAD) rams with an initial body weight of 18.5 ± 0.6 kg and aged between 16 and 18 months were used. Before the commencement of the experiment, animals underwent a 14-day quarantine period during which they were treated against internal and external parasites and vaccinated following standard veterinary recommendations.

Animals were housed individually in well-ventilated pens equipped with feed and water troughs. Fresh drinking water was supplied continuously throughout the experimental period.

The experimental design consisted of a completely randomized design involving three dietary treatments with eight animals per treatment. The treatments were:

RS: Rice straw + poultry-litter-based concentrate

MS: Maize stovers + poultry-litter-based concentrate

MC: Maize cobs + poultry-litter-based concentrate

The feeding trial lasted 70 days following a 14-day adaptation period.

Experimental Diets and Feeding Management

Rice straw, maize stovers, and maize cobs were collected from local farmers after crop harvesting. The residues were air-dried, cleaned, and stored under dry conditions until use. Maize cobs were mechanically processed into smaller particles to improve intake and handling.

Broiler poultry litter was obtained from a commercial poultry farm and processed before incorporation into the concentrate. The litter was sun-dried, screened to remove foreign materials, and stored until formulation.

A concentrate mixture containing deoiled rice bran, processed poultry litter, molasses, salt, and vitamin-mineral premix was formulated. The concentrate was offered daily at 2% of body weight, while crop residues were supplied ad libitum allowing approximately 10% refusals. Concentrate allowances were adjusted periodically according to changes in body weight.

Table 1
Ingredient composition and chemical composition of experimental diets (%)

Component	Concentrate Diet	Rice Straw	Maize Stovers	Maize Cobs
Ingredient Composition (%)				
Deoiled rice bran	51.5	—	—	—
Poultry litter	38.5	—	—	—
Molasses	8.5	—	—	—
Common salt	1.0	—	—	—
Premix	0.5	—	—	—
Total	100.0	—	—	—
Proximate Composition				
Dry matter (%)	91.2	91.5	90.7	92.3
Crude protein (%)	20.8	4.2	6.8	3.5
Crude fibre (%)	13.8	32.0	28.5	36.8
Ether extract (%)	5.2	2.1	2.5	1.8
Ash (% DM)	11.6	11.5	9.8	8.7
Organic matter (%)	88.4	88.5	90.2	91.3
Nitrogen-free extract (%)	48.6	50.2	52.4	49.2
Fibre Fractions				
Neutral detergent fibre (NDF, %)	33.2	72.5	65.2	80.4
Acid detergent fibre (ADF, %)	19.4	45.6	38.1	52.7
Energy Values				
Metabolizable energy (MJ/kg DM)	10.5	6.5	7.8	5.9
Net energy for gain (MJ/kg DM)	5.5	3.0	3.8	2.5
Calculated Daily Nutrient Supply*	—	—	—	—
Daily ME intake (MJ/day)	—	63.5	82.4	58.6
Daily CP intake (g/day)	—	110	145	100

Feed Intake and Nutrient Intake Determination

Daily feed offered and refusals were recorded throughout the experimental period. Dry matter intake was determined as the difference between feed offered and refused after correction for dry matter content.

Nutrient intake values including crude protein, ether extract, crude fibre, neutral detergent fibre, and acid detergent fibre were calculated by multiplying dry matter intake by the respective nutrient concentration of each feed.

Growth Performance Evaluation

Animals were weighed at the beginning of the experiment and subsequently at weekly intervals before morning feeding.

Growth performance parameters were calculated as:

Total weight gain (kg) = Final body weight – Initial body weight

Average daily gain (g/day) = Total weight gain ÷ Experimental period

Feed conversion ratio = Dry matter intake ÷ Weight gain

Digestibility and Nitrogen Balance

At the end of the feeding period, a digestibility trial was conducted. Animals were transferred to individual metabolic cages for separate collection of faeces and urine.

Following a 3-day adaptation period, total faecal and urine collections were performed for seven consecutive days. Faecal samples were weighed daily, subsampled, stored at – 20°C, and later analysed. Urine was collected into containers containing 10% sulphuric acid to prevent nitrogen losses.

Apparent nutrient digestibility was calculated as:

Digestibility (%) = [(Nutrient intake – Nutrient in faeces) / Nutrient intake] × 100

Nitrogen utilization parameters were calculated as:

Nitrogen intake = Crude protein intake ÷ 6.25

Nitrogen retention = Nitrogen intake – (Faecal nitrogen + urinary nitrogen)

Nitrogen retention (%) = (Nitrogen retention ÷ Nitrogen intake) × 100

Chemical Analysis

Samples of feeds, refusals, and faeces were dried at 65°C, ground through a 1-mm sieve, and analysed.

Dry matter, crude protein, ether extract, ash, and crude fibre were determined according to AOAC (2019). Organic matter was calculated as: $OM = 100 - \text{Ash}$

Neutral detergent fibre and acid detergent fibre were determined according to Van Soest et al. (1991).

Metabolizable energy values were estimated using predictive equations based on feed chemical composition.

Blood Sampling and Serum Biochemical Analysis

At the end of the experiment, blood samples were collected from the jugular vein before morning feeding.

Approximately 10 mL of blood was collected into tubes without anticoagulant and centrifuged at 3,000 rpm for 15 min after clotting to obtain serum.

Serum biochemical parameters including total protein, albumin, glucose, cholesterol, urea, creatinine, calcium, and phosphorus were analysed using commercial diagnostic kits.

Globulin concentration was calculated as: $\text{Globulin} = \text{Total protein} - \text{Albumin}$

Economic Analysis

Economic evaluation was performed using prevailing market prices of feed ingredients and animals.

Parameters calculated included feed cost per kilogram diet, total feed cost, cost per kilogram weight gain, gross revenue, net profit, and benefit-cost ratio.

Net profit was calculated as: $\text{Net profit} = \text{Gross revenue} - \text{Total production cost}$

Statistical Analysis

Data obtained from feed intake, growth performance, digestibility, nitrogen utilization, serum metabolites, and economic parameters were analysed using one-way analysis of variance (ANOVA) with SAS software version 9.4 (SAS Institute Inc., Cary, NC, USA).

The statistical model used was:

$$Y_{ij} = \mu + T_i + e_{ij}$$

where Y_{ij} represents the observed value, μ represents the overall mean, T_i represents the dietary treatment effect, and e_{ij}

represents random residual error.

Treatment means were separated using Duncan's Multiple Range Test, and differences were considered significant at $P < 0.05$.

RESULTS

3.1 Ingredient Composition and Chemical Characteristics of Experimental Diets

The ingredient composition and chemical characteristics of the concentrate supplement and basal crop residues are presented in Table 1. The poultry litter-based concentrate contained 20.8% crude protein (CP), 13.8% crude fibre (CF), and 10.5 MJ/kg DM metabolizable energy (ME), indicating that it provided adequate nitrogen and energy supplementation for improving the nutritive value of low-quality crop residues.

Marked variations were observed among the basal roughages in their chemical composition. Maize stovers recorded the highest crude protein concentration (6.8%) and metabolizable energy value (7.8 MJ/kg DM), whereas maize cobs had the lowest crude protein concentration (3.5%) and the highest fibre fractions, including neutral detergent fibre (80.4%) and acid detergent fibre (52.7%). Rice straw exhibited intermediate nutritional characteristics but contained relatively high structural fibre components (NDF = 72.5%; ADF = 45.6%).

The calculated daily nutrient supply reflected differences in the nutritive quality of the crop residues. Rams offered maize stovers received the highest estimated metabolizable energy intake (82.4 MJ/day) and crude protein supply (145 g/day), compared with rice straw (63.5 MJ/day and 110 g CP/day) and maize cobs (58.6 MJ/day and 100 g CP/day).

These results indicate that maize stovers provided a more balanced nutrient profile, characterized by higher protein availability, greater energy density, and lower fibre constraints compared with rice straw and maize cobs.

3.2 Feed Intake and Growth Performance

The effects of basal crop residues supplemented with poultry litter-based concentrate on feed intake and growth performance of West African Dwarf rams are presented in Table 2.

Total dry matter intake differed significantly ($P < 0.05$) among dietary treatments. Rams fed maize stovers recorded the highest dry matter intake (910 g/day), followed by rice straw (780 g/day), while maize cobs resulted in the lowest intake (720 g/day).

Initial body weight was similar ($P > 0.05$) among treatments, indicating that experimental animals had comparable starting weights. However, significant differences ($P < 0.05$) were observed in final body

weight, total weight gain, average daily gain, and feed conversion ratio.

Animals fed maize stovers achieved the greatest final body weight (27.8 kg), total weight gain (9.2 kg), and average daily gain (132 g/day). Rams fed rice straw recorded intermediate performance, whereas maize cob-fed animals exhibited the poorest growth response.

Feed conversion ratio was significantly affected ($P < 0.05$) by dietary treatment. The maize stover group showed the lowest FCR value (6.89), indicating superior feed utilization efficiency, while rice straw and maize cobs recorded higher values of 9.51 and 10.14, respectively.

Table 2

Effects of basal diets supplemented with poultry-litter-based concentrate on feed intake and growth performance of WAD rams

Parameter	Rice straw	Maize stovers	Maize cobs	SEM	P-value
Total DM intake (g/d)	780 ^a	910 ^b	720 ^a	25.3	0.032
Initial weight (kg)	18.4	18.6	18.5	0.41	0.912
Final weight (kg)	24.2 ^a	27.8 ^b	23.5 ^a	0.65	0.028
Total weight gain (kg)	5.8 ^a	9.2 ^b	5.0 ^a	0.44	0.024
Average daily gain (g/d)	82 ^a	132 ^b	71 ^a	6.4	0.021
Feed conversion ratio	9.51 ^b	6.89 ^a	10.14 ^c	0.38	0.017

*a–c Means within a row with different superscripts differ significantly ($P < 0.05$); SEM = Standard error of means.

3.3 Nutrient Digestibility

The apparent nutrient digestibility coefficients of West African Dwarf rams fed crop residues supplemented with poultry litter-based concentrate are shown in Table 3.

Significant differences ($P < 0.05$) were observed among treatments for all measured digestibility parameters. Dry matter digestibility was highest in maize stover-fed animals (68.4%), followed by rice straw (64.2%), while maize cobs recorded the lowest value (60.8%).

A similar pattern was observed for organic matter digestibility, where maize stovers produced the greatest value (69.2%), whereas maize cobs had the lowest digestibility coefficient (61.7%).

Crude protein digestibility differed significantly among treatments. Rams fed maize stovers had the highest CP digestibility (70.2%), followed by rice straw (66.5%), while maize cobs recorded the lowest value (63.0%).

Digestibility of fibre fractions followed the same trend. Neutral detergent fibre digestibility was highest in maize stovers (59.6%) and lowest in maize cobs (52.8%). Similarly, acid detergent fibre digestibility

ranged from 55.4% in maize stovers to 49.5% in maize cobs.

Ether extract digestibility was also significantly influenced ($P < 0.05$), with maize stovers producing the highest value (76.5%), followed by rice straw (73.2%) and maize cobs (70.8%).

The improved nutrient digestibility observed in maize stover-fed rams reflects the superior chemical composition and greater availability of nutrients in this residue compared with rice straw and maize cobs.

Table 3
Nutrient digestibility (%) of WAD rams fed crop residues supplemented with poultry-litter-based concentrate

Parameter	Rice straw	Maize stovers	Maize cobs	SEM	P-value
Dry matter	64.2 ^a	68.4 ^b	60.8 ^a	1.12	0.035
Organic matter	65.4 ^a	69.2 ^b	61.7 ^a	1.08	0.038
Crude protein	66.5 ^a	70.2 ^b	63.0 ^a	0.98	0.029
Neutral detergent fibre	56.3 ^a	59.6 ^b	52.8 ^a	1.05	0.041
Acid detergent fibre	52.1 ^a	55.4 ^b	49.5 ^a	1.01	0.047
Ether extract	73.2 ^a	76.5 ^b	70.8 ^a	1.02	0.043
*a–c Means within a row with different superscripts differ significantly ($P < 0.05$); SEM = Standard error of means					

3.4 Nitrogen Utilization

The effects of dietary treatments on nitrogen utilization characteristics of West African Dwarf rams are presented in Fig. 1.

Nitrogen intake differed significantly ($P < 0.05$) among treatments. Rams fed maize stovers recorded the highest nitrogen intake (14.8 g/day), followed by rice straw (12.5 g/day), whereas maize cobs resulted in the lowest nitrogen intake (11.8 g/day). The observed pattern corresponded with differences in crude protein concentration and dry matter intake among the dietary treatments.

Faecal nitrogen excretion was significantly influenced ($P < 0.05$) by dietary treatment. Animals fed maize stovers had the lowest faecal nitrogen loss (3.6 g/day), indicating improved nitrogen digestion and absorption. In comparison, rice straw and maize cobs resulted in greater faecal nitrogen losses, with values of 4.2 and 4.5 g/day, respectively.

Urinary nitrogen excretion and total nitrogen excretion were not significantly affected ($P > 0.05$) by dietary treatment, suggesting that differences among diets primarily influenced nitrogen intake, digestion, and retention rather than post-absorptive nitrogen metabolism.

Nitrogen retention differed significantly ($P < 0.05$) among treatments. Rams fed maize stovers retained the greatest amount of nitrogen (9.2 g/day), followed by rice straw (6.8 g/day) and maize cobs (5.9 g/day). Similarly, nitrogen retention expressed as a percentage of nitrogen intake followed the same trend, with maize stovers recording the highest efficiency of nitrogen utilization (62.1%).

The improved nitrogen retention observed in maize stover-fed rams indicates greater efficiency of microbial protein synthesis and enhanced utilization of absorbed nutrients for tissue growth.

poultry-litter-based concentrate

3.5 Serum Metabolites

The serum biochemical profile of West African Dwarf rams fed crop residues supplemented with poultry litter-based concentrate is presented in Fig. 2.

Serum total protein concentration was significantly affected ($P < 0.05$) by dietary treatment. Rams fed maize stovers recorded the highest serum total protein concentration (6.9 g/dL), whereas rice straw and maize cobs resulted in lower values of 6.3 and 6.1 g/dL, respectively.

Albumin concentration followed a similar pattern, with maize stovers producing the highest value (3.6 g/dL). Animals fed rice straw and maize cobs showed comparatively lower albumin concentrations.

Serum glucose concentration differed significantly ($P < 0.05$) among treatments. The highest glucose concentration was observed in maize stover-fed rams (65 mg/dL), followed by rice straw (58 mg/dL), while maize cobs recorded the lowest value (55 mg/dL).

In contrast, serum urea and cholesterol concentrations were not significantly influenced ($P > 0.05$) by dietary treatments, indicating that the diets maintained relatively stable nitrogen metabolism and lipid regulation.

The increased serum protein and glucose concentrations observed in maize stover-fed animals suggest improved nutrient availability and enhanced metabolic status resulting from superior feed quality and nutrient utilization.

with poultry-litter-based concentrate

3.6 | Economic Analysis

The economic evaluation of feeding crop residues supplemented with poultry litter-based concentrate to West African Dwarf rams is presented in Table 4.

Feed intake was highest in animals fed maize stovers (63.7 kg) and lowest in those fed maize cobs (50.4 kg). Feed and labour costs showed minimal variation among treatments, ranging from USD 61.8 to USD 63.2.

Although total production costs were relatively similar among dietary groups, differences in animal performance resulted in substantial variation in economic returns. Rams fed maize stovers produced the highest sale value (USD 151.6), generating the greatest net profit (USD 38.4) and benefit-cost ratio (1.61).

Rice straw produced intermediate economic performance, with a net profit of USD 26.1 and benefit-cost ratio of 1.42, whereas maize cobs resulted in the lowest economic return, with a net profit of USD 21.4 and benefit-cost ratio of 1.35.

The cost per kilogram of weight gain was lowest for maize stovers (USD 1.08/kg gain), followed by rice straw (USD 1.37/kg gain), while maize cobs had the highest production cost (USD 1.57/kg gain).

These results demonstrate that maize stovers provided the greatest economic advantage due to improved biological performance and more efficient conversion of feed resources into live weight gain.

Table 4
Economic analysis of feeding crop residues supplemented with poultry-litter-based concentrate to West African Dwarf rams

Parameter	Feed intake (kg)	Feed & labour cost (USD)	Purchase cost (USD)	Total cost (USD)	Sale value (USD)	Cost per kg gain (USD)	Net profit (USD)	BCR
Rice straw	54.6	62.4	50.0	112.4	138.5	1.37	26.1	1.42
Maize stovers	63.7	63.2	50.0	113.2	151.6	1.08	38.4	1.61
Maize cobs	50.4	61.8	50.0	111.8	133.2	1.57	21.4	1.35

DISCUSSION

4.1 Ingredient Composition and Chemical Characteristics of Experimental Diets

The chemical characteristics of the experimental diets demonstrated the importance of supplementation in improving the feeding value of crop residues commonly used in tropical small ruminant production systems. The poultry litter-based concentrate contained 20.8% crude protein and 10.5 MJ/kg DM metabolizable energy, providing an adequate supply of nitrogen and fermentable energy required for efficient rumen microbial activity.

Low-quality crop residues such as rice straw, maize stovers, and maize cobs are generally characterized by limited protein content and high structural carbohydrate concentration, which restrict microbial fermentation and animal productivity when fed without supplementation. Similar nutritional limitations

have been reported for cereal crop residues used in tropical livestock systems (Shah et al., 2025; Sharma et al., 2024).

The higher crude protein content of the concentrate likely improved ruminal nitrogen availability, enhancing microbial growth and increasing microbial protein flow to the small intestine. The inclusion of molasses may have further improved diet acceptability and supplied rapidly fermentable carbohydrates, supporting improved microbial efficiency as previously described by Mordenti et al. (2021).

Among the evaluated residues, maize stovers showed superior nutritional characteristics, with higher crude protein and metabolizable energy concentrations and lower fibre fractions compared with rice straw and maize cobs. These characteristics explain the improved animal responses observed throughout the study.

The present findings agree with Li et al. (2014), who reported that maize stovers generally possess greater feeding value than several other cereal residues due to improved nutrient availability and reduced fibre limitations. Similarly, Vanhevel et al. (2024) highlighted that differences in lignification and cell wall composition strongly influence the digestibility and utilization of crop residues.

The relatively poor nutritional quality of maize cobs observed in the current study may be attributed to their high NDF and ADF concentrations, which reduce microbial attachment and enzymatic degradation within the rumen. Similar limitations associated with highly lignified residues have been reported by Nurika et al. (2021) and Zhong et al. (2021).

The effectiveness of poultry litter as a protein supplement agrees with Gebru et al. (2019), who reported improved nutrient supply and animal performance when poultry litter-based supplements were incorporated into ruminant feeding systems. However, variation in poultry litter composition may occur due to differences in bedding materials, bird management, storage duration, and processing methods (Kyakuwaire et al., 2019).

4.2 Feed Intake and Growth Performance

The significant differences observed in feed intake and growth performance among the dietary treatments highlight the importance of basal roughage quality in determining the productive response of ruminants offered crop residue-based diets. Rams fed maize stovers recorded the highest total dry matter intake compared with those fed rice straw and maize cobs, indicating that maize stovers possessed superior physical and nutritional characteristics that enhanced voluntary feed consumption. Feed intake in ruminants is largely regulated by the interaction between diet digestibility, rumen fill, fibre characteristics, and nutrient availability. Diets containing highly lignified and slowly degradable fibre fractions generally limit intake due to prolonged ruminal retention time and delayed passage rate (Mertens, 1992).

The greater intake observed in maize stover-fed rams may be attributed to its comparatively higher crude protein concentration, lower NDF and ADF contents, and greater metabolizable energy value. Higher

dietary nitrogen availability stimulates rumen microbial growth, improving fibre degradation and accelerating feed passage, which subsequently increases voluntary intake. Similar relationships between improved forage quality, increased dry matter intake, and enhanced growth performance have been reported in ruminants fed crop residue-based diets supplemented with nitrogen sources (Kanyinji et al., 2017; Rehman et al., 2020). In contrast, the lower intake recorded in maize cob-fed animals is likely associated with its high fibre concentration, particularly the greater NDF and ADF values observed in the present study. High levels of structural carbohydrates reduce microbial accessibility and increase rumen fill, thereby restricting feed consumption (Nurika et al., 2021).

The improved final body weight, total weight gain, and average daily gain recorded in rams fed maize stovers demonstrate the importance of providing a basal feed with adequate nutrient availability. Growth performance is a cumulative response to feed intake, nutrient digestibility, metabolic utilization, and the efficiency with which absorbed nutrients are converted into body tissues. The greater growth response observed with maize stovers was likely due to increased intake of digestible nutrients and improved ruminal fermentation conditions, resulting in greater availability of energy and microbial protein for tissue deposition.

The results agree with previous findings showing that supplementation of poor-quality crop residues with protein-rich supplements enhances animal growth by correcting dietary nitrogen deficiencies and improving microbial protein synthesis (Abu El-Hamed et al., 2024). The poultry litter-based concentrate used in the present study likely supplied sufficient nitrogen to support rumen microbial activity, while maize stovers provided a more favourable carbohydrate source for efficient microbial fermentation. The synchrony between nitrogen supply from the concentrate and energy supply from the roughage may have contributed to improved nutrient capture and enhanced animal performance.

Feed conversion ratio was also significantly improved in maize stover-fed rams, indicating more efficient conversion of consumed feed into live weight gain. Feed efficiency reflects the combined effects of intake, digestion, nutrient absorption, and metabolic utilization. The lower feed conversion ratio recorded for maize stovers suggests that a greater proportion of ingested nutrients was directed towards productive functions rather than being lost through incomplete digestion or increased maintenance requirements. Similar improvements in feed efficiency have been reported in sheep and other ruminants receiving improved-quality roughage supplemented with additional nitrogen sources (Raju et al., 2021; Yi et al., 2018).

The relatively poorer feed conversion observed in rice straw and maize cob treatments may be explained by their higher fibre concentrations and lower energy availability. Rice straw is commonly characterized by low crude protein content, high silica deposition, and reduced digestibility, which limits microbial degradation and nutrient availability. Likewise, maize cobs contain high levels of resistant structural carbohydrates that reduce fermentation efficiency and energy release. These limitations likely contributed to the lower growth rates and poorer biological efficiency observed in these groups.

The findings indicate that the nutritional characteristics of the basal roughage strongly influenced the response of WAD rams even when supplemented with the same concentrate formulation. Maize stovers provided the most favourable combination of nutrient availability, intake stimulation, and feed utilization efficiency, resulting in superior growth performance. This confirms the potential of maize stovers as a valuable component of sustainable small ruminant feeding systems when combined with appropriate protein supplementation.

4.3 Nutrient Digestibility

The significant improvement in nutrient digestibility observed in rams fed maize stovers compared with rice straw and maize cobs demonstrates the important role of roughage quality in regulating nutrient availability in crop residue-based feeding systems. Digestibility is a major determinant of animal performance because it influences the quantity of nutrients absorbed for maintenance, growth, and productive functions. The higher dry matter and organic matter digestibility recorded in maize stover-fed animals indicate improved degradation and utilization of dietary components within the gastrointestinal tract.

The superior digestibility of maize stovers can be attributed to its more favourable chemical composition, particularly the higher crude protein concentration and lower fibre fractions compared with rice straw and maize cobs. Adequate dietary nitrogen enhances ruminal microbial multiplication, increasing microbial attachment to feed particles and improving degradation of structural carbohydrates. Consequently, greater microbial activity results in increased breakdown of cell wall components and improved nutrient availability to the animal. Similar improvements in digestibility associated with improved nitrogen supply and forage quality have been reported in ruminants fed supplemented crop residue diets (Kanyinji et al., 2017; He et al., 2024).

The higher crude protein digestibility observed in maize stover-fed rams further suggests improved utilization of dietary nitrogen. Protein digestion in ruminants depends largely on the availability of degradable nitrogen for rumen microbes and the synchronization between nitrogen release and fermentable energy supply. The combination of maize stovers and poultry litter-based concentrate likely created a more balanced rumen environment, promoting microbial protein synthesis and increasing the flow of microbial protein to the small intestine. This explains the improved nitrogen retention and growth responses observed in animals receiving maize stovers.

The digestibility of neutral detergent fibre and acid detergent fibre followed a similar pattern, with maize stovers producing higher values than rice straw and maize cobs. Fibre digestibility is particularly important in tropical feeding systems because most available feed resources are fibrous crop residues. The greater fibre digestibility observed in maize stovers suggests reduced lignification and greater accessibility of cellulose and hemicellulose fractions to rumen microorganisms. In contrast, the lower fibre digestibility of maize cobs may be associated with their greater structural carbohydrate concentration and increased resistance to microbial degradation (Nurika et al., 2021).

The improved ether extract digestibility observed in maize stover-fed rams may also reflect enhanced overall digestive efficiency and improved rumen function. Better-quality roughages support a more stable microbial population, which can enhance the digestion of multiple nutrient fractions. These findings support earlier reports that improving the nutritive value of crop residues through supplementation enhances nutrient digestion and animal productivity (Rehman et al., 2020).

Overall, the results demonstrate that maize stovers provided a more digestible and nutritionally balanced basal diet compared with rice straw and maize cobs. The improved digestibility characteristics of maize stovers likely contributed directly to the enhanced feed intake, growth performance, and nutrient utilization observed in the present study.

4.4 Nitrogen Utilization

Nitrogen utilization parameters were significantly influenced by the type of basal roughage offered to WAD rams, with maize stovers supporting superior nitrogen intake, reduced nitrogen losses, and greater nitrogen retention compared with rice straw and maize cobs. Nitrogen balance is an important indicator of protein utilization efficiency because it reflects the relationship between nitrogen intake, digestion, absorption, and incorporation into body tissues.

The higher nitrogen intake observed in maize stover-fed animals was primarily associated with their greater dry matter intake and higher crude protein content. Increased feed consumption results in greater nutrient supply, while improved dietary protein concentration provides additional nitrogen required for rumen microbial activity. Efficient ruminal nitrogen utilization depends on the availability of sufficient nitrogen to support microbial growth and the presence of fermentable carbohydrates needed for microbial protein synthesis.

The reduced faecal nitrogen excretion recorded in maize stover-fed rams indicates improved digestion and absorption of dietary nitrogen. Lower faecal nitrogen losses suggest that a greater proportion of ingested nitrogen was retained and utilized by the animal. Similar improvements in nitrogen digestibility and reduced nitrogen losses have been reported when animals receive diets containing higher-quality roughages and adequate nitrogen supplementation (Rehman et al., 2020).

Although urinary nitrogen excretion was not significantly affected by dietary treatment, the numerical differences observed suggest that variations in dietary quality mainly influenced nitrogen capture before absorption rather than post-absorptive nitrogen metabolism. Stable urinary nitrogen losses across treatments indicate that the animals maintained physiological regulation of nitrogen metabolism despite differences in dietary nutrient supply.

The significantly higher nitrogen retention observed in maize stover-fed rams confirms improved efficiency of protein utilization. Nitrogen retention is directly associated with tissue growth and weight gain, explaining the superior performance observed in these animals. Improved nitrogen retention may have resulted from enhanced microbial protein production, increased amino acid supply to tissues, and better synchronization between energy and nitrogen availability in the rumen.

The findings agree with previous studies showing that supplementation of low-protein crop residues with nitrogen-rich supplements improves nitrogen balance and animal productivity (Kanyinji et al., 2017; Abu El-Hamed et al., 2024). The present results emphasize that the combination of maize stovers and poultry litter-based concentrate provided a favourable nutritional environment for efficient nitrogen utilization in WAD rams.

4.5 Serum Metabolites

Serum biochemical parameters are important indicators of nutritional status, metabolic activity, and physiological adaptation of animals to dietary treatments. In the present study, the observed differences in serum total protein, albumin, and glucose concentrations among treatments reflected variations in nutrient supply and utilization efficiency resulting from the different basal roughages.

The higher serum total protein concentration observed in maize stover-fed rams indicates improved protein availability and utilization. Serum protein levels are closely associated with dietary protein intake, amino acid absorption, and hepatic protein synthesis. The increased crude protein intake and improved digestibility recorded in maize stover-fed animals likely enhanced amino acid availability for protein synthesis, resulting in elevated circulating protein concentrations. Similar relationships between dietary protein supply and serum protein concentration have been reported in sheep receiving improved-quality diets (Du et al., 2023; Kyawt et al., 2024).

The higher albumin concentration observed in maize stover-fed animals further supports improved protein metabolism. Albumin is synthesized in the liver and serves as an important indicator of long-term protein status. Increased albumin concentration suggests adequate dietary protein supply and efficient utilization of absorbed nutrients for physiological functions and tissue development.

Serum glucose concentration was also higher in rams fed maize stovers, reflecting improved energy availability. In ruminants, glucose is mainly derived from hepatic gluconeogenesis using volatile fatty acids, particularly propionate produced during ruminal fermentation. The superior digestibility and energy value of maize stovers likely promoted more efficient fermentation and increased glucose availability. Improved glucose status supports enhanced growth performance by providing energy required for protein synthesis and tissue deposition.

The absence of significant differences in serum urea concentration indicates that nitrogen metabolism remained within a normal physiological range across treatments. Blood urea is influenced by the balance between nitrogen intake, microbial protein synthesis, and excess nitrogen excretion. Similar serum urea responses have been reported in sheep fed diets with different roughage sources but adequate nitrogen supplementation (Souza et al., 2020).

Serum cholesterol concentration was not significantly affected by dietary treatments, suggesting that lipid metabolism remained relatively stable among animals. This indicates that the differences in roughage quality primarily affected nutrient availability and growth responses rather than causing

alterations in lipid metabolic regulation. Similar observations have been reported where dietary forage variation produced minimal effects on blood lipid metabolites (Hussein et al., 2020).

Overall, the serum metabolite profile confirms that maize stovers improved the nutritional status and metabolic efficiency of WAD rams without negatively affecting physiological health indicators.

4.6 Economic Efficiency

The economic evaluation demonstrated that differences in biological performance among treatments translated into clear variations in profitability. Although the costs associated with feeding the different crop residues were relatively similar, maize stovers produced the highest economic return due to improved growth rate, feed efficiency, and final animal value.

The greater sale value obtained from maize stover-fed rams was primarily a consequence of their superior final body weight and total weight gain. In livestock production systems, feed resources that improve growth performance while maintaining reasonable input costs provide greater economic advantages. Similar findings have been reported where improved utilization of crop residues resulted in increased profitability of small ruminant production systems (Abera et al., 2018).

The lower cost per kilogram of weight gain observed in maize stovers indicates more efficient conversion of feed resources into marketable animal weight. Improved feed conversion efficiency reduces the amount of feed required per unit of gain, thereby decreasing production costs. This agrees with Martínez-Martínez et al. (2022), who reported that enhanced nutrient digestibility and feed utilization efficiency contribute significantly to improved economic outcomes in ruminant production.

The highest net profit and benefit-cost ratio recorded for maize stovers demonstrate the economic superiority of this feeding strategy. The combination of greater intake, improved digestibility, enhanced nitrogen retention, and better growth performance increased revenue generation beyond the additional feeding costs. Similar economic benefits from improved crop residue utilization have been reported in small ruminant systems where nutrient supplementation enhanced animal productivity (Raju et al., 2021).

Although rice straw and maize cobs represent readily available feed resources, their lower nutritive value resulted in reduced biological efficiency and profitability. Maize cobs, in particular, produced the lowest economic return due to reduced intake, poorer digestibility, lower weight gain, and higher cost per kilogram of gain.

Therefore, from both biological and economic perspectives, maize stovers supplemented with poultry litter-based concentrate represent the most efficient feeding option for WAD rams. This feeding strategy provides an opportunity to utilize locally available crop residues while improving productivity and profitability in smallholder sheep production systems.

Conclusion

Supplementation of crop residues with a poultry litter-based concentrate successfully improved nutrient supply, nutrient utilization, growth performance, nitrogen retention, and economic returns in West African Dwarf rams. Among the crop residues evaluated, maize stovers produced the most favourable responses in feed intake, digestibility, growth performance, nitrogen utilization, serum biochemical characteristics, and profitability.

The results indicate that maize stovers represent the most suitable basal roughage when supplemented with poultry litter-based concentrate, while rice straw may serve as an alternative feed resource where maize stovers are unavailable. Maize cobs supported animal performance but produced comparatively lower biological and economic responses. The findings further demonstrate that properly processed poultry litter can serve as an effective and economical protein source in sheep feeding systems. Future studies should evaluate long-term animal health implications, optimum inclusion rates, and adoption under smallholder production conditions.

Declarations

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Ethics Statement

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to. The experimental protocol was reviewed and approved by the Odeda Farm Institute Animal Care and Use Committee (Approval No. OFI/00184/2023) before commencement of the study

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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CRediT authorship contribution statement

Abisoye Adeola Adesote: Writing - original draft, Conceptualization, Methodology, Investigation Project administration, Validation, **Immanuel Ishaku Madziga:** Conceptualization, Investigation, Methodology, Data curation, Visualization, Formal analysis. **Olalere Johnson Olayide:** Writing – review & editing, software. **Stephen Kehinde Moses:** Visualization, Writing – review & editing

Declaration of Competing Interest

The authors declare that there are no conflicts of interest in all aspects of this study or the interpretation of the results presented.

Consent to publication

The authors consent to the publication of this manuscript.

Declaration of generative AI

Author declare that generative AI was not used in the preparation of the manuscript.

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Figures

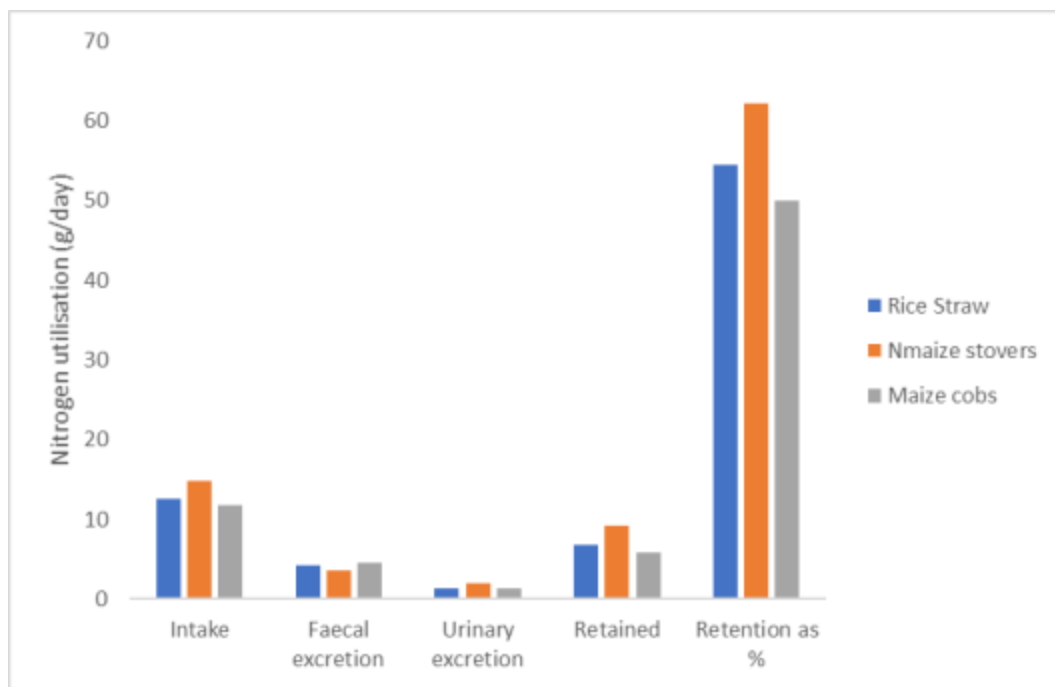


Figure 1

Nitrogen utilization of WAD rams fed crop residues supplemented with poultry-litter-based concentrate

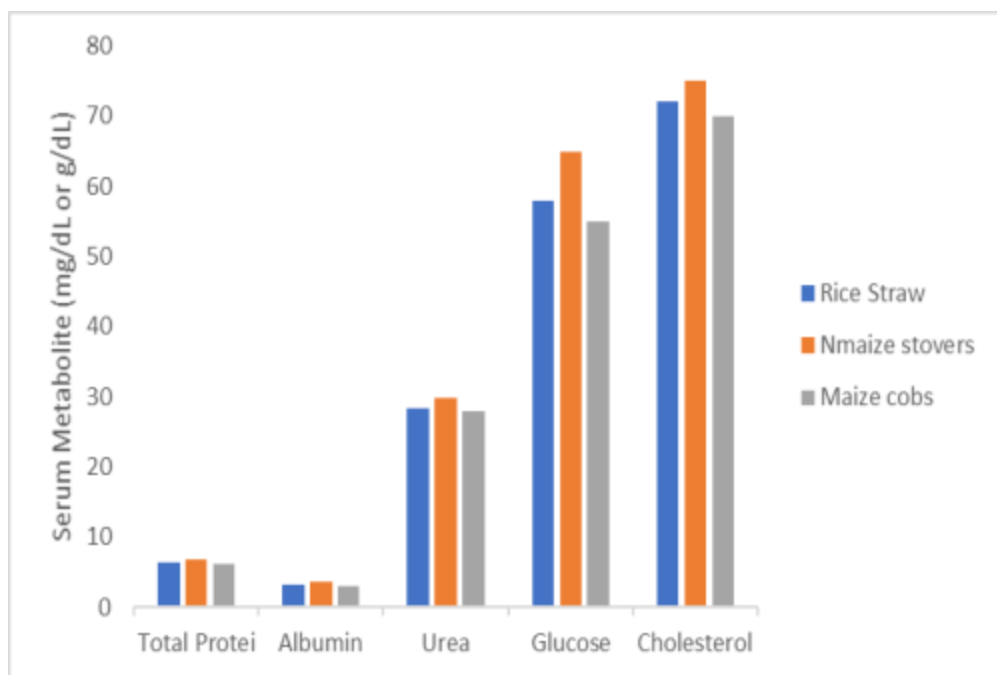


Figure 2

Serum metabolites of WAD rams fed crop residues supplemented with poultry-litter-based concentrate