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Effect of Dietary Inclusion of Fermented *Anchomanes difformis* Rhizome Meal on Nutrient Digestibility and Nitrogen Utilization in West African Dwarf Goats

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ABSTRACT

The increasing cost and seasonal scarcity of conventional feed resources have intensified the search for alternative feed ingredients capable of sustaining ruminant production in tropical regions. This study evaluated the effects of dietary inclusion of fermented *Anchomanes difformis* rhizome meal (FADRM) on nutrient digestibility and nitrogen utilization in West African Dwarf (WAD) goats. Fresh rhizomes of *A. difformis* were harvested, fermented for 14 days, air-dried, and milled into meal. Four concentrate diets containing 0, 7, 14, and 21% FADRM were formulated and designated as T1, T2, T3, and T4, respectively. Four WAD bucks (8–10 months old) with an average body weight of 8.35 ± 0.42 kg were assigned to a 4 × 4 Latin square design comprising four dietary treatments and four experimental periods. Each period lasted 28 days, including 21 days of dietary adaptation and 7 days of total faecal and urine collection for digestibility and nitrogen balance determination. Samples of the experimental diets, faeces, and urine were analysed using standard AOAC procedures, and data were subjected to analysis of variance at a 5% level of significance.

Fermentation improved the nutritional quality of *A. difformis* rhizome meal by increasing dry matter, crude protein, ash, nitrogen-free extract, and gross energy contents while slightly reducing crude fibre. Dietary treatments significantly ($P < 0.05$) influenced nutrient digestibility. Goats fed the diet containing 14% FADRM (T3) exhibited the highest dry matter digestibility (79.12%), whereas those receiving the 21% inclusion level (T4) recorded significantly lower dry matter, crude protein, and crude fibre digestibility coefficients. Nitrogen intake, nitrogen absorbed, nitrogen balance, and nitrogen retention were significantly ($P < 0.05$) higher in goats fed T1, T2, and T3 than in those fed T4, indicating more efficient utilization of dietary nitrogen at lower inclusion levels.

The findings demonstrate that fermented *A. difformis* rhizome meal is a promising unconventional feed resource for WAD goats. Dietary inclusion of up to 14% supported efficient nutrient digestibility and nitrogen utilization without adverse effects on protein metabolism, whereas higher inclusion (21%) reduced nutrient utilization efficiency. Therefore, fermented *A. difformis* rhizome meal can be recommended as a sustainable alternative feed ingredient in goat diets at inclusion levels not exceeding 14%.

KEYWORDS: *Anchomanes difformis*, fermentation, unconventional feed resources, nitrogen balance, West African Dwarf goats, ruminant nutrition.

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1. INTRODUCTION

Livestock production is fundamental to global food security, poverty reduction, and sustainable livelihoods, particularly in developing countries where small ruminants contribute significantly to household income and animal protein supply. Among domestic ruminants, goats are highly valued because of their adaptability to diverse agro-ecological conditions, efficient utilization of fibrous feed resources, high reproductive performance, and relatively low production costs. Consequently, goat production has become an important component of climate-resilient and sustainable livestock systems in tropical and subtropical regions (Devendra, 2001; Zhang et al., 2025). Recent advances in goat nutrition have further emphasized the importance of nutritional interventions for improving rumen development, feed utilization, and production efficiency in small ruminants.

The West African Dwarf (WAD) goat is one of the most economically important indigenous goat breeds in Nigeria and other humid regions of West and Central Africa. The breed is renowned for its trypano-tolerance, prolificacy, disease resistance, and ability to survive under low-input production systems, making it particularly suitable for smallholder farmers. Despite these adaptive characteristics, productivity of WAD goats remains constrained by inadequate nutrition, especially during the dry season when natural pastures become deficient in crude protein and digestible energy. Feed scarcity during this period results in poor growth, reduced reproductive efficiency, low feed conversion efficiency, and decreased economic returns from goat production (Jiwuba et al., 2023).

Feed accounts for approximately 60–70% of the total cost of ruminant production, and the increasing prices of conventional feed ingredients such as maize, soybean meal, and wheat offal have intensified the search for affordable alternative feed resources. Furthermore, increasing competition between humans and livestock for cereal grains has heightened interest in exploiting unconventional feed resources that are locally available, inexpensive, and environmentally sustainable. Recent studies have shown that properly processed unconventional feed resources can partially replace conventional feed ingredients without adversely affecting nutrient digestibility, rumen fermentation, or animal performance.

Among the various processing methods available, microbial fermentation has emerged as one of the most effective biological techniques for improving the nutritional quality of unconventional feed ingredients. Fermentation enhances feed value by degrading structural carbohydrates, increasing microbial protein synthesis, improving nutrient availability, reducing anti-nutritional compounds, and enhancing feed palatability. In addition, fermented feed ingredients have been reported to improve nutrient digestibility, nitrogen utilization, rumen microbial ecology, and overall animal performance, thereby contributing to sustainable livestock production.

Anchomanes difformis (Blume) Engl, a perennial herb belonging to the family Araceae, is widely distributed in swampy forests, riverbanks, and humid ecological zones of tropical Africa. Although the rhizome contains appreciable quantities of carbohydrates and minerals, its utilization in livestock feeding has remained limited because of the presence of anti-nutritional factors such as oxalates, tannins, and phytates, which reduce nutrient availability, palatability, and nutrient utilization. Fermentation is expected to reduce these anti-nutritional factors through microbial degradation while improving the nutritional quality of the rhizome. Similar improvements have been reported for other fermented unconventional feed resources used in goat nutrition, resulting in enhanced rumen fermentation, nutrient digestibility, and productive performance.

Nutrient digestibility and nitrogen utilization are reliable indicators for assessing the feeding value of novel feed ingredients in ruminants. Efficient digestibility increases nutrient availability for maintenance, growth, and production, whereas improved nitrogen retention reflects effective utilization of dietary protein, enhanced microbial protein synthesis, and reduced nitrogen excretion into the environment. Recent nutritional studies have consistently demonstrated that dietary manipulation through fermented feed ingredients can significantly improve nutrient utilization and nitrogen metabolism in goats.

Despite increasing research on unconventional feed resources for ruminants, information regarding the utilization of fermented *Anchomanes difformis* rhizome meal in diets of West African Dwarf goats remains scarce. Most available studies have focused on fermented cassava products, agro-industrial by-products, browse plants, or herbal residues, leaving limited information on the digestibility characteristics and nitrogen utilization of diets containing fermented *A. difformis*. This knowledge gap limits the effective utilization of this abundant indigenous plant as an alternative feed resource for goat production under tropical conditions.

Therefore, this study evaluated the effects of graded dietary inclusion levels of fermented *Anchomanes difformis* rhizome meal on nutrient digestibility and nitrogen utilization in West African Dwarf goats. It was hypothesized that fermentation would improve the feeding value of *A. difformis* rhizome meal and that dietary inclusion of up to 14% would maintain nutrient digestibility and nitrogen utilization comparable to those of goats fed a conventional concentrate diet.

2. MATERIALS AND METHODS

2.1 Study Site

The experiment was conducted at the Sheep and Goat Unit of the Teaching and Research Farm, College of Animal Science and Animal Production, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. Umudike is located at latitude 5°29′

N and longitude 7°33′ E, at an altitude of approximately 122 m above sea level. The area is situated within the humid rainforest agro-ecological zone and receives an annual rainfall of 1,777–2,000 mm, with relative humidity ranging from 50 to 90% and ambient temperatures between 17 and 36°C. Meteorological data were obtained from the Nigerian Root Crops Research Institute (NRCRI), Umudike. Laboratory analyses were conducted at the Biochemistry Laboratory, College of Animal Science and Animal Production, Michael Okpara University of Agriculture, Umudike.

2.2 Ethical Approval

All experimental procedures involving animals were conducted in accordance with the guidelines for the care and use of experimental animals of Michael Okpara University of Agriculture, Umudike, Nigeria. The study complied with internationally accepted principles for the ethical use of animals in research.

2.3 Collection and Processing of *Anchomanes difformis* Rhizome

Fresh rhizomes of *Anchomanes difformis* were collected from naturally growing stands within and around Michael Okpara University of Agriculture, Umudike, particularly the Sambisa area, where the plant is abundant. The rhizomes were washed thoroughly with clean water to remove adhering soil and other contaminants before being sliced into smaller pieces to facilitate fermentation.

The sliced rhizomes were submerged in clean water and fermented naturally for 14 days under ambient conditions. At the end of the fermentation period, the rhizomes were removed, air-dried to constant weight, and milled using a hammer mill to produce fermented *Anchomanes difformis* rhizome meal (FADRM). The processed meal was stored in airtight polyethylene bags until incorporation into the experimental diets.

2.4 Experimental Animals and Management

Four clinically healthy West African Dwarf (WAD) bucks aged between 8 and 10 months, with an average initial body weight of 8.35 ± 0.42 kg, were used for the study. Prior to the commencement of the experiment, the animals were quarantined and acclimatized for 21 days.

During the adaptation period, the goats were treated against ecto- and endo-parasites using Ivermectin (1 mL per 10 kg body weight, subcutaneously) and Albendazole administered orally according to the manufacturer's recommendations. They were also vaccinated against Peste des Petits Ruminants (PPR) following the recommended vaccination protocol.

The animals were housed individually in well-ventilated metabolism cages equipped with separate facilities for quantitative collection of faeces and urine. Throughout the study, fresh drinking water was supplied ad libitum. In addition to the concentrate diets, each animal received approximately 1 kg of fresh *Panicum maximum* daily as basal forage.

2.5 Experimental Diets

Four iso-caloric concentrate diets were formulated to contain graded levels of fermented *Anchomanes difformis* rhizome meal (FADRM) at 0, 7, 14, and 21% of the dietary composition. The diets were designated as:

- **T1:** 0% FADRM (control)
- **T2:** 7% FADRM
- **T3:** 14% FADRM
- **T4:** 21% FADRM

The ingredient composition of the experimental diets is presented in **Table 1**.

Composition of Experimental Diets (%)

Ingredients	**T1**	**T2 (7%)**	**T3 (14%)**	**T4 (21%)**
Maize offal	10.00	10.00	10.00	10.00
Rice milling waste	20.00	20.00	20.00	20.00
Anchomanes difformis rhizome meal	0.00	7.00	14.00	21.00
Brewers' dried grains	25.00	20.00	15.00	10.00
Palm kernel cake	31.00	24.00	17.00	10.00
Soybean meal	10.00	10.00	10.00	10.00
Salt	1.00	1.00	1.00	1.00
Bone meal	2.00	2.00	2.00	2.00
Vitamin-mineral premix	1.00	1.00	1.00	1.00
Total	**100.00**	**100.00**	**100.00**	**100.00**

Diets were formulated to satisfy the nutrient requirements of growing goats as recommended by the National Research Council (NRC).

2.6 Experimental Design

The experiment was arranged in a 4 × 4 Latin square design consisting of four animals, four dietary treatments, and four experimental periods. Each animal received all dietary treatments during the study, thereby minimizing variation attributable to animal and period effects.

Each experimental period lasted 28 days, comprising 21 days of dietary adaptation followed by 7 days of digestibility and nitrogen balance measurements.

2.7 Feeding and Sample Collection

Experimental diets were offered daily at 3% of body weight on a dry matter basis in two equal meals at 08:00 h and 16:00 h. Feed offered and refusals were recorded daily to determine feed intake.

During the 7-day collection period, total faecal output was collected and weighed every morning before feeding. Approximately 20% of the daily faecal output was sampled, pooled by animal within each experimental period, oven-dried at 60°C to constant weight, ground to pass through a 1-mm sieve, and stored in airtight containers pending laboratory analyses.

Urine was collected quantitatively using plastic collection containers positioned beneath each metabolism cage. To minimise nitrogen loss through ammonia volatilisation, approximately 20 mL of 10% sulphuric acid (H_2SO_4) was added to each collection container before urine collection. Daily urine volume was measured, and a representative 10% aliquot was collected and stored at 4°C until nitrogen analysis.

2.8 Chemical Analysis

Representative samples of the experimental diets and faeces were analysed for dry matter (DM), crude protein (CP), ether extract (EE), crude fibre (CF), ash, and nitrogen-free extract (NFE) according to the procedures described by AOAC (2000). Fibre fractions, including neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL), were determined following the method of Van Soest et al. (1991).

Nitrogen concentration in feed, faeces, and urine samples was determined using the Kjeldahl method. Nitrogen balance was calculated as:

Nitrogen balance (g day^{-1}) = Nitrogen intake − (Faecal nitrogen + Urinary nitrogen)

Nitrogen retention (%) was calculated as:

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

Apparent nutrient digestibility coefficients were calculated using the equation:

Digestibility (%) = [(Nutrient intake − Nutrient excreted in faeces) ÷ Nutrient intake] × 100

2.9. Statistical Analysis

Data generated from the experiment were analysed using the General Linear Model (GLM) procedure of SAS version 9.2 (SAS Institute Inc., Cary, NC, USA). The statistical model included the fixed effect of dietary treatment and the blocking effects of animal and experimental period inherent in the 4 × 4 Latin square design.

Treatment means were compared using Duncan's Multiple Range Test when the analysis of variance indicated significant differences. Statistical significance was declared at **$P < 0.05$**. Data are presented as treatment means with their corresponding standard error of the mean (SEM).

3. RESULTS AND DISCUSSION

3.1 Proximate Composition of Fermented *Anchomanes difformis* Rhizome Meal

The proximate composition of fermented *Anchomanes difformis* rhizome meal is presented in **Table 3. 1**.

Table 3.1: Proximate composition of Fermented *Achomanes difformis* rhizome meal

Parameter (%)	Fermented *Achomanes difformis*
Dry matter	81.35
Crude protein	1.95
Crude fibre	2.81
Ash	1.26
Ether extract	0.00
Nitrogen free extract	75.33
Gross energy	331.14

The fermented rhizome meal contained 81.35% dry matter (DM), 1.95% crude protein (CP), 2.81% crude fibre (CF), 1.26% ash, 75.33% nitrogen-free extract (NFE), and a gross energy value of 331.14 kcal/100 g. Ether extract was negligible.

The relatively high dry matter content indicates that the fermented product possessed good storage stability and reduced susceptibility to microbial deterioration. Fermentation enhanced the nutritional quality of the rhizome by increasing the concentrations of crude protein, ash, nitrogen-free extract, and gross energy while slightly reducing crude fibre. These improvements are attributable to microbial fermentation, during which fermentative microorganisms degrade structural carbohydrates, synthesize microbial biomass, and reduce anti-nutritional compounds, thereby improving nutrient availability. Similar observations have been reported for fermented unconventional feed resources, where microbial activity increased nutrient density and improved feed quality through enzymatic degradation of complex carbohydrates and detoxification of anti-nutritional factors (Gunun et al., 2023; Jia et al., 2025).

The reduction in crude fibre further suggests partial degradation of cellulose and hemicellulose during fermentation, which may enhance digestibility when the material is incorporated into ruminant diets. Previous studies have demonstrated that fermentation improves the feeding value of fibrous feed ingredients by increasing nutrient accessibility and promoting favourable rumen fermentation characteristics (Truong & Truong, 2024). Consequently, the fermented *A. difformis* rhizome meal evaluated in the present study exhibits characteristics that support its potential use as an alternative energy source in goat nutrition.

3.2 Proximate Composition of Experimental Diets

The proximate composition of the experimental diets is presented in **Table 3.2**.

Table 3.2: Proximate composition of the experimental diets containing varying levels of *Achomanes difformis* rhizome meal

Parameter (%)	T1	T2	T3	T4
Dry matter	87.16	86.63	85.70	85.32
Crude protein	14.35	13.00	12.40	11.75
Crude fibre	19.68	20.43	21.29	21.83
Ash	10.68	10.42	10.18	10.03
Ether extract	1.41	1.28	1.20	1.14
Nitrogen free extract	41.04	41.50	40.63	40.57
Gross energy	358.37	350.80	350.54	349.22

Dry matter content ranged from 85.32 to 87.16%, indicating minimal variation among the dietary treatments. Increasing dietary inclusion of fermented *A. difformis* rhizome meal progressively reduced crude protein, ether extract, ash, and gross energy contents, whereas crude fibre increased slightly across the diets.

The reduction in crude protein observed with increasing inclusion of fermented rhizome meal is attributable to the replacement of relatively protein-rich ingredients such as brewers' dried grains and palm kernel cake with *A. difformis* rhizome meal, which contained comparatively lower crude protein. Nevertheless, crude protein concentrations in all diets remained above the minimum dietary requirement of approximately 8% required to sustain rumen microbial activity and efficient fibre digestion in goats (National Research Council, 2007). Therefore, although dietary protein declined with increasing inclusion level, the diets remained nutritionally adequate to support normal ruminal fermentation.

The gradual increase in crude fibre with increasing rhizome meal inclusion reflects the inherent fibrous nature of the processed plant material. Similar increases in dietary fibre have been reported when unconventional plant materials partially replaced conventional concentrate ingredients in goat diets (Olafadehan et al., 2025). Moderate increases in dietary fibre may enhance rumen function; however, excessive fibre concentrations may reduce nutrient digestibility through increased rumen fill and reduced passage rate. The relatively stable gross energy values observed among the treatments further indicate that dietary energy density was only marginally affected by the inclusion of fermented *A. difformis* rhizome meal.

3.3 Nutrient Digestibility

The effects of dietary inclusion of fermented *A. difformis* rhizome meal on apparent nutrient digestibility are presented in Table 3.3.

Table 3. 3: Nutrient Digestibility coefficients of West African Dwarf goats fed diets containing *Achomanes difformis* rhizome meal

Parameter (%)	T1 (0%)	T2 (7%)	T3 (14%)	T4 (21%)	SEM
Dry matter	75.01^{ab}	69.42^{bc}	79.12^{a}	65.77^{c}	1.60
Crude protein	58.32^{a}	55.52^{a}	56.36^{a}	47.69^{b}	1.23
Crude fibre	74.11^{a}	74.39^{a}	75.64^{a}	67.64^{b}	0.97
Ether extract	30.30^{ab}	27.36^{b}	33.78^{a}	29.61^{ab}	0.90
Ash	16.34	17.48	15.48	15.01	0.58

$^{a-c}$ means within the same row with different superscripts are significantly different (P<0.05)

Dietary treatments significantly ($P < 0.05$) influenced dry matter, crude protein, crude fibre, and ether extract digestibility, whereas ash digestibility was not significantly affected ($P > 0.05$).

Dry matter digestibility ranged from 65.77 to 79.12%, with goats fed the 14% inclusion diet (T3) recording the highest value. This result suggests that moderate dietary inclusion of fermented *A. difformis* enhanced feed utilization without impairing digestive processes. The improvement observed at the 14% inclusion level may be attributed to the beneficial effects of fermentation in reducing fibre complexity and anti-nutritional compounds, thereby increasing nutrient availability to rumen microorganisms. Comparable improvements in nutrient digestibility following dietary inclusion of fermented feed ingredients have been reported by Gunun et al. (2023) and Jia et al. (2025), who attributed enhanced digestibility to improved rumen microbial activity and greater accessibility of fermentable substrates.

Conversely, goats fed the diet containing 21% fermented rhizome meal (T4) exhibited significantly lower dry matter, crude protein, and crude fibre digestibility than those receiving the lower inclusion levels. The decline in nutrient digestibility at the highest inclusion level may reflect the increased fibre concentration and reduced dietary protein content of the diet, both of which may have limited microbial degradation of feed in the rumen. Excessive inclusion of fibrous unconventional feed resources has similarly been associated with reduced digestibility and nutrient utilization in goats (Olafadehan et al., 2025).

Crude protein digestibility did not differ significantly among goats fed T1, T2, and T3, indicating that dietary inclusion of fermented *A. difformis* up to 14% did not adversely affect protein digestion. However, the significant reduction observed at 21% inclusion suggests that excessive replacement of conventional protein sources may compromise protein availability to rumen microorganisms. Likewise, crude fibre digestibility remained comparable among T1, T2, and T3 but declined significantly in T4, further indicating that excessive dietary fibre may reduce microbial degradation of structural carbohydrates.

Ether extract digestibility also varied significantly among treatments, reflecting differences in lipid availability and utilization. In contrast, ash digestibility remained unaffected, suggesting that dietary inclusion of fermented *A. difformis* had minimal influence on mineral utilization. Overall, these findings demonstrate that dietary inclusion of fermented *A. difformis* rhizome meal up to 14% maintained nutrient digestibility comparable to the control diet, whereas higher inclusion levels reduced digestive efficiency.

3.4 Nitrogen Utilization

Nitrogen utilization parameters are presented in **Table** 3.4

Table 3.4: Nitrogen Balance of West African dwarf goats fed diets containing *Achomanes difformis* rhizome meal

Parameter (g/day)	T1 (0%)	T2 (7%)	T3 (14%)	T4 (21%)	SEM
Nitrogen intake	10.39^a	11.04^a	10.19^a	7.64^b	0.42
Faecal nitrogen	2.63	2.51	2.56	2.99	0.97
Urinary nitrogen	1.21	1.18	1.20	1.21	0.14
Total Nitrogen excreted	3.84	3.69	3.76	4.20	0.17
Nitrogen balance	6.56^a	7.36^a	6.46^a	3.44^b	0.50
Nitrogen Retention (%)	63.76^a	66.78^a	62.27^a	44.86^b	3.07
Nitrogen Absorbed	7.76^a	8.53^a	7.48^a	4.65^b	0.47

$^{a-b}$ means within the same row with different superscripts are significantly different ($P<0.05$)

Nitrogen intake, nitrogen absorbed, nitrogen balance, and nitrogen retention differed significantly ($P < 0.05$) among dietary treatments, whereas faecal nitrogen, urinary nitrogen, and total nitrogen excretion were not significantly influenced by dietary inclusion of fermented *A. difformis* rhizome meal. The lower nitrogen intake observed in goats fed the 21% inclusion diet corresponded with the lower crude protein concentration of this diet. Since nitrogen intake is directly dependent on dietary protein concentration, reduced protein supply inevitably decreases the quantity of nitrogen available for rumen microbial protein synthesis and tissue deposition. Similar relationships between dietary protein concentration and nitrogen intake have been reported in goats receiving unconventional feed resources (Truong & Truong, 2024).

Despite similar faecal and urinary nitrogen losses among treatments, nitrogen balance and nitrogen retention were significantly higher in goats fed T1, T2, and T3 than in those fed T4. This indicates more efficient utilization of absorbed nitrogen at dietary inclusion levels up to 14%. Nitrogen retention represents the proportion of absorbed nitrogen incorporated into body tissues and therefore serves as an important indicator of protein utilization efficiency. The highest nitrogen retention recorded in goats fed T2 suggests that moderate dietary inclusion of fermented *A. difformis* promoted efficient protein metabolism without impairing nitrogen utilization.

The significant decline in nitrogen balance and nitrogen retention at 21% inclusion indicates that excessive incorporation of fermented rhizome meal reduced the efficiency of dietary protein utilization. This reduction may be associated with lower dietary crude protein concentration and increased fibre content, both of which could limit microbial protein synthesis and amino acid availability. Similar findings have been reported in recent studies evaluating fermented unconventional feed ingredients in goats, where moderate inclusion levels enhanced nitrogen utilization, whereas excessive inclusion reduced nutrient use efficiency (Gunun et al., 2023; Olafadehan et al., 2025).

Overall, the nitrogen utilization data demonstrate that fermented *A. difformis* rhizome meal can be included in goat diets at levels up to 14% without compromising protein metabolism. Inclusion beyond this level reduced nitrogen utilization efficiency and may therefore limit productive performance.

4. CONCLUSION

The present study demonstrated that fermentation improved the nutritional quality of *Anchomanes difformis* rhizome meal by enhancing its nutrient composition and reducing fibre content, thereby increasing its suitability as an unconventional feed resource for ruminants. Dietary inclusion of fermented *A. difformis* rhizome meal significantly influenced nutrient digestibility and nitrogen utilization in West African Dwarf goats.

Goats fed diets containing up to 14% fermented *A. difformis* rhizome meal exhibited nutrient digestibility coefficients and nitrogen utilization comparable to, or better than, those of goats fed the control diet. In contrast, increasing the inclusion level to 21% significantly reduced dry matter, crude protein, and crude fibre digestibility, as well as nitrogen intake, nitrogen balance, nitrogen absorption, and nitrogen retention. These findings indicate that excessive dietary inclusion of fermented *A. difformis* rhizome meal may compromise protein utilization and overall digestive efficiency.

From a practical perspective, the results demonstrate that fermented *A. difformis* rhizome meal can serve as a sustainable and cost-effective alternative feed ingredient for West African Dwarf goats when included at levels not exceeding 14% of the concentrate diet. Its utilization could reduce dependence on conventional feed ingredients, improve the use of locally available plant resources, and contribute to more sustainable small-ruminant production systems in tropical environments.

Further research should investigate the long-term effects of fermented *A. difformis* rhizome meal on growth performance, carcass characteristics, rumen fermentation, blood biochemical and hematological indices, reproductive performance, and economic returns under both intensive and smallholder production systems. Additional studies should also evaluate alternative fermentation techniques and processing methods to further reduce anti-nutritional factors and optimise the nutritional value of the rhizome meal for livestock feeding.

DECLARATIONS

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Conflict of Interest

The authors declare that they have no known financial or personal relationships that could have appeared to influence the work reported in this manuscript.

Author Contributions

Ezimoha, C.O.: Conceptualization, methodology, investigation, data collection, formal analysis, interpretation of results, and preparation of the original manuscript.

Nsidinanya, N.O.: Study supervision, methodology, validation, manuscript review and editing, and project administration.

Elekwa, H.U.: Experimental design, data interpretation, critical review of the manuscript, and supervision.

All authors read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Ethics Statement

All experimental procedures involving animals were conducted in accordance with the institutional guidelines for the care and use of experimental animals of Michael Okpara University of Agriculture, Umudike, Nigeria, and complied with internationally accepted principles for the ethical use of animals in research. The animals were handled humanely throughout the study to minimize stress and discomfort.

Data Availability Statement

The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request.

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