NUTRITIONAL EVALUATION AND SUPPLEMENTATION EFFECT OF BAMBOO LEAVES ON INTAKE, GROWTH PERFORMANCE, AND BLOOD INDICES OF DJALLONKÉ SHEEP FED CENCHRUS PURPUREUS AND BRACHIARIA DECUMBENS AS BASAL DIETS

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ABSTRACT
In ruminant nutrition, the persistent issue of feed scarcity especially during the dry season necessitates the exploration of diverse feeding options. This study evaluated the suitability of Oxytenanthera abyssinica (OA) and Bambusa balcooa (BB) bamboo leaves as supplements for Djallonké sheep fed Cenchrus purpureus (CP) and Brachiaria decumbens (BD) grass basal diets. Leaf ingredients were subjected to standard chemical and in vitro fermentation assessments. Furthermore, a total of 20 Djallonké ewes, initially weighing 14.3±1.17 kg, were randomly assigned to a 2 x 2 factorial arrangement of treatments: CPOA (400 g CP + 200 g OA), CPBB (400 g CP + 200 g BB), BDOA (400 g BD + 200 g OA), and BDBB (400 g BD + 200 g BB). Among the leaves, OA had the highest crude protein content (124 g/kg DM), in vitro gas yield (24 ml), and fermentation rate (0.67 ml/h). The COA-supplemented sheep significantly (p < 0.05) consumed more feed (505 g/d), and gained more weight (96 g/d), with higher plasma protein levels compared to the BB supplement. The feeding of bamboo leaves, especially O. abyssinica has the potential to improve ruminant nutrition. Further research on practical applications in various ruminant systems is required.

Keywords: *Bamboo leaf fodder, conventional grasses, chemical composition, in vitro gas production, Djallonké sheep.*

INTRODUCTION
Food security is just one of the many aspects of human life that are significantly impacted by global population growth. As the world population is expected to increase from 6 billion to roughly 8.3 billion by 2030 at an average growth rate of 1.1% per year (Wanapat *et al*., 2013), it is imperative to be able to produce enough food based on local feed resources, especially in developing countries. The global food system is under immense pressure to supply the growing demand for food as a result of increasing population growth, shifting dietary patterns, and expanding urbanisation. A projected 2.4 billion people will live in Sub-Saharan Africa (SSA) by 2050, making it one of the regions with the fastest population growth over the next few decades (Godfray *et al.*, 2010). The rapid population growth in the region poses a threat to food security, as it calls for a substantial increase in food production, with a particular emphasis on animal products, to meet the surging demand.

The livestock sector, particularly small ruminants, plays a crucial role in ensuring food security by meeting the rising demand for animal products and providing essential protein, income, and draught power for rural communities (Duguma and Janssens, 2021). However, in SSA, the persistent challenge of inadequate feed and subpar feed quality, exacerbated during the dry season due to limited forage resources, results from multiple factors. These include climate change-induced weather pattern shifts, constrained grazing land access, competition for land with crop farming, and insufficient resources and knowledge for effective feed conservation and supplementation. This collectively leads to reduced animal productivity, slower growth rates, and compromised reproductive performance (Duguma and Janssens, 2021; Tona, 2018).

In Ghana and similar low-income countries, small ruminant farmers heavily depend on low-quality native grass fodder resources and crop residues, resulting in poor animal productivity. In such situations, the pursuit of alternative and sustainable feed sources becomes paramount to adequately meet the nutritional needs of ruminant animals. The diversification of feed sources for small ruminants not only alleviates the strain on natural resources but also fosters sustainable land management practices (Danso-Abbeam *et al.*, 2021; Distel *et al.*, 2020).

To tackle the dry season feeding challenges in these countries, it is essential to consider underutilized plant fodder options, with bamboo emerging as a promising solution (Altamirano-Gutiérrez, *et al.*, 2023; Sasu *et al.*, 2023a, 2023b). Bamboo could potentially serve as a reliable feed choice, especially in situations where conventional forage resources are limited. It is believed to offer distinct advantages, including potential drought resilience (Kitaw *et al.*, 2022; Sasu *et al.*, 2023b; Tirusew *et al.*, 2023). Nonetheless, the utilization of bamboo leaves as a substitute for other animal feed sources in Ghana is still in its early stages and requires further research and enhancement (Antwi-Boasiko *et al.*, 2011; Coffie, *et al.*, 2014). Extensive documentation underscores that bamboo leaves boast a nutritionally rich profile, containing vital dietary components such as crude protein, fibre, and ash (Asaolu *et al.*, 2010; Singhal *et al.*, 2011; Andriarimalala *et al.*, 2019; Sasu *et al.*, 2023b). Furthermore, bamboo leaves are enriched with bioactive compounds like flavonoids and polyphenols, making them well-suited for ruminant feed (Jo *et al.*, 2022). Similarly, research has shown that bamboo leaves can improve rumen fermentation characteristics, reduce methane emissions, and augment microbial populations in the rumen (Li *et al.*, 2021). As emphasized by Andriarimalala *et al.* (2019), bamboo leaves are associated with predominantly positive environmental impacts, due to their rapid growth and high biomass yield. This enables sustainable harvesting practices without causing significant harm to the ecosystem.

In Ghana, bamboo emerges as a readily accessible, distinguished by its rapid growth and abundant leaf biomass (Antwi-Boasiko *et al.*, 2011; Coffie, *et al.*, 2014; INBAR, 2019). Previous research conducted by Sasu *et al.* (2023a, 2023b) within the same geographic region has drawn favourable comparisons between bamboo leaves and traditional tree forages and grasses, suggesting that bamboo holds promise as a nutrient-rich leaf supplement for ruminant animals. Nevertheless, these findings underscore the need for further investigations in animal feeding to establish conclusively the suitability of bamboo leaves as a component of ruminant diets. To address this research gap, the current study evaluated the nutritional value and supplementation effects of bamboo leaves on the intake, growth performance, and blood parameters of Djallonké sheep fed *Cenchrus purpureus* and *Brachiaria decumbens* as basal diets. It was hypothesized that supplementing the diets of small ruminants with bamboo leaves could have a significant positive impact on feed intake, growth performance, and blood parameters.

MATERIALS AND METHODS

Study area

The study took place at the Livestock Section of the Department of Animal Science, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. The area is in the semi-deciduous humid forest zone of Ghana which experiences a bimodal rainfall pattern of 1300 mm per year. The average daily temperature is 26^0C, with daily temperatures ranging from 20 to 35 ◦C. During the wet season, relative humidity ranges from 97% in the morning to as low as 20% in the late afternoon with daily temperatures ranging from 20 to 35 ◦C and relative humidity of 67–80% (Unpublished 2022 meteorological data, Department of Animal Science, KNUST). All the necessary standard operating procedures outlined by the Animal Research

Ethics Committee (AREC, 2018) of the Quality Assurance and Planning Unit of the Kwame Nkrumah University of Science and Technology, Kumasi were followed.

Source of bamboo leaves and grasses, sampling procedure, and sample preparation

The study encompassed the collection of plant leaf biomass from various locations to facilitate subsequent chemical analysis, in vitro production, and in vivo feeding trials. Fresh leaves from approximately 2½-year-old *Oxytenanthera abyssinica* (A. Rich.) Munro and *Bambusa balcooa* (Beema) bamboo species were obtained from the INBAR[1] bamboo agroforestry site. In contrast, fresh leaves of *Cenchrus purpureus* (*Napier*) and *Brachiaria decumbens* grasses were harvested from their natural growth fields, all situated within a 1-kilometer radius of the Department of Animal Science at KNUST, where the study was conducted. Sampling from each plant species occurred at three distinct locations in the field, with preference given to non-over-matured plant branches. Each plant biomass was harvested in 3.0 kg leaf samples, individually packed in airtight bags, and subsequently transported to the laboratory for further analysis.

In the laboratory, triplicate samples were prepared for each plant biomass, ensuring statistical replication from the three sampling locations. These samples were initially chopped into smaller fragments and left to air dry in a designated room for 24 hours. Subsequently, they underwent further drying in an oven set at 60°C for 48 hours, ensuring a constant weight was achieved. The oven-dried samples were then coarsely milled using a laboratory mill (Wiley Mill[2]) until they could pass through a 2mm screen. Finally, these milled samples were placed in Ziploc bags, ready for subsequent chemical and nutritional analyses.

Laboratory chemical analyses

The nutritional composition of the test feeds was thoroughly assessed using the proximate analytical procedure, following the standardized protocol outlined by the Association of Official Analytical Chemists (AOAC, 1990). This comprehensive procedure encompassed the determination of various essential nutritional components, including dry matter (DM), crude protein (CP), and ash. The evaluation of dry matter (DM) involved subjecting the samples to a precise drying process in a hot air oven maintained at a constant temperature of 105°C for 8 hours. Concurrently, the determination of total ash content was carried out by incinerating the samples at a temperature of 550°C for an extended period of 8 hours within a muffle furnace. The quantification of crude protein content was done employing the Kjeldahl method (Rothman *et al.*, 2006). This method relies on nitrogen values, with crude protein (CP) being calculated as a function of the nitrogen concentration (CP = N concentration x 6.25). Since all amino acids found in proteins naturally contain nitrogen as part of their amino groups and both plant and animal proteins typically contain about 16% nitrogen, multiplying nitrogen concentrations by 6.25 results in an estimate of the protein content of the test feeds. Using the ANKOM[3] 2000 Automated Fibre Analyzer and following the guidelines outlined by Van Soest *et al.* (1991), neutral detergent fibre (NDF) and acid detergent fibre (ADF) contents were determined. Each sample of the test feeds underwent three separate analyses to obtain the statistical replications.

In vitro gas production

The *in vitro* gas production of the test feeds milled through a 1-mm sieve was incubated *in vitro* in rumen fluid using calibrated glass syringes following the procedures described by Menke and Steingass (1988). Rumen digesta (liquor) was obtained from five Djallonke sheep, with an average live weight of 18 kg and an approximate age of 1½ years, which were slaughtered at the Kumasi Abattoir Company Limited in Ghana after being fed grass hay before slaughter. The collection of rumen digesta took place early in the morning following a 12-hour fasting period for the animals before slaughter.

[1]International Network of Bamboo and Rattan (INBAR) bamboo agroforestry cultivated in the Sekyere Central District of Ashanti Region, Ghana.
[2]The Thomas ® Model 4 Wiley Mill. Made in the USA. Marketed and distributed by Onrion LLC. 93 South Railroad Avenue, STE C Bergenfield, 07621-2352, New Jersey, USA.
The ANKOM 2000 Automated Fiber Analyzer. Made in USA. Marketed and distributed by ANKOM Technology, Macedon NY 14502, 2052 O'Neil Road.

The digesta was promptly collected during the evisceration process and transferred to the laboratory for analysis. In the laboratory, the rumen digesta underwent a series of steps. It was initially strained through four layers of cheesecloth, followed by homogenization. A digestion medium was prepared by mixing 500 ml of distilled water, 0.1 ml of micro-mineral solution, 200 ml of bicarbonate buffer solution, 200 ml of macro-mineral solution, 1 ml of Resazurin solution, and a reducing solution serving as artificial saliva. Carbon dioxide gas was bubbled through the solution until the colour turned pink per purple or for 3 hours. A total of 200mg (0.200 g) dry weight of test samples was weighed into calibrated glass syringes of 100 ml each fitted with a piston. Before insertion into the syringes, the pistons were coated with Vaseline[4] for lubrication. The syringes were pre-warmed at 39°C before the dispersion of 30 ml of rumen fluid-buffer mixture consisting of 10 ml rumen fluid and 20 ml digestion medium into each syringe followed by incubation in a water bath at 39°C to mimic the natural rumen environment. Triplicates of each test sample were used in two separate runs for accurate statistical replication. To ensure uniform mixing of the incubated contents, the syringes were periodically agitated at hourly intervals. Gas volume measurement entailed reading before incubation (0) following the tracking of the movement of the pistons at designated time points, including 3, 6, 12, 24, 48, 72, and 96 hours of incubation. The total gas values were corrected for blank incubation. To determine the fermentation kinetics, the corrected gas data were subjected to a curve-fitting statistics software programme called SigmaPlot (Microsoft Windows version 15.0) developed by SYSTAT Software Inc. The mathematical model of Orskov and McDonald (1979) was employed for fitting the curve as follows:

$$y = a + b\,(1 - e^{-ct}).$$

Where:

- a = the gas production from an immediately soluble fraction (ml/200 mgDM)
- b = the gas production from the insoluble fraction (ml/200 mgDM)
- c = rate at which gas was produced from the insoluble fraction a + b = the potential gas production (ml)
- t = the incubation time (ml/h).
- y = volume of gas produced at time t (ml)

[4] *Marketed and distribution by Unilever Ghana Limited, Tema, Ghana*

Source of animals, experiment design, and treatments

A total of twenty Djallonké ewes, each initially weighing an average of 14.3±1.17kg, were procured from the Ejura Livestock Breeding Station in Ghana and transported to the Department of Animal Science, KNUST for the feeding experiment. The animals were subsequently allocated into four dietary groups using a 2 × 2 factorial treatment arrangement within a completely randomized design, with each group comprising five animal replicates. The animals were fed dietary treatments designated as follows: CPOA, where the diet consisted of 400 g of *Cenchrus purpureus* (CP) leaves as a basal diet, supplemented with 200 g of *Oxytenanthera abyssinica* (OA) leaves per day; CPBB, with a basal diet of 400 of *Cenchrus purpureus* (CP) leaves supplemented with 200 g of *Bambusa balcooa* (BB) leaves per day; BDOA, which included a basal diet of 400 g of *Brachiaria decumbens* (BD) leaves supplemented with 200 g of *Oxytenanthera abyssinica* (OA) leaves per day; and BDOA, where the basal diet comprised 400 g of *Brachiaria decumbens* (BD) leaves along with 200 g of *Bambusa balcooa* (BB) leaves per day.

Animal management, feed preparation, and feeding

The sheep were housed individually in an experimental barn with slatted floors measuring 4 × 7 ft. Before the study began, several preparatory management practices were undertaken for the sheep. These included the application of plastic ear tags for identification, weighing, deworming, and vaccination against Peste des Petits ruminants (PPR). Furthermore, the sheep received multivitamin injections, with follow-up administrations on the 30th and 60th days of the experimental period. Throughout the 70-day study period, the sheep had continuous access to feed, water, and a urea molasses block. Before feeding, the bamboo leaves were room air-dried for 72 hours to be used as supplements, while the grasses were harvested and air-dried for 24 hours and used as basal diets. All the feeds were uniformly chopped into 2.5 cm segments and subsequently weighed. They were then offered to the animals twice daily at fixed times, specifically at 09:00 and 16:00, using distinct wooden feeding troughs. It is important to note that the bamboo supplements were introduced two hours before the grass basal diets. This approach was chosen to ensure that the animals had adequate time to consume the bamboo supplements. A two-week adaptation period preceded the trial to ensure the sheep were accustomed to the experimental diets. Daily feed intake was monitored by measuring the difference between the feed offered and the leftovers. To evaluate the sheep's efficiency in converting feed into growth, the feed conversion ratio was computed by dividing the cumulative feed intake of each animal by their total weight gain.

Blood sampling and laboratory analyses

Blood samples were collected both before the commencement and after the trial, typically around 07:00 in the morning before the animals were fed. About 5 ml of blood was drawn from the jugular vein using a syringe and needle. This blood was then distributed into test tubes, with some containing anti-coagulant (Ethylene Diamine Tetra Acetic Acid, EDTA) for the assessment of haematological parameters, and others without anti-coagulants for serum metabolite analysis. (Ansah *et al.,* 2015). The tubes were promptly sealed, and their contents were gently mixed for approximately one minute through repeated inversion or rocking. In the laboratory, the blood without EDTA was subjected to centrifugation at 500 revolutions per minute (rpm), leading to the separation of serum. Subsequently, the serum was transferred into clean test tubes and stored at 4°C for further analysis.

Estimation of haematological parameters

The blood samples preserved with EDTA were employed to assess red blood cell (RBC) and white blood cell (WBC) counts using the Dymind DH36 3-part Auto Haematology Analyzer[5].

[5]*Blood auto analyzer marketed and distributed by JHB Medical, L.B, Fuyong Twon, Bao'an District, Shenzhen City, Guangdong, China.*

Estimation of total protein (g/L) and albumin (g/L)

The BT 3000 Random Access Chemistry analyzer (Elan Diagnostics, Smithfield, CA, USA) was used for the estimation of total protein based on the modifications of Gornall *et al.* (1949). Protein in serum forms a blue-coloured complex when reacted with cupric ions in an alkaline solution. The intensity of the violet colour is proportional to the number of proteins present when compared to a solution with known protein concentration. The method used for albumin assay was based on that of Doumas *et al.* (1971) where at a controlled pH, bromocresol green (BCG) forms a coloured complex with albumin. The intensity of the colour at 630 nm is directly proportional to the albumin content.

Statistical analysis

The chemical composition data were analyzed using a replicated completely randomized design with PROC MIXED in the SAS (2006) software. In contrast, animal experimental data were analyzed using PROC GLM, employing a generalized linear 2 × 2 factorial model within the same statistical software with fixed effects associated with the basal diet, supplement, and their interaction. The two basal diets and supplements were included in the model as fixed effects, and sheep nested in the basal and supplement interaction as a random effect. The time of blood collection was included in the repeated measure model procedure (PROC MIXED). The gas production assay adopted the PROC NLINMIXED procedures of SAS. Where there was a significant effect (at $p < 0.05$), treatment means were compared by least-square means, and the mean separation was done using the Student-Newman-Keuls Test.

RESULTS AND DISCUSSION

Analytical chemical constituents of the forages fed to sheep

Numerous studies have highlighted the significance of diversifying feed resources and improving feeding systems in ruminant production. In their research, Ma *et al.* (2021) and Moorby and Fraser (2021) emphasized the importance of examining the nutrient composition, rumen degradation characteristics, and feeding value of various types of roughage commonly used in ruminant feed.

The analytical chemical compositions of the forages provided to sheep are presented in Table 1. The results revealed significant differences ($p < 0.05$) in chemical constituents between bamboo forages (*Oxytenanthera abyssinica* and *Bambusa balcooa*) and grasses (*Cenchrus purpureus* and *Brachiaria decumbens*). Dry matter, an indicator of higher nutrient concentration and energy density in forages, was notably higher ($p < 0.001$) in both *B. balcooa* (369 g/kg) and *O. abyssinica* (343 g/kg), followed by *C. purpureus* (207 g/kg) and *B. decumbens* (187 g/kg). These results align with the findings of Hummel *et al.* (2006) and Ni *et al.* (2013), who asserted that bamboo leaves tend to have a greater energy density and higher nutrient concentration due to their lower moisture content.

Similarly, comparing the crude protein levels of the bamboo leaves to those of the grasses, which ranged from 66 g/kg in *C. purpureus* to 97 g/kg in *B. decumbens*, revealed that the bamboo leaves had considerably higher levels ($p = 0.001$), with values ranging from 95 g/kg in *B. balcooa* to 124 g/kg in *O. abyssinica*. According to Sasu *et al.* (2022, 2023a, 2023b), bamboo has a higher protein content than *Brachiaria decumbens*, *Megathyrsus maximus* (*Panicum* spp), and other common grass species. The consistently higher protein content of bamboo leaves is significant for ruminant nutrition as it may offer smallholder livestock farmers beneficial high-quality feed and fodder options, particularly during dry seasons when forage quantity and quality are more erratic (Sahoo *et al.*, 2010).

Ash levels between bamboo leaves and grass did not differ significantly ($p = 0.66$), showing that bamboo can provide critical minerals to the consuming animal in a manner comparable to traditional grasses.

Likewise, the comparable amounts of cell wall content (NDF) found in both the bamboo and grasses show that bamboo leaves are a typical source of feed for ruminants, acting as valuable dietary fibre sources that can help with bulk fill. This bulk fill is essential for triggering the rechewing reflex in ruminants, which produces a lot of saliva and supports healthy rumen function (Hummel *et al.*, 2006). In contrast to *B. decumbens* grass, it is important to note that bamboo leaves are anticipated to undergo a little slower fermentation when fed to ruminants. This is partly because they contain more ($p = 0.01$) acid detergent fibre (ADF), an important but less digestible component of the diet.

Comparatively, among the two varieties of bamboo, *O. abyssinica* leaves had higher quality than those of *B. balcooa*, which is in line with the findings of previous studies (Sasu *et al.*, 2022, 2023b). Notably, the results of this study confirm the exceptional nutritional qualities of bamboo leaves when compared to other fodder plant biomass including mulberry leaves as reported by Temel and Pehluvan (2015), the leaves of *Brighia sapida*, *Terminalia catappa*, and *Mangifera indica*, as reported by Sasu *et al.* (2023a).

Furthermore, it is worth highlighting that the analytical chemical profile of the bamboo leaves in this study is consistent with findings from previous research conducted by Antwi-Boasiako *et al.* (2011), Coffie *et al.* (2014), and Andriarimalala *et al.* (2019). An important point to emphasize is that, within the context of this study, the range of crude protein (CP) values (95 to 124 g/kg DM) recorded for the bamboo leaves exceeded the minimum requirement of 70 g/kg DM for sheep, as specified by Lazzarini *et al.* (2009). These values also significantly surpassed the protein content of other common feed sources such as wheat straws (31.4 g/kg DM), barley straw (42.2 g/kg DM), and maize silage (78 g/kg DM), as reported by Kamalak (2005). In addition, Ansah *et al.* (2014) reported protein levels of 126.25 g/kg DM and 151.23 g/kg DM for the leaves of *Ceiba pentandra* and *Gmelina arborea*, respectively, which are comparable to the protein content recorded for *O. abyssinica* leaves in this study.

Numerous scientific studies have explored the nutritional potential of bamboo leaves as a valuable feed ingredient for ruminants. Sahoo *et al.* (2010) examined bamboo leaves from various species and found them to have a favourable chemical composition, characterized by high crude protein content and good fibre content. Additionally, their research revealed that bamboo leaves exhibited promising ruminal fermentation characteristics, making them a suitable choice for ruminant diets. Similarly, Andriarimalala *et al.* (2019) assessed the use of bamboo leaves in feeding dairy cattle and highlighted their abundance as a valuable alternative fodder source, especially during dry seasons when feed shortages are common. In a study by Wu *et al.* (2009) investigating nutrition elements in bamboo, it was found that the leaves contained higher concentrations of essential nutrients compared to branches and stems. This signifies that bamboo leaves can serve as a rich source of vital nutrients for ruminants. It is important to note that the dietary crude protein content in both bamboo leaf supplements exceeded the minimum requirement (60 - 80 g/kgDM) for sustaining microbial growth, as suggested by Van Soest (1982, as cited in Ansah *et al.*, 2015). Collectively, these studies offer compelling evidence that the results of the present study are correct, showing that bamboo leaves can successfully supplement ruminant diets, especially when grass, straws, and tree leaves make up the bulk of the feed.

In vitro gas production and degradation kinetics from the forages fed to the Djallonké Sheep

The analytical methods of in vitro gas production and the estimated degradation kinetics used in this study, as described by Getachew *et al.* (2005), also provided helpful indicators of the DM digestibility and, consequently, the rate of degradation of the bamboo leaves and grasses within the digestive system of sheep. The pattern of cumulative *in vitro* gas production from the bamboo supplements and grass-basal diets fed to the sheep is shown in Figure 1. Longer incubation times resulted in higher cumulative gas yields (CGY), which ranged from 1 to 24 ml for every 200 mg of incubated dry matter. Notably, the leaves of *O. abyssinica* yielded the highest gas production, followed by *B. decumbens* and *B. balcooa*, while *C. purpureus* produced the least gas. The observed range of values and pattern of CGY across incubation times mirror trends reported in previous studies by Filya (2002), Kamalak (2005), and Osafo *et al.* (2023) for various ruminant fodder plants. Additionally, Sasu *et al.* (2023a) reported that among several non-conventional forages, the leaves of *O. abyssinica* ranked second in terms of CGY, following only the leaves of *Moringa oleifera*. These

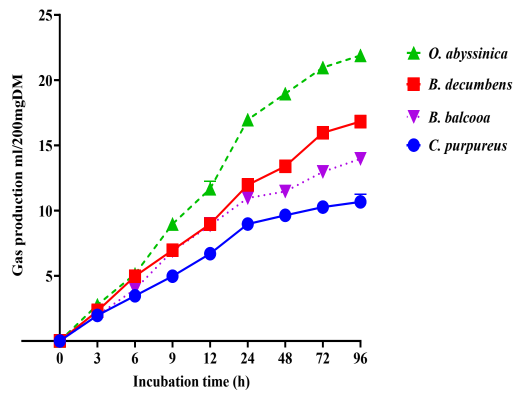

Figure 1: Cumulative *in vitro* gas yield patterns at different incubation times recorded for bamboo leaf supplements and grass basal diets fed to the sheep. Data points are the mean gas volumes produced from three replicates of each leaf sample.

Table 1: Analytical chemical constituents of the forages fed to the sheep

Constituents (g/kg)*	*Grass basal diets*		*Bamboo Supplements*		SEM	Sig.
	C. purpureus	*B. decumbens*	*O. abyssinica*	*B. balcooa*		
Dry matter	207.0^{b}	187.0^{b}	343.0^{a}	369.0^{a}	8.39	<0.001
Crude protein	66.1^{c}	97.9^{b}	124.0^{a}	95.1^{b}	4.82	<0.001
Ash	120.0	115.0	80.0	95.0	24.8	0.66
NDF	502.0	464.0	564.0	598.0	39.2	0.19
ADF	378.0^{a}	180.0^{b}	368.0^{a}	326.0^{a}	29.1	0.01

*Mean values within a row with the same superscript (a, b, c) are not significantly (p > 0.05) different; SEM = standard error of means; Sig. = significance level; *Data values are the means of triplicates of leaf samples analysed; NDF =Neutral detergent fibre; ADF = Acid detergent fibre.*

results consistently highlight the significant gas-producing propensity of *O. abyssinica* leaves.

Table 2 shows the degradation kinetics for bamboo leaf supplements and grass basal diets fed to the sheep. The bamboo and grasses showed significantly different degradation kinetics ($p < 0.05$), with *C. purpureus* recording the highest *'a'* value at 5.17 ml/0.2g DM, showing it had more readily fermentable material while the least value was found in *O. abyssinica* (0.38 ml/0.2g DM). Despite having a lower initial fermentable fraction ('a'), *O. abyssinica* consistently produced more gas from the insoluble fraction ('b'), reaching 21.51 ml/0.2g DM, leading to a higher potential gas production ('a+b') of 21.89 ml/0.2g DM, the highest of all the feed ingredients tested, and displaying the highest fermentation rate ('c') of 0.064 ml/h. This implies that it can produce short -chain fatty acids, a form of energy that is very useful for ruminant nutrition. The other feed ingredients exhibited lower degradation estimates, a phenomenon that can be attributed to the presence of more robust lignocellulose linkages within their cell wall structures. This characteristic is well-documented to reduce microbial activity, particularly in the face of increasingly adverse environmental conditions as the incubation time progresses (Ndlovu and Nherera, 1997; Abdulrazak *et al.*, 2000; Kamalak, 2005; Osuga *et al.*, 2006; Afshar *et al.*, 2011).

In general, the two species of grass produced gas at noticeably different rates, with *B. decumbens* exhibiting a larger gas yield at a significantly higher rate of 0.054 ml/h than *C. purpureus* (0.004 ml/h). The other bamboo species displayed a similar pattern, with *O. abyssinica* having a greater rate of 0.068 ml/h than *B. balcooa* at 0.064 ml/h. According to research by Getachew *et al.* (2004), differences in fermentation rates can be ascribed to the proliferation of rumen bacteria and their easier access to the digesta. The variations in gas production values among these feed ingredients can also be attributed to plant genetics, which likely played a role in shaping their chemical composition, including factors such as crude protein and fiber content. Additionally, the timing of forage harvest during different growth stages can influence these compositional differences, as highlighted by Akinfemi *et al.* (2009). This phenomenon is further supported by an earlier study that reported a strong positive correlation ($r = 0.92$, $p < 0.001$) between the crude protein (CP) content and the 96-hour gas production for the leaf fractions of bamboo and multipurpose trees (Sasu *et al.*, 2023a). These findings emphasize the multifaceted nature of feed ingredient composition and its impact on gas production, highlighting the importance of considering both genetic factors and growth stages when evaluating forage suitability for ruminant nutrition.

Effect of bamboo leaf supplementation on feed intake, and growth performance of Djallonké Sheep

Table 3 provides a summary of how the two different grass diets (*C. purpureus* and *B. decumbens*) and the two bamboo supplements (O. *abyssinica* and *B. balcooa*) interacted differently

Table 2: *In vitro* degradation kinetics at different incubation times of the forages fed to the Djallonké Sheep

Parameter (ml)	*Grass basal diets*		*Bamboo supplements*		SEM	Sig.
	C. purpureus	***B. decumbens***	***O. abyssinica***	***B. balcooa***		
a_{gas}	5.17[a]	1.18[b]	0.38[b]	3.68[a]	0.823	0.0037
b_{gas}	10.83[d]	15.52[b]	21.51[a]	12.95[c]	0.192	<0.001
$(a+b)_{gas}$	16.00[b]	16.70[b]	21.89[a]	16.63[b]		<0.001
$c_{gas\ (h^{-1})}$	0.004[b]	0.054[a]	0.068[a]	0.064[a]	0.006	0.0007

Mean values within a row with different superscripts (a, b, c, d) letters are significantly ($p < 0.05$) different; a_{gas} = gas production (ml) from readily soluble fraction; b_{gas} = gas production (ml) from insoluble fraction; $(a + b)_{gas}$ = potential gas production (ml); c_{gas} = gas production rate (ml/h) of b; SEM = standard error of means; Sig. = significance level.

($p < 0.05$) to influence feed intake, growth performance, and the feed-to-gain ratio in the sheep. Among the interactions between the basal diets and supplements, it was observed that the CPOA group had a significantly higher ($p = 0.04$) dry matter intake, consuming 34.7 kg (505.7 g/d), followed by the BDOA group at 33.2 kg (471.4 g/d), and the BDBB group at 32.5 kg (464.3 g/d), with the lowest intake recorded in the CPBB group at 30.4 kg (434.2 g/d). These variations in dry matter intake can be attributed to several factors, including protein levels and anti-nutritional factors, known to impact palatability and influence animal consumption (McDonald *et al.*, 1995; Brown, 2008; Konlan *et al.*, 2012). Conversely, animals in the CPBB group may have found BB leaves less visually appealing or experienced an astringent taste during chewing, resulting in lower intake. The reduction in palatability can be attributed to the interaction between salivary mucoproteins and tannins, or a direct interaction with taste receptors, triggering the astringent sensation (McLeod, 1974).

The higher feed intake by the CPOA group translated into a substantially higher total weight gain (TWG) of 6.7 kg, with an average daily gain (ADG) of 95.71 g/d. This represents a significant difference when compared to the CPBB group, which recorded the lowest TWG of 3.10 kg and an ADG of 44.3 g/d. One of the key factors contributing to these differences in growth performance can be attributed to the varying chemical constituents, including crude protein, found in bamboo supplements. For instance, the *O. abyssinica* (OA) leaf supplement in the CPOA diet is known to have higher crude protein levels ranging from 12 to 14 g/kg DM (Antwi-Boasiako *et al.*, 2011; Coffie *et al.*, 2014; Sasu *et al.,* 2022, 2023b) compared to several other bamboo species and have shown higher estimates of *in vitro* gas production when compared to many non-conventional tree forages explored for smallholder ruminant production (Sasu *et al.*, 2022a). Therefore, the higher protein content in OA leaves, as part of the CPOA diet, likely provided the sheep with more abundant and higher-quality amino acids for muscle development and overall weight gain. Furthermore, there may have been a synergistic additive effect on the sheep's growth from the presence of *C. purpureus* (CP) as part of the CPOA treatment, as it contained a higher amount of readily soluble fibre fraction when incubated *in vitro* (as shown in Table 2). The ADG observed in all treatment groups in this study fell within the range of 44 to 109 g/d, which is consistent with findings by Muhammad *et al.* (2008) when using rice milling waste as sheep feed, but notably higher than the 20 to 40 g/d range reported by Osman (2011) for improved leaf fractions of C. purpureus supplemented with various levels of paper mulberry leaves. These results are in line with studies by Gibson (1981) and Gebeyew (2014), which indicated a positive relationship between higher supplement intake in sheep and increased ADG and overall feed efficiency.

Regarding feed efficiency, the performance of Djallonke sheep in this study followed the sequence: CPOA (FCR: 4.96) > BDOA (FCR: 5.71) > BDBB (FCR: 9.79) > CPBB (FCR: 9.80). This suggests that providing sheep with more frequent feedings of bamboo leaves in grass-based diets can lead to more efficient conversion of feed into body mass, which is consistent with the findings of Jiang *et al.* (2020). A similar improvement in feed efficiency was seen by Cronje (1990) when supplementing grass hay with urea molasses blocks for older sheep. Furthermore, Asmare *et al.* (2010) demonstrated that supplementation improved feed efficiency and profitability in farta sheep. Okoruwa *et al.* (2016) also reported a significant enhancement in feed efficiency for Djallonke sheep fed bamboo leaves and neem seed cake, as well as a combination of guinea grass, bamboo leaves, and neem seed cake, which agrees with the findings of this study.

Effect of bamboo leaf supplementation on haematology of Djallonké Sheep

Figure 2 provides a repeated measure of the sheep's red blood cell (RBC) and white blood cell (WBC) counts between the initial and final stages of the trial and examines the overall supplementation effects of bamboo leaves on these parameters. There was no statistically significant difference ($p = 0.061$) in mean RBC counts between the initial and final blood samples, with an average count of 7.7 x 10^12/L, indicating no interaction effects ($p = 0.324$) among all dietary treatment combinations. However, these values were higher than those reported by Ansah *et al.*

Table 3: The effects of basal diet, supplement, and their interactions on feed intake and growth performance of Djallonké Sheep

Parameter (n = 20)	Basal Diet (B)		Supplement (S)		SEM	Basal (B) × Supplement (S)				SEM	Sig.		
	CP	BD	BB	OA		CPBB	CPOA	BDOA	BDBB		Basal	Sup	B × S
Initial LW, kg	13.60	13.60	14.04	13.20	0.37	14.00	13.20	13.10	14.10	0.52	1.00	0.11	0.82
Final LW, kg	17.30	17.40	17.98[b]	19.09[a]	0.29	17.10[b]	19.95[a]	19.4[a]	17.8[b]	0.41	0.31	0.79	0.77
TWG, kg	3.70	3.80	3.94[b]	5.89[a]	0.66	3.10[b]	6.75[a]	6.2[a]	3.7b	0.11	0.69	0.03	0.02
ADG, g/d	52.86	54.29	56.29[b]	84.14[a]	0.09	44.3[d]	95.71[a]	88.57[b]	52.85[c]	6.18	0.35	0.04	0.01
Basal intake, kg	17.40	18.70	17.30	18.80	0.67	16.60	19.50	18.20	18.00	0.95	0.18	0.12	0.99
Sup intake, kg	14.40	15.20	14.13	15.43	0.45	13.70	15.20	15.00	14.50	0.63	0.20	0.06	0.97
Total intake, kg	31.80	33.90	31.43[b]	34.27[a]	0.94	30.40[c]	34.70[a]	33.00[b]	32.50[b]	1.33	0.12	0.04	0.99
Daily intake, g/d	454.3	484.3	449.0[b]	489.6[a]	14.40	432.9[d]	505.7[a]	471.4[b]	464.3[c]	20.3	0.42	0.06	0.04
FCR	4.70	4.92	3.58[a]	2.61[b]	0.67	9.80[a]	5.14[c]	5.32[c]	8.79[b]	0.94	0.28	0.018	0.02

Mean values within a row with different superscripts (a,b,c,d) differ significantly ($P < 0.05$); SEM = standard error of means ; Sig. = Probability; LW = live weight, TWG = total weight gain; ADG = average daily gain, FCR = Feed conversion ratio (intake /gain); Basal (B): CP= Cenchrus purpureus; BD = Brachiaria decumbens; Supplements (S): OA = Oxytenanthera abyssinica; BB = Bambusa balcooa; B×S = Basal × Supplement interactions: CPOA - a basal diet composed of 400 g of C. purpureus supplemented with 200 g of O. abyssinica; CPBB - a basal diet composed of 400 g of C. purpureus supplemented with 200 g of B. balcooa; BDOA - a basal diet composed of 400 g of B. decumbens supplemented with 200 g of O. abyssinica (OA); BDOA - a basal diet composed of 400 g of B. decumbens supplemented with 200 g of B. balcooa (BB).

(2012) for sheep supplemented with whole cottonseed while feeding on rice straw and when partially replacing rice straw with browse plants Ansah *et al.* (2015). Similarly, the value surpassed the value reported by Konlan *et al.* (2012) for sheep receiving shea nut cake supplementation alongside a rice straw basal diet. This variation could be related to the different types of supplements utilised, which suggests that bamboo leaves are likely to contain a relatively higher amount of iron, which may have contributed to the increase in RBC levels in sheep. Notably, the RBC count in all the sheep blood samples fell within the reference range of values (8.0 – 18.0 × 10^12/L) considered normal for sheep, as reported by Radostits *et al.* (2000). This suggests that there were no signs of anaemia-related diseases resulting from the bamboo leaf supplementation.

More so, at the end of the trial, a significant change was observed in the mean WBC count ($p < 0.001$). The initial value of 15.8 × 10^9/L decreased substantially, reaching as low as 4.2 × 10^9/L. This reduction was consistent across all treatment groups ($p = 0.466$). The observed reduction in WBC count was comparable to the findings of Bello and Tsado (2013), who fed sheep sorghum stover supplemented with graded levels of dried poultry droppings. Additionally, it fell within the normal physiological range of values reported by Fadiyimu *et al.* (2010). Of much interest is the general decline in WBC count across the treatment groups which suggests that both bamboo supplements had similar effects on pathogenic microorganisms in the blood. Various components of the bamboo plant, including its leaves, have a long history of ethnomedical use, including use as anthelmintics and for treating various diseases and parasites, particularly gastrointestinal worms, in diverse cultures. Studies have indicated that bamboo leaves possess several beneficial properties, including antioxidant, anticancer, and antibiotic properties (Tanaka *et al.*, 2012). These properties suggest that bamboo leaves may have therapeutic effects on various diseases and parasites, including gastrointestinal nematodes. Bamboo leaves contain active substances such as tannins, flavonoids, polysaccharides, chlorophyll, amino acids, vitamins, and microelements (Antwi-Boasiako *et al.*, 2011; Coffie *et al.*, 2014; Widiarso *et al.*, 2020). These components play vital roles in mitigating oxidation or free radical formation, anti-aging effects, and maintaining stamina. A study conducted by Widiarso *et al.* (2020) investigated the effects of bamboo leaf extract on *Haemonchus contortus*, a gastrointestinal nematode parasite, and found ultrastructural changes in the parasite, indicating potential anthelmintic activity. This may offer a plausible explanation for the observed reduction in WBC counts in the blood of experimental sheep in the current study, suggesting a general improvement in their health.

Effect of bamboo leaf supplementation on serum metabolites of Djallonké Sheep

Figure 3 evaluates changes in total protein and albumin concentrations before the start and at the end of the study and shows the impact of various treatment groups on these parameters. In Figure 3, the data bars illustrate a significant increase in total protein concentration ($p = 0.006$) among the various treatment groups at the end of the experiment. The sheep that received the CPOA treatment displayed the highest total protein concentrations, reaching 92.1 g/L. However, these levels were statistically comparable ($p > 0.05$) to those of the BDOA treatment group (82.2 g/L) and the BDBB treatment group (77.2 g/L). In contrast, the CPBB treatment group exhibited the lowest total protein concentration at 59.5 g/L. The observed increase in plasma protein concentration in the sheep can be attributed to the relatively higher crude protein content present in the bamboo leaves used as a supplement in the grass basal diets. Previous studies have indicated a positive correlation between dietary protein and plasma protein concentrations (Yousef and Zaki, 2001; Shahen *et al.*, 2004). This correlation was particularly evident in diets containing *O. abyssinica* supplements, known for their higher crude protein content, thereby rendering a net positive plasma protein balance in the blood of the host sheep. Conversely, the lower plasma protein levels observed in the CPBB treatment group could suggest that there was reduced protein degradation in the rumen by proteolytic bacteria. Thus, condensed tannins, which are known for their capacity to reduce dietary protein breakdown in the rumen by forming complexes with proteins (Barry *et al.*, 1986, as referenced in Ansah *et al.*, 2015), may have been present in higher concentrations in the *B. balcooa* supplement.

In a similar array, the concentration of albumin exhibited a significant increase (p = 0.024) from the initial to the final stages of the trial, with values ranging from 29.5 g/L to 36.1 g/L. This increment, although, showed no significant differences (p = 0.530) across the various treatments, it was noted that the levels exceeded those reported for similar sheep breeds in studies conducted by Ansah *et al.* (2015) and Konlan *et al.* (2012). These differences may be attributed to the use of different supplement types in these two studies, which could have impacted the digestibility of dietary protein differently. Importantly, the range of values for total protein (59.5 – 92.1 g/L) and albumin (27.3 – 36.5 g/L) observed in this study aligns well with the nor-

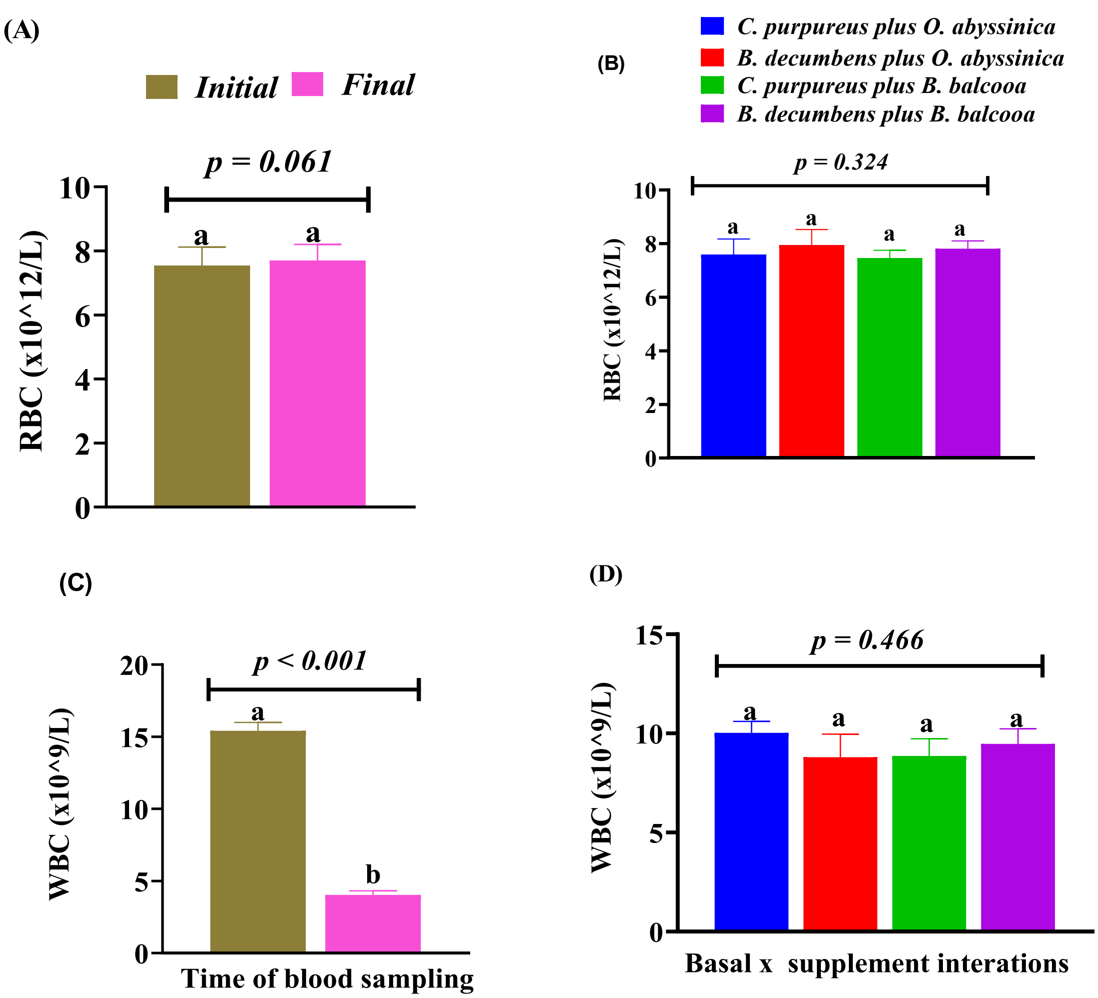

Figure 2: Haematological indices of sheep supplemented with bamboo leaves: A –Comparison of initial and final RBC counts, B – Comparison of basal x supplement interaction effect on final RBC count, C - Comparison of initial and final WBC counts, D – Comparison of basal supplement x interaction effect on final WBC count.

mal physiological values typically seen in sheep, falling within the range of 60 – 93 g/L for total protein and 30 – 38 g/L for albumin, as reported in studies by Borjesson *et al.* (2000) and Milne and Scott (2006).

CONCLUSIONS

This study highlighted the significance of both conventional grasses, including *Cenchrus purpureus* (Napier) and *Brachiaria decumbens*, and unconventional bamboo leaves, notably *Oxytenanthera abyssinica* and *Bambusa balcooa*, as crucial components of ruminant diets. Grasses have long been a dependable source of nourishment for ruminants, providing a wide nutritional profile and adding to the variety of their diets. However, it became clear from this study that bamboo leaves offer special benefits when taking into account the possible advantages of supplementation. The current findings and earlier ones support the assertion that ruminant diets can benefit from including bamboo leaves, especially those from *O. abyssinica*. They offer a viable alternative to conventional grasses, especially during dry seasons when feed supply is constrained, due to their superior chemical composi-

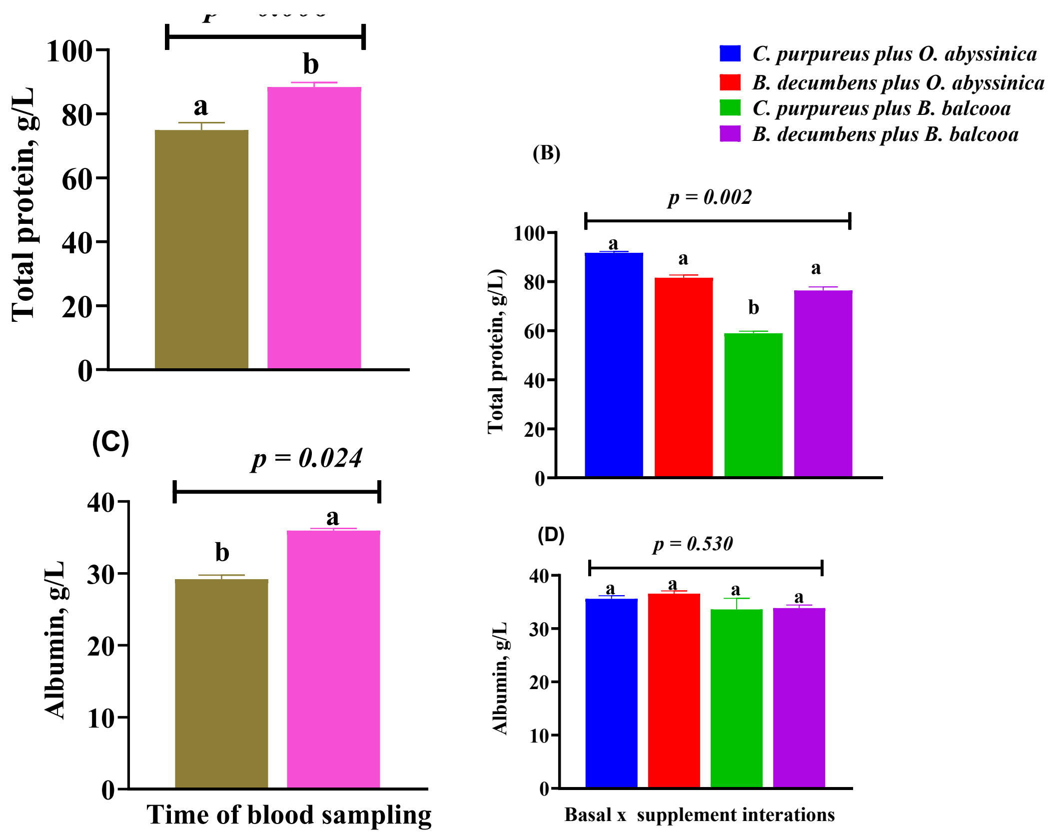

Figure 3: Serum biochemical indices of sheep supplemented with bamboo leaves: A – Comparison of initial and final total protein concentration, B – Comparison of basal × supplement interaction effect on final total protein concentration, C - Comparison of initial and final albumin concentration, D – Comparison of basal supplement × interaction effect on final albumin concentration.

tion, which also increased their in vitro fermentative yields and improved daily feed intake, weight gain, and feed conversion efficiency in sheep. In addition to their nutritional benefits, bamboo leaves have shown medical benefits in numerous scientific studies, as they contain active ingredients with antibacterial and anthelmintic qualities. This was seen in the current study, where supplementation with bamboo leaf helped to restore normal white blood cell counts and raise plasma proteins in Djallonke sheep. This implies that feeding bamboo leaves to small ruminants, like goats and sheep, can help them stay healthy and experience fewer parasitic infections. Further research is needed to determine the optimal inclusion levels and investigate the long-term effects of bamboo leaf supplementation in ruminant nutrition.

Recommendations for feeding bamboo leaves to animals

For farmers considering the incorporation of bamboo leaves into their ruminant diets, several specific factors should be taken into account:

1. **Bamboo Species Selection:** Select bamboo species that grow well in the area and are compatible with the soil and temperature there. Although this study has shown potential for *Oxytenanthera abyssinica* and *Bambusa balcooa*, other indigenous bamboo varieties should also be taken into account.
2. **Harvesting and Processing:** To maximise their nutritious value, bamboo leaves should be harvested at the proper stage of development. To maintain their quality, proper processing methods including drying and storing should be used.
3. **Balancing with Grasses:** Although bamboo leaves have many health advantages, they should not be utilised as a complete substitute for traditional grasses or fed as a sole diet. To provide their animals with a well-rounded diet, farmers should strive for a balanced blend of bamboo leaves and other forages.
4. **Feeding Regimen:** To give animals time to adjust, farmers should introduce bamboo leaves to the diet gradually. Keep an eye on how they are responding and change the feeding schedule as necessary.
5. **Sustainability:** To secure a steady and long-term supply, farmers should think about the sustainability of their bamboo leaf sourcing. Encourage ethical bamboo harvesting and cultivation methods.
6. **Local Research:** To adapt bamboo leaf supplements to particular geographical conditions and livestock breeds, animal nutritionists should promote local research and testing.

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