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Comparative nutritional evaluation of the leaves of selected plants from the Poaceae family (bamboos and grasses) for sustainable livestock production in Ghana

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Background: Sustainable animal feeding is essential for reducing poverty among Ghanaian smallholder livestock farmers. However, seasonality has a severe impact on the availability and quality of conventional animal feedstuffs, necessitating alternate feed sources.

Objective: This study evaluated and compared the nutritional characteristics of the leaves of three bamboo species namely; *Bambusa balcooa (Beema), Oxytenanthera abyssinica (A. Rich.) Munro and Bambusa vulgaris;* and three conventional types of grass, namely; *Cenchrus purpureus, Megathyrsus maximus, and Brachiaria decumbens*.

Materials and methods: The plant biomasses were subjected to the standard analytical procedures of proximate and detergent fiber systems to highlight their dry matter (DM), crude protein (CP), crude fiber (CF), ether extract (EE), ash, nitrogen-free extract (NFE), neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL). Other nutritional characteristics were estimated using the chemical compositions.

Statistical analysis: Data was analyzed using Generalized Linear Model procedures in Minitab Statistical Software at a 5% significant level.

Results: Results showed a significantly ($P < 0.05$) higher DM (∼918 g/kgDM), CP (∼153 g/kgDM), and EE (∼153 g/kgDM) in *B. vulgaris leaves*. *O. abyssinica* leaves had the maximum ash (∼139 g/kgDM) while those of *M. maximus* had the highest carbohydrate (∼709 g/kgDM) and CF (∼492 g/kgDM). Compared to the grasses, the bamboo had a higher pool of DM (∼910 vs. 836 g/kgDM), CP (∼133 vs. 75 g/kgDM), EE (∼137 vs. 82 g/kgDM), ash (∼134 vs. 89 g/kgDM), hemicellulose (∼79 vs. 28 g/kgDM), dry matter intake (∼25 vs. 24%), digestible dry matter (∼58 vs. 53%), and relative feed value (∼111 vs. 105). In contrast, the grasses had higher mean ADF (∼461 vs. 402 g/kgDM), cellulose (∼417 vs. 397 g/kgDM), and ADL (∼5 vs. 0.4 g/kgDM).

Conclusion: The study suggests that bamboo leaves could have high nutritional characteristics to supplement or even replace conventional grasses and other crop residues in the diets of ruminants, especially during the dry season.

KEYWORDS

bamboo leaves, sustainable feed production, smallhold farming systems, livestock, Ghana

Introduction

The demand to intensify livestock output grows as the majority of people in Sub-Saharan Africa (SSA) consume mainly meat and meat products to meet their daily protein requirements. However, livestock intensification puts pressure on the amount of feed that farmers can access, especially in urban and peri-urban areas of SSA (Graefe et al., 2008). A decrease in feed supply as a result of the conversion of grazing lands into arable lands and infrastructure development exacerbates the poor livestock output, particularly during the dry season since most livestock farmers rely mainly on native pastures (Smith, 2010; Awuma, 2012; Ansah and Issaka, 2018).

According to estimates [Statistical Research and Information Directorate (SRID), 2014], Ghana's native vegetation (pastures without improvements) covers about 26,000 km^2 (11% of the country's total land area), and if the additional 63,000 km^2 (or 26% of the total land area) of uncontrolled savannah woodland area is included, the amount of potentially usable land for grazing is estimated to be 89,000 km^2 (or 37% of the total land area). Additional forage may be provided by portions of fallowed lands [Statistical Research and Information Directorate (SRID), 2014]. It is estimated that 10,600,000 tons of fodder are produced nationwide, with around 70% coming from grassland (Ziblim et al., 2015). The widespread grasses and forbs that makeup Ghana's grassland are frequently consumed and preferred by livestock including but not limited to *Tridax procumbens, Tephrosia purpurea, Sida acuta, Pennisetum pedicellatum, Andropogon pseudapricus, Amarantus spinosus, Commelina sp, Boerhavia diffusa, Cenchrus purpureus, Paspalum scrobiculatum, Isoberlinia tomentosa, Vetiveria nigritana, Megathyrsus maximus, Cymbopogon giganteus, Andropogon gayanus, Imperata cylindrica, Sporobulus pyramidalis, Ellinsia guinensis, Combretum mole, Zornia glochidiata, Setaria pallide-fusca, Rottboellia cochinchinensis, Allysicarpus ovalifolius, Indigofera sp, Cyperus rotundus* and *Stylosanthes mucronate* (Ziblim et al., 2015). These fodder resources make up a significant portion of the feed for livestock, particularly ruminants. However, their availability to animals varies throughout the year. Additionally, even though, some resistant and nutrient-dense leguminous forages are over-sown on grazing grounds for communal use, this technique is uncommon and is only permitted at state livestock stations where grazing land is set aside (Oppong-Anane, 2006). In a similar array, the use of crop residues in crop-livestock systems has been expanding to augment natural pastures (Samdup et al., 2010). In these supposedly less cumbersome systems, goats and sheep are either allowed to forage on crop wastes or are tethered. However, these tethered animals typically produce less since they have less access to forages. Even worse, to guarantee access to enough pasture, it is necessary to move the animals to new areas each day, increasing labor costs.

Aside limited supply of feed and fodder throughout the entire nation, the country's typical rainfall pattern has an impact on the growth patterns of these forages in different ecological zones. Even in areas where the dry matter supply is sufficient throughout the dry season, it is severely deficient in protein, vitamins, and minerals (Oppong-Anane, 2006). At the start of the rainy season, the dry matter is estimated to typically contain crude protein between 8 and 12%, and as low as 2–4% in the dry season, while phosphorus concentration ranges from 0.16–0.06% DM (Agrovets Consultancy, 1989). There is, therefore, a need to investigate additional non-conventional and/or underutilized feed and fodder options to supplement the current ones and eventually replace the scarce ones.

One promising alternative is bamboo leaves. Bamboo, which is primarily evergreen (INBAR, 2019; Sasu et al., 2023), belongs to the grass (Poaceae) family (Armstrong, 2008), and is described as an "unfamiliar" plant (INBAR, 2019), yet a "wonder" plant (Zehui, 2007). The bamboo plant is noted for producing a large amount of leaf biomass and can be used as a viable source of both green and dry roughages for smallholder livestock farming communities (Sasu et al., 2023). Ghana has an estimated 42,889.63 hectares of indigenous bamboo stands, predominantly distributed in the southern regions of the country as natural stands (INBAR, 2020a,b). The Ashanti region has the largest bamboo area (10,325.51 ha), followed by the Central (9,518.23 ha), Western (9,397.49 ha), Eastern (8,991.80 ha), and Western North regions (4,656.60 ha). The distribution of bamboo in Ghana is ecologically linked to moist ecozones, mainly moist semi-deciduous and moist evergreen, with less bamboo present in dry ecozones such as dry semi-deciduous and savannah. Literature on Ghana bamboo (INBAR, 2020b) shows that some exotic species, such as the thick-walled Beema (*Bambusa balcooa*) bamboo from India and the near-solid *Oxytenanthera abyssinica* from Ethiopia, have been introduced into Ghana. These species are well adapted to drier areas and are particularly useful for biomass energy. Bamboo harvesting and use for furniture production and construction scaffolding are common in Ghana (INBAR, 2020b), while the leaves are often left unattended to. Nonetheless, it is established that various wild animals, including pandas and goats, commonly graze on new bamboo shoots and leaves from the lower sections of bamboo stems as a source of wild forage (Hayashi et al., 2005; Asaolu et al., 2009; Halvorson et al., 2011). Bamboo leaves are particularly promising as a feed source for ruminant livestock during the dry season in Ghana, as they can withstand drought conditions better than most pasture grasses. In fact, bamboo leaves have been referred to as the "hope" for dry season ruminant livestock production in Ghana (Sasu et al., 2022). Mammalian herbivores, including ruminant animals, commonly exhibit dietary diversity (Distel et al., 2020). Ruminant animals have the ability to choose from various types of food with different nutrient concentrations, allowing them to select diets that meet their nutritional needs while avoiding toxicity and nutritional disorders (Villalba et al., 2002, 2004). Bamboo, therefore, has the potential to be a suitable fodder plant as its leaves can provide a perfect feed resource that aligns with the selective nature of ruminant animals. Furthermore, foraging hens eat the newly sprouted shoots, while goats graze the lower leaf sections that are not overgrown (personal observation). This demonstrate that bamboo is a natural feed source for animals and may present grazing livestock species with an acceptable feed alternative and supplement to their daily nutritional requirements.

Despite these promising attributes of bamboo plants and their consistent supply of edible leaves especially during the dry season as noted by Antwi-Boasiako et al. (2011), INBAR (2019), Sasu et al. (2022, 2023), the use of bamboo leaves as animal feed is still in its infancy in most parts of Africa, and specifically, it has not gained much popularity in Ghana. There is, therefore, a need for more research to be conducted on the feasibility of using them as a source of animal feed in different ecological zones in the region.

It is against this background that the current study sought to explore the nutritional quality and fodder potentials of the leaves of three bamboo species, namely; *Oxytenanthera abyssinica (A. Rich.) Munro, Bambusa balcooa (Beema),* and *Bambusa vulgaris* through analytical comparison with three selected conventional types of grass, namely; *Cenchrus purpureus, Megathyrsus maximus,* and *Brachiaria decumbens*. This research could help to unlock the potential of bamboo fodder as a sustainable and cost-effective source of animal feed, which could help to support the growth of the livestock sector in Sub-Saharan Africa and improve food security in the region. The findings of this study may particularly be helpful to smallholder farmers who primarily rely on natural pasture and agricultural wastes as their main sources of animal feed.

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 during the dry season from late November 2020 to mid-February 2021. The area is in the semi-deciduous humid forest zone of Ghana which experiences a bimodal rainfall pattern of 1,300 mm per year. The average daily temperature is 26°C, 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 2021 meteorological data, Department of Animal Science, KNUST).

Source of plant leaf biomass, sampling procedure, and sample preparation

The study involved collecting plant samples from different locations for further analysis. Fresh leaves of ∼3½ years old *Oxytenanthera abyssinica (A. Rich.) Munro* and *Bambusa balcooa (Beema)* bamboo species were collected from the INBAR[1] bamboo agroforestry site, while the leaves of another bamboo *(Bambusa vulgaris*) with similar age were sampled from their mature stands that naturally grow in the KNUST Botanical Garden, near the study site. For the grasses, fresh leaves from the regrowth of *Cenchrus purpureus, Megathyrsus maximus,* and *Brachiaria decumbens* were sampled on their natural growing fields within a 1-kilometer radius of the Department of Animal Science, KNUST, where the study was conducted. The sampling of the leaves from all the plant species was done in three separate locations on the field, and distinct plant branches were considered provided they were not conspicuously over-matured. For each plant biomass, ∼3.0 kg of representative samples were harvested, packed in air-tight bags separately, and transported to the laboratory for further analysis.

At the laboratory, triplicate samples of each plant biomass were prepared based on the three sampling locations to get statistical repetitions. The samples were chopped into smaller pieces and allowed to air dry in a room for 24 h. Afterwards, they were dried in an oven at 60°C for 48 h until a constant weight was achieved. The oven-dried samples were then coarsely milled using a laboratory mill (Wiley Mill)[2] to pass through a 2 mm screen before being placed in Ziploc bags for chemical and nutritional analyses.

Laboratory chemical analyses

The proximate analytical procedure was employed, following the standard procedures of the Association of Official Analytical Chemists (AOAC, 1990) to determine the nutritional composition of the collected plant biomass samples. The procedure included the determination of dry matter (DM), crude protein, ether extract (EE), crude fiber (CF), and ash. Dry matter (DM) was determined by drying the samples in a hot air oven at 105°C for 8 h, while total ash was analyzed by incineration at 550°C for 8 h in a muffle furnace. Crude protein (was calculated from the nitrogen values (CP = N concentration * 6.25) using the Kjeldahl method (Rothman et al., 2006). All amino acids contain N, in the amino group, and plant and muscle proteins contain on average 16% N, so multiplying the N concentrations by 6.25 (i.e., 100% divided by 16%) gives a value for the protein content of the experimental plant biomasses. To determine the crude fiber content, the samples were subjected to acid and base digestion before incineration.

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 nitrogen-free extract (NFE) and carbohydrate (CARB) were estimated using the formulae described by Agolisi et al. (2020).

$$NFE, \% = 100 - (\% \, moisture + \% \, fat + \% \, crude \, fibre\% + \% \, Protein + \% \, ash) \quad (1)$$

$$CARB, \% = 100 - (\% \, moisture + \% \, fat + \% \, Protein + \% \, ash) \quad (2)$$

To determine the contents of neutral detergent fiber (NDF) and acid detergent fiber (ADF), the ANKOM[3] 2000 Automated Fiber Analyzer was used, and standard procedures as described by Van Soest et al. (1991) were followed. Acid detergent lignin (ADL) was evaluated by subjecting the acid detergent fiber residue to 72% sulphuric acid. All analyses were carried out in triplicate for each sample of the collected plant biomass.

The non-structural carbohydrate (NSC) was determined according to the formula by Van Soest et al. (1991);

$$NSC, \% = 100 - (\%NDF + \%CP + \%EE + \%ASH) \quad (3)$$

The hemicellulose (HEM) and cellulose (CEL) contents were estimated as proposed by Hindrichsen et al. (2006) as follows:

$$HEM, \% = \%NDF - \%ADF \quad (4)$$

$$CEL, \% = \%ADF - \%ADL \quad (5)$$

Feed quality estimation

The feed quality was determined by estimating the dry matter intake (DMI), digestible dry matter (DDM), and relative feed value (RFV) using the following equations (Rohweder et al., 1978).

$$DMI, \% \, of \, body \, weight = \frac{120}{NDF \, (\% \, of \, DM)} \quad (6)$$

$$DDM, \% \, of \, DM = 88.9 - [ADF \, (\% \, of \, DM)] * 0.779) \quad (7)$$

$$RFV = \frac{DMI * DDM}{1.29} \quad (8)$$

Statistical analysis

All data were analyzed using the GLM procedure of Minitab Statistical Software, version 19.0 (Minitab, LLC, NY, US, 2019). The chemical compositions (DM, CP, CF, EE, NFE, ash, NDF, ADF, ADL, NSC, CEL, and HEM, DDM, DMI, and RFV) were considered as the response (variables) whilst the plant species evaluated were considered as the factors (fixed term) using the three different sampling locations as statistical replications. As discussed by Hogg and Ledolter (2011), assumptions that underpinned the ANOVA procedure were: (1) The values for nutrient levels follow a normal distribution, and (2) The variances are the same for each nutrient level. The following model was used: $Y_{ij} = \mu + N_i + e_{ij}$, where $Y_{ij=}$ observed variation, μ = population means, N_i = nutritional values in the test forages and e_{ij} = error term. Significant differences among sample means were tested using Turkey's pairwise comparison at 5% ($P < 0.05$).

Results

Analytical chemical compositions of bamboo and grass leaf samples

The results showed significant heterogeneity ($P < 0.05$) in dry matter (DM), crude protein (CP), crude fiber (CF), nitrogen-free extract (NFE), carbohydrate (CARB), ether extract (EE), and ash among the leaves assayed (Table 1). Results showed that *B. vulgaris* had the highest dry matter (DM) content (917.7 g/kgDM), while *C. purpureus* had the lowest value (790.7 g/kgDM). The highest crude protein (CP) value was reported for *B. vulgaris* (152.9 g/kgDM) and *M. maximus* had the lowest value (53.7 g/kgDM). In terms of ash content, *O. abyssinica* had the maximum value (138.8 g/kgDM), while *C. purpureus* had the minimum value (64.3 g/kgDM). *B. vulgaris* had the highest ether extract (EE) value (152.6 g/kgDM), while *M. maximus* had the lowest value (43.7 g/kgDM). *B. balcooa* had the highest nitrogen-free extract (NFE) value (246.4 g/kgDM), while *C. purpureus* had the lowest value (127.2 g/kgDM). The lowest crude fiber (CF) value was found in *B. decumbens* (285.8 g/kgDM), and the highest value was in *M. maximus* (492.4 g/kgDM). *M. maximus* had the maximum carbohydrate (CARB) content (708.5 g/kgDM), while *B. vulgaris* had the lowest value (481.7 g/kgDM).

When the nutrient compositions were pooled and compared (Figure 1), the mean values suggest that bamboo leaves were more nutrient-dense ($P < 0.05$), with mean DM (910.3 g/kgDM), CP (133.0 g/kgDM), ash (133.6 g/kgDM), and EE (137.3 g/kgDM), but lower mean CF (321.3 g/kgDM) and CARB (506.4 g/kgDM) than the grasses, which had a mean DM of 835.5 g/kgDM, CP of 75.1 g/kgDM, ash of 88.7 g/kgDM, EE of 82.0 g/kg/DM, CF of 407.4 g/kgDM, and CARB of 589.7 g/kgDM.

Detergent fiber fractions of bamboo and grass leaf samples

As summarized in Table 2, the fiber fractions of the leaves significantly varied ($P < 0.05$) in the amount of neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), non-structural carbohydrate (NSC), cellulose (CEL), and hemicellulose (HEM) with the highest NDF and ADF content (509.5 and 484.7 g/kgDM respectively), were found in the leaves of *C. purpureus* while the lowest content (468.8 and 386.1 g/kgDM respectively) were recorded in the leaves of *O. abyssinica*. The maximum HEM concentration was observed in the leaves of *B. vulgaris* (87.9 g/kgDM) and the minimum concentration was found in those of *B. decumbens* (12.1 g/kgDM). The leaves of *B. decumbens* had the lowest NSC content (365.0 g/kgDM), while *M. maximus* had the highest ($P < 0.05$) NSC content (432.7 g/kgDM). A higher ($P < 0.05$) level of CEL was recorded for *M. maximus* (440 g/kgDM), whereas *B. decumbens* leaves had the lowest ($P < 0.05$)

3 The ANKOM 2000 Automated Fiber Analyzer. Made in USA. Marketed and distributed by ANKOM Technology, Macedon NY 14502, 2052 O'Neil Road.

TABLE 1 Analytical proximate compositions of bamboo leaves and grass samples.

Plant leaf biomass	Composition (g/kgDM)						
	DM	CP	CF	NFE	CARB	EE	ASH
[a]Grasses							
C. purpureus	790.7[c]	80.0[c]	444.0[b]	12.7[c]	571.2[b]	75.3[d]	64.3[c]
M. maximus	894.7[b]	53.7[d]	492.4[a]	21.6[ab]	708.5[a]	43.7[e]	88.8[bc]
B. decumbens	821.0[b]	91.5[bc]	285.8[d]	20.3[b]	489.3[c]	127.1[bc]	113.1[ab]
[b]Bamboo leaves							
O. abyssinica	904.3[a]	142.9[a]	333.0[c]	14.7[c]	479.7[c]	142.9[ab]	138.8[a]
B. balcooa	909.0[a]	103.1[b]	311.4[c]	24.6[a]	557.8[b]	116.4[c]	131.6[a]
B. vulgaris	917.7[a]	152.9[a]	319.4[c]	16.2[c]	481.7[c]	152.6[a]	130.3[a]
SEM	0.816	0.336	0.470	0.699	0.724	0.396	0.509
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Means of each parameter along a column with different superscripts (a, b, c, d, e) differed significantly ($P < 0.05$). SEM, standard error of means.
DM, dry matter; CP, crude protein; CF, crude fiber; NFE, nitrogen-free extract; CARB, carbohydrate; EE, ether extract.
[a]Grasses, Cenchrus purpureus, Megathyrsus maximus, and Brachiaria decumbens.
[b]Bamboos, Bambusa balcooa (Beema), Oxytenanthera abyssinica (A. Rich.) Munro and *Bambusa vulgaris*.

CEL (383.2 g/kgDM). The level of ADL was highest ($P < 0.05$) in *B. decumbens* leaves (7.5 g/kgDM) and lowest ($P < 0.05$) in *O. abyssinica leaves* (0.2 g/kgDM).

Comparatively (Figure 2), the mean pools of neutral detergent fiber (NDF) and non-structural carbohydrate (NSC) were similar ($P > 0.05$) between bamboo and grasses. However, the grasses had relatively higher fiber fractions than bamboo leaves ($P < 0.05$), with mean levels of acid detergent fiber (ADF) at 461.4 g/kg DM compared to 402.7 g/kg DM for bamboo leaves, and cellulose (CEL) at 417.0 g/kg DM compared to 397.4 g/kg DM for bamboo leaves. Grasses also had lower content of hemicellulose (HEM) at 27.9 g/kgDM compared to 79.3 g/kgDM for bamboo leaves.

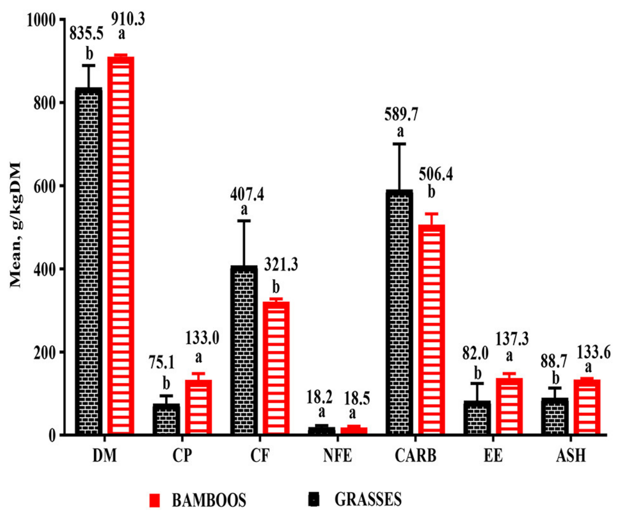

FIGURE 1
Average proximate and fiber pools for bamboo (*Bambusa balcooa* (*Beema*), *Oxytenanthera abyssinica* (*A. Rich.*) *Munro* and *Bambusa vulgaris*) and grass (*Cenchrus purpureus, Megathyrsus maximus, and Brachiaria decumbens*) leaf biomasses. Data points are mean of means ($n = 3$) ± SEM. Data bars *with similar superscripts (a, b)* are not *significantly different* ($p > 0.05$)*;* DM, dry matter; CP, crude protein; CF, crude fiber; EE, ether extract: NFE, nitrogen-free extract; CARB, carbohydrate.

Feed quality indices and grading of bamboo and grass leaf samples

Table 3 provides estimates of dry matter intake (DMI), digestible dry matter (DDM), relative feed value (RFV), and the quality scale for grading bamboo leaves and grasses. The estimates of DMI were similar ($P > 0.05$) in the leaves of *O. abyssinica* and *B. decumbens* (25.1 vs. 24.9% BW), which were slightly higher ($P < 0.05$) than the values obtained for *B. balcooa* and *B. vulgaris* (both 24.8% BW), and those obtained for *C. purpureus* and *M. maximus* (both 24.1% BW).

The DDM estimates ranged from the highest ($P < 0.05$) in the leaves of *O. abyssinica* (58.8%), which was similar ($P > 0.05$) to those of *B. vulgaris*, followed closely ($P < 0.05$) by 55.9% in both *B. balcooa* and *M. maximus*, and 53.2% in *B. decumbens*, while the least estimate of 51.1% was obtained for *C. purpureus*.

Regarding the relative feed value, the leaves of *O. abyssinica* bamboo had the highest ($P < 0.05$) feeding value among the plants tested and were nutritionally comparable ($P > 0.05$) to *B. decumbens* grass (both with an RFV of 116.7), followed ($P < 0.05$) by both *B. vulgaris* (110.3) and *B. balcooa* (106.3), which were followed closely ($P < 0.05$) by *M. maximus* (103.8). However, *C. purpureus* had the lowest ($P < 0.05$) value (93.4).

Except for *C. purpureus*, which was considered of fair quality with a score of "3" on the grading scale, all the plant biomasses were given a score of "2," indicating good quality forage.

TABLE 2 Analytical detergent fiber fractions of bamboo and grass leaf samples.

Plant leaf biomass	Composition (g/kgDM)					
	NDF	ADF	ADL	NSC	HEM	CEL
[a]Grasses						
C. purpureus	509.5[a]	484.7[a]	5.7[b]	430.9[a]	24.8[d]	427.9[a]
M. maximus	488.5[b]	441.6[bc]	1.7[c]	432.7[a]	46.9[bc]	440.0[a]
B. decumbens	470.1[c]	458.0[b]	7.5[a]	381.2[b]	12.1[d]	383.2[b]
[b]Bamboo leaves						
O. abyssinica	468.8[c]	386.1[d]	0.2[d]	392.3[b]	82.7[a]	384.4[b]
B. balcooa	490.0[b]	422.6[c]	0.5[d]	365.0[b]	67.4[ab]	422.1[a]
B. vulgaris	488.5[b]	399.3[d]	0.4[d]	382.7[b]	87.9[a]	385.6[b]
SEM	0.313	0.424	0.019	0.925	0.453	0.349
P-value	<0.001	<0.001	<0.001	0.002	<0.001	<0.001

Means of each parameter along a column with different superscripts (a, b, c, d) differed significantly ($P < 0.05$). DM, dry matter. SEM, standard error of means. NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; NSC, non-structural carbohydrate; HEM, hemicellulose; CEL, cellulose.
[a]Grasses, Cenchrus purpureus, Megathyrsus maximus, and Brachiaria decumbens.
[b]Bamboos, Bambusa balcooa (Beema), Oxytenanthera abyssinica (A. Rich.) Munro and *Bambusa vulgaris*.

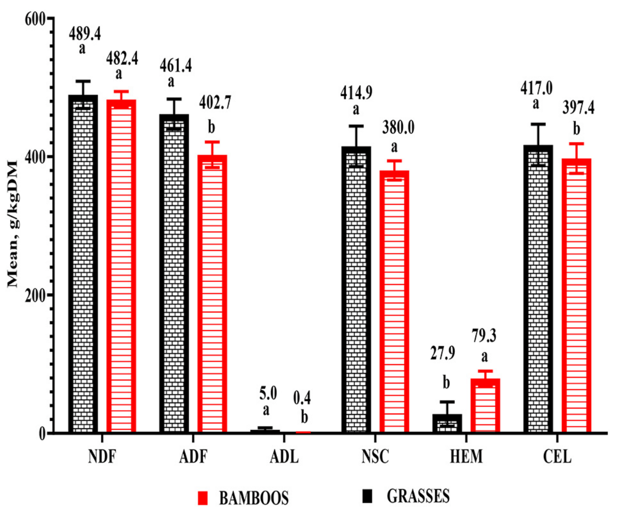

FIGURE 2
Average detergent fiber pools for the leaf biomasses of bamboo (*Bambusa balcooa (Beema), Oxytenanthera abyssinica (A. Rich.)* Munro and *Bambusa vulgaris)* and grass (*Cenchrus purpureus, Megathyrsus maximus,* and *Brachiaria decumbens*). Data points are mean of means ($n = 3$) ± SEM. Data bars *with similar superscripts (a, b)* are not *significantly different (p > 0.05);* NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; NSC, non-structural carbohydrate; HEM, hemicellulose; CEL, cellulose.

TABLE 3 Estimated forage quality indices for bamboo and grass leaf samples.

Plant leaf biomass	DMI,% BW	DDM,%	RFV	*Forage quality grading
[a]*Grasses*				
C. purpureus	24.1[c]	51.1[d]	93.4[d]	3 (fair)
M. maximus	24.1[c]	54.5[bc]	103.8[c]	2 (good)
B. decumbens	24.9[a]	53.2[c]	116.7[a]	2 (good)
Mean	*(24.4)	* (52.9)	* (104.6)	
[b]Bamboos				
O. abyssinica	25.1[a]	58.8[a]	116.7[a]	2 (good)
B. balcooa	24.8[b]	55.9[b]	106.3[bc]	2 (good)
B. vulgaris	24.8[b]	57.7[a]	110.3[b]	2 (good)
**Mean*	*(24.9)	* (57.5)	*(111.1)	
SEM	0.137	0.642	1.029	
P-value	0.123	<0.001	<0.001	

Within the column, parameters with similar superscripts (a, b, c, d) are not significantly different ($p > 0.05$). *Values in parenthesis, column mean estimates for grasses and bamboo; SEM, standard error of means; DMI, dry matter intake; DMD, digestible dry matter; RFV, relative feed value.
*Quality Grading Standard assigned by The Hay Marketing Task Force of the American Forage and Grassland Council, the RFV was assessed as roughages based on prime >151; 1 (premium) = 151–125; 2 (good) = 124–103; 3 (fair) = 102–87; 4 (poor) = 86–75; 5(reject) < 75 (Rohweder et al., 1978).
[a]Grasses, Cenchrus purpureus, Megathyrsus maximus, and Brachiaria decumbens.
[b]Bamboos, Bambusa balcooa (Beema), Oxytenanthera abyssinica (A. Rich.) Munro and *Bambusa vulgaris.*

Discussion

The nutritional composition of forages plays a critical role in ruminant nutrition, and different analytical methods are used to determine forage nutrient content. Proximate analysis, detergent fiber analysis, and relative feed quality analysis are commonly used methods for assessing the nutritional quality of forages. These analytical methods are important in evaluating the nutritional value of grasses and bamboo leaves for ruminant nutrition and can help guide dietary choices for optimal animal health and production. In this context, the results obtained from these analyses are discussed in more detail in order to highlight their importance in ruminant nutrition.

In this study, there were significant nutritional disparities between the grasses and bamboo leaves which could be linked to their different genetic makeup and the prevailing edaphic conditions during the dry season when this study was conducted. The bamboo leaves had a higher dry matter content compared to the grasses, suggesting that they are relatively more nutrient-dense. However, it is worth noting that the dry matter content of bamboo leaves was higher than what is typically found in most fresh forages. This difference could be due to the prevailing dry condition during the study period, which likely reduced the moisture content of the leaves prior to the harvesting. Thus, it is crucial to consider the impact of seasonality on the quality of bamboo leaves when evaluating their suitability for ruminant nutrition. While high dry matter content can benefit ruminant nutrition, it is essential to ensure that it does not reduce palatability or limit nutrient availability, particularly nitrogen. Hence, monitoring the quality and accessibility of bamboo leaves is necessary to ensure optimal ruminant nutrition.

More so, the mean CP levels in the grasses in the current study confirmed the mean value of 70.0 g/kgDM noted for the majority of dry season pasture grasses reported in previous studies (Nori et al., 2009; Njidda, 2010; Gadberry, 2018), even though they were lower than the 100 g/kgDM threshold that Norton (1994) and Bhandari et al. (2015) reported as being the required CP threshold in pasture fodders to initiate voluntary intake in ruminants and below which rumen functions are significantly hampered. The lower CP levels in the grasses compared to the bamboo leaves suggest that the grasses may not be able to support high levels of animal productivity during the dry season without adequate protein supplementation. On the other hand, comparable to previous studies on similar bamboo species in the same ecological zone (Sasu et al., 2022, 2023), the CP levels of the bamboo leaves were found to be consistent. This suggests that bamboo leaves could be a reliable source of fodder for ruminants across dry seasons when the quality of grasses usually decreases, and feed scarcity is eminent. Again, the reported mean CP value of the bamboo leaves was higher than that of rice straws commonly fed to ruminants during the dry season, which has been reported to have a mean value of 50 g/kgDM (Babayemi and Adebayo, 2020). The implications of these findings are significant for ruminant nutrition, as they suggest that bamboo leaves could be a promising alternative to grasses and rice straws, which are commonly fed to ruminants. Furthermore, the higher nutritional value of bamboo leaves could help to address the nutritional disparities and high cell wall constituents associated with most pasture plants, especially grasses and crop residues during the dry season. By using bamboo leaves as fodder, farmers may be able to improve the nitrogen and fiber (bulk) content of their animal feeds and reduce the impact of feed scarcity on their livestock. In plants, fiber refers to the material that gives structure to the cell wall. Dietary fiber is composed of two structural carbohydrates—cellulose and hemicellulose—and a non-carbohydrate compound called lignin. Although lignin is not a carbohydrate, it binds to the structural carbohydrates and reduces their accessibility to rumen enzymes, making them less digestible. As plants age, their lignin content increases, resulting in less digestible fiber. Generally, the high fiber content in conventional diets for ruminants is usually linked with low protein concentrations, as observed for the grasses in this study. However, fiber content plays an important role in ruminant nutrition. In order to maintain healthy rumen function, ruminants require dietary fiber and its consumption triggers chewing, saliva production and rumination, which are important for proper digestion. Saliva contains sodium bicarbonate and phosphate salts (Humphrey and Williamson, 2001) which facilitates feed ingestion, and nutrient circulation, and represent an important pH buffer for ruminants, especially for cattle fed high-concentrate diets that promote rumen acidification (Ricci et al., 2021). In the current study, both bamboo leaves and the grasses were fibrous, thus, can enhance chewing and stimulate saliva to maintain the rumen pH required to prevent metabolic disorders in ruminants fed high-grain diets. Ruminal pH considerably affects cellulose degradation (Weimer, 2022). Our data showed that compared to the grasses, the bamboo leaves had relatively lower concentrations of cellulose (a less readily digestible plant cell wall component) and a higher level of hemicellulose (a more easily digestible fiber fraction). Thus, with the right pH condition in the rumen, bamboo leaves may provide better nutrition for certain animals compared to grasses. Thus, lower concentrations of cellulose and a higher level of hemicellulose in bamboo leaves may make them more easily broken down and absorbed in the digestive system of animals, which is especially important for herbivorous animals that rely on plant material as their primary source of nutrition. In addition, it was observed that the grasses exhibited a superior lignification profile, as indicated by their high acid detergent lignin (ADL) content when compared to the bamboo leaves. Lignin poses a challenge for rumen microbes to enzymatically break down, as it interacts with polysaccharides and proteins. Therefore, the relatively lower ADL content in bamboo leaves provides an advantage for rumen microbes to efficiently digest the soluble carbohydrates.

Furthermore, the authors noted that the fiber concentrations in the bamboo leaves were higher than those reported by Sasu et al. (2022) for similar bamboo species examined during the rainy season in the same geographical area. This discrepancy can be attributed to seasonality. Nonetheless, the fiber values in the bamboo leaves were higher than the levels needed for growing or fattening ruminants (150–200 g/kgDM) and high-producing dairy cows (250–280 g/kgDM). However, the values fell below the threshold of 700–800 g/kgDM, which, according to Mertens (1994), is required in the diet to cause voluntary feed intake in mature beef cows (Bos spp.). Notably, all bamboo species examined had acid detergent fiber (ADF) contents comparable to leguminous tree forages, which are considered high-quality forages with 350 g/kgDM ADF (Moore and Undersander, 2002). This suggests that bamboo leaves can effectively meet the National Research Council [National Research Council (NRC), 2001] recommendation of 300 g/kgDM neutral detergent fiber (NDF) in cow rations, with a minimum of 210 g/kgDM NDF supplied from other quality forage sources. However, since nutrient constraints and detoxification limitations have been proposed as alternative biological explanations for the varied diets among herbivores, it is important to consider the "nutrient constraints" or "nutrient complementation" hypothesis, which suggests that no single plant species can provide all the necessary nutrients in the right proportions for herbivores, and that dietary mixing is necessary to achieve a balanced nutrient intake (Westoby, 1974, 1978; Rapport, 1980; Distel et al., 2020). In line with this, bamboo leaves are not to be fed as the sole diet for ruminants, but rather be incorporated into a mixed diet to provide optimal nutrition for ingesting animals.

Finally, in terms of forage quality and its link to animal performance, high relative feed values are crucial (Babayemi and Adebayo, 2020). The bamboo leaves appeared to have a higher mean digestible dry matter compared to their grass counterparts, estimated at 57.5% and 52.9%, respectively. However, the value was notably lower than the mean value of 68.8% estimated for similar bamboo species in the same ecological zone during the rainy season reported by Sasu et al. (2022). This nutritional variation may be due to seasonal differences, as Agrovets Consultancy (1989) noted that the nutritional content of natural range fodders is often highest at the beginning of the rainy season and rapidly declines during the dry season.

Conclusion

This study provides insights into the nutritional composition of grasses and bamboo leaves and their potential as forage sources for ruminants during the dry season, which is a common period of feed scarcity. It compares the nutrient content of these Poaceae plants using different analytical methods and highlights the importance of their fiber content in ruminant nutrition. According to the analytical procedures and nutrient estimation equations utilized in this study, it was revealed that among the grasses, *Brachiaria decumbens* exhibited relatively higher nutritional characteristics followed by *Cenchrus purpureus* and *Megathyrsus maximus*. On the other hand, among the bamboo species, the leaves of *Bambusa vulgaris* had the highest nutritional characteristics, followed by *Oxytenanthera abyssinica* and *Bambusa balcooa*. A further comparison of results points toward the conclusion that bamboo leaves have a better nutritional profile than conventional grasses. Therefore, incorporating bamboo leaves into animal diets may increase productivity, particularly during the dry season when feed scarcity is common. Additionally, it was observed that the lower cellulose and higher hemicellulose concentrations in bamboo leaves may make them more easily broken down and absorbed in the rumen compared to the grasses. Therefore, bamboo leaves could be a reliable additive in grass-based ruminant diets and the diets of other herbivorous animals.

Gap

Although the study identifies the potential benefits of bamboo leaves as a forage source for ruminants in addition to the conventional grasses already available, it does not provide data on the specific nutrients especially minerals that contribute to the higher nutritional quality of bamboo leaves compared to grasses. Additionally, the study does provide data on the effects of bamboo leaves on animal performance, such as milk or meat production, and does not evaluate the economic feasibility of using bamboo leaves as a forage source. Therefore, further research could focus on identifying the specific nutrients in bamboo leaves that contribute to their higher nutritional quality, as well as the effects of bamboo leaves on animal performance and the economic viability of using bamboo leaves as a forage source. Additionally, future research could explore the effects of the leaves of different bamboo species and cultivars on ruminant nutrition, the optimal supplementation levels for ruminants fed *in vivo* with bamboo leaves, and the effects of different processing methods, such as ensiling, haymaking, chopping, and pelleting on the nutrient composition and digestibility of bamboo leaves. Lastly, further research could investigate the potential use of bamboo leaves as a source of bioactive compounds for animal health and production.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

PS conceptualized and designed the study and drafted the manuscript. OA, BA-M, DE, MK, and DO assisted in data collection. PS, VA-K, and BA-M analyzed and interpreted results. AA-J and AO assisted in data collection, analysis, and interpreted results. RA assisted in data analysis and interpreted results. All authors reviewed the results and approved the final version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Agolisi, H. M., Abonuusum, A., and Jacob, A. (2020). Nutritional value of dried rumen digesta from cattle, sheep, and goat: a case of bolgatanga Abattoir, Ghana. *Anim. Health J.* 2, 7–15. doi: 10.47941/ahj.445

Agrovets Consultancy, A. (1989). *Livestock Study: Ghana. Preparation of the Medium-term Agricultural Development Programme.*

Ansah, T., and Issaka, A. C. (2018). *Ruminant Livestock Feed Resources in the Kumbungu District of Ghana.*

Antwi-Boasiako, C., Coffie, G. Y., and Darkwa, N. A. (2011). Proximate composition of the leaves of *Bambusa ventricosa*, *Oxytenanthera abyssinica*, and two varieties of Bambusa vulgaris. *Scientific Res. Essays* 6, 6835–6839. doi: 10.5897/SRE11.797

AOAC (1990). *Official Methods of Analysis. 15th edition. Association of Official Analytical Chemists. Arlington, Virginia.*

Armstrong, W. P. (2008). *Bamboo: Remarkable Giant Grasses (grass family: Poaceae).* Available online at: http//waynesworld.palomar.edu/ecoph39.htm (accessed February 14, 2023).

Asaolu, V. O., Odeyinka, S. M., Akinbamijo, O. O., and Sodeinde, F. G. (2009). Feed intake, nutrient digestibility, and nitrogen utilization of graded levels of moringa and bamboo leaves by West African Dwarf Goats. *Bulletin of Animal Health and Production in Africa,* 57(4). doi: 10.4314/bahpa.v57i4.51682

Awuma, K. S. (2012). "Description and diagnosis of crop–livestock systems in Ghana," in *Proceeding of Regional Workshop on Sustainable Intensification of Crop-Livestock Systems in Ghana for Increased Farm Productivity and Food/Nutrition Security*, 34.

Babayemi, O. J., and Adebayo, A. A. (2020). Assessment of the nutritive value of selectively grazed forbs by cattle in communal grazing land of Ido Local Government Area, Oyo State, Nigeria. *Nigerian J. Anim. Product.* 47, 239–253. doi: 10.51791/njap.v47i5.1264

Bhandari, M., Kaushal, R., Banik, R. L., and Tewari, S. K. (2015). Genetic evaluation of nutritional and fodder quality of different bamboo species. *Indian For.* 141, 265–274. Available online at: https://www.cabdirect.org/cabdirect/abstract/20153314756 (accessed February 14, 2023).

Distel, R. A., Arroquy, J. I., Lagrange, S., and Villalba, J. J. (2020). Designing diverse agricultural pastures for improving ruminant production systems. *Front. Sustain. Food Syst.* 4, 596869. doi: 10.3389/fsufs.2020.596869

Gadberry, S. (2018). *Beef Cattle Nutrition Series. Part 3: Nutrient requirement tables. University of Arkansas, United States Department of Agriculture and county. Cooperating Division of Agricultural Research and Extension.* Available online at: http://www.uaex.edu/Other%5FAreas/publications/PDF/FSA-3078.pdf (Accessed on February 14, 2023).

Graefe, S., Schlecht, E., and Buerkert, A. (2008). Opportunities and challenges of urban and peri-urban agriculture in Niamey, Niger. *Outlook Agricult.* 37, 47–56. doi: 10.5367/000000008783883564

Halvorson, J. J., Cassida, K. A., Turner, K. E., and Belesky, D. P. (2011). Nutritive value of bamboo as browse for livestock. *Renew. Agricult. Food Syst.* 26, 161–170. doi: 10.1017/S1742170510000566

Hayashi, Y., Shah, S., Shah, S. K., and Kumagai, H. (2005). Dairy production and nutritional status of lactating buffalo and cattle in small-scale farms in Terai, Nepal. *Livestock Res. Rural Develop.* 17, 65–74. Available online at: http://lrrd.cipav.org.co/lrrd17/7/haya17075.htm (accessed February 14, 2023).

Hindrichsen, I. K., Kreuzer, M., Madsen, J., and Knudsen, K. B. (2006). Fiber and lignin analysis in concentrate, forage, and feces: detergent versus enzymatic-chemical method. *J. Dairy Sci.* 89, 2168–2176. doi: 10.3168/jds.S0022-0302(06)72287-1

Hogg, R. V., and Ledolter, J. (2011). *Applied statistics for engineers and physical scientists*. London: Pearson Higher Ed.

Humphrey, S. P., and Williamson, R. T. (2001). A review of saliva: normal composition, flow, and function. *J. Prosthet. Dent.* 85, 162–169. doi: 10.1067/mpr.2001.113778

INBAR (2019). *Bamboo and Rattan Facts*. Available online at: http://www.inbar.int/Board.asp?Boardid=173 (accessed 14/02/2023).

INBAR (2020a). *Bamboo Resource Assessment in Five Regions of Ghana in INBAR Working Paper.* Available online at: https://www.inbar.int/wp-content/uploads/2020/12/Dec-2020_WARO_Ghana-Bamboo-Resource-Assessment.pdf. (accessed 15/02/2023).

INBAR (2020b). *Promoting Sustainable Bamboo Harvesting and Improving Incomes in Ghana*. Available online at: https://www.inbar.int/harvesting-improves-incomes-ghana/. (accessed 14/02/2023).

Mertens, D. (1994). Regulation of forage intake. *Forage Qual. Eval. Utilizat.* 11, 450–493. doi: 10.2134/1994.foragequality.c11

Moore, J. E., and Undersander, D. J. (2002). "January. Relative forage quality: an alternative to relative feed value and quality index," in *Proceedings 13th annual Florida ruminant nutrition symposium*, pp. 16–29.

National Research Council (NRC) (2001). *Nutrient Requirements of Dairy Cattle, Seventh Revised Edition 2001. National Research Council.*

Njidda, A. A. (2010). Chemical composition, fiber fraction, and anti-nutritional substances of semi-arid browse forages of North-Eastern Nigeria. *Nigerian J. Basic Appl. Sci.* 18, 2. doi: 10.4314/njbas.v18i2.64308

Nori, H., Sani, S. A., and Tuen, A. A. (2009). Chemical and physical properties of Sarawak (East Malaysia) rice straws. *Cellulose* 78, 80–7. Available online at: https://www.lrrd.cipav.org.co/lrrd21/8/nori21122.htm (accessed February 14, 2023).

Norton, B. W. (1994). "The nutritive value of tree legumes," in *Forage Tree Legumes in Tropical Agriculture*. p. 177–191. Available online at: https://www.cabdirect.org/cabdirect/abstract/19941400417 (accessed February 14, 2023).

Oppong-Anane, K. (2006). *Country Pasture/Forage Resource Profiles. Animal Production Directorate, Ministry of Food and Agriculture. Accra North, Ghana.* Available online at: koanane2000.yahoo.com.

Rapport, D. J. (1980). Optimal foraging for complementary resources. *Am. Nat.* 116, 324–346. doi: 10.1086/283631

Ricci, S., Rivera-Chacon, R., Petri, R. M., Sener-Aydemir, A., Sharma, S., Reisinger, N., et al. (2021). Supplementation with phytogenic compounds modulates salivation and salivary physico-chemical composition in cattle fed a high-concentrate diet. *Front. Physiol.* 12, 645529. doi: 10.3389/fphys.2021.645529

Rohweder, D., Barnes, R. F., and Jorgensen, N. (1978). Proposed hay grading standards based on laboratory analyses for evaluating quality. *J. Anim. Sci.* 47, 747–759. doi: 10.2527/jas1978.473747x

Rothman, J. M., Dierenfeld, E. S., Molina, D. O., Shaw, A. V., Hintz, H. F., and Pell, A. N. (2006). Nutritional chemistry of foods eaten by gorillas in Bwindi Impenetrable National Park, Uganda. *Am. J. Primatol.* 68, 675–691. doi: 10.1002/ajp.20243

Samdup, T., Udo, H. M. J., Eilers, C. H. A. M., Ibrahim, M. N. M., and Van der Zijpp, A. J. (2010). Crossbreeding and intensification of smallholder crop–cattle farming systems in Bhutan. *Livestock Sci.* 132, 126–134. doi: 10.1016/j.livsci.2010.05.014

Sasu, P., Attoh-Kotoku, V., Akorli, D. E., Adjei-Mensah, B., Tankouano, R. A., and Kwaku, M. (2023). Nutritional evaluation of the leaves of *Oxytenanthera abyssinica, Bambusa balcooa, Moringa oleifera, Terminalia catappa, Blighia sapida,* and *Mangifera indica* as non-conventional green roughages for ruminants. *J. Agricult. Food Res.* 11, 100466. doi: 10.1016/j.jafr.2022.100466

Sasu, P., Attoh-Kotoku, V., Simpah Anim-Jnr, A., Osafo, E. L., Mensah, A. B. M., Tankouano, R. A., et al. (2022). Bamboo leaves: Hope for dry season ruminant livestock production in Ghana. *Int. J. Innov. Res. Technol.* 22, 1463–8. doi: 10.5281/zenodo.6760039

Smith, T. (2010). *Some tools to combat dry season nutritional stress in ruminants under African conditions, University of Reading, Reading, UK*, pp 145–152.

Statistical Research and Information Directorate (SRID) (2014). *Agriculture in Ghana. Facts and Figures. Statistical Research and Information Directorate, Ministry of Food and Agriculture, Accra, Ghana.*

Van Soest, P. V., Robertson, J. B., and Lewis, B. (1991). Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74, 3583–3597. doi: 10.3168/jds.S0022-0302(91)78551-2

Villalba, J. J., Provenza, F. D., and Bryant, J. P. (2002). Consequences of the interaction between nutrients and plant secondary metabolites on herbivore selectivity: benefits or detriments for plants? *Oikos* 97, 282–292. doi: 10.1034/j.1600-0706.2002.970214.x

Villalba, J. J., Provenza, F. D., and GouDong, H. (2004). Experience influences diet mixing by herbivores: implications for plant biochemical diversity. *Oikos* 107, 100–109. doi: 10.1111/j.0030-1299.2004.12983.x

Weimer, P. J. (2022). Degradation of Cellulose and Hemicellulose by Ruminal Microorganisms. *Microorganisms* 10, 2345. doi: 10.3390/microorganisms10122345

Westoby, M. (1974). An analysis of diet selection by large generalist herbivores. *Am. Nat.* 108, 290–304. doi: 10.1086/282908

Westoby, M. (1978). What are the biological bases of varied diets? *Am. Nat.* 112, 627–631. doi: 10.1086/283303

Zehui, J. (2007). *Bamboo and Rattan in the World. China Forestry Publishing House. 1st Edition. Beijing, China*, 360.

Ziblim, A. I., Abdul-Rasheed, S., and Aikins, T. K. (2015). *Forage Species Used by Livestock in the Kumbungu District of the Northern Region, Ghana.*