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Forage Preference, Voluntary Intake, and In Vivo Digestibility of Six Tropical Tree Leaves by Sheep in Semi-Arid Areas in Benin Republic (West Africa)

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Citation: Gninkplékpo, E.L.R.; Koura, B.I.; Lesse, P.D.A.; Yaoïtcha, A.; Accalogoun, J.; Hornick, J.-L.; Cabaraux, J.-F.; Houinato, M.R.B. Forage Preference, Voluntary Intake, and In Vivo Digestibility of Six Tropical Tree Leaves by Sheep in Semi-Arid Areas in Benin Republic (West Africa). *Sustainability* **2024**, *16*, 2270. https://doi.org/10.3390/su16062270

Academic Editor: María Pilar González-Hernández

Received: 11 December 2023
Revised: 16 February 2024
Accepted: 22 February 2024
Published: 8 March 2024

Abstract: Livestock supplementation with forage trees is becoming a sustainable alternative to traditional grazing on the open pastures during the dry season in Benin. However, little is known about the feeding preferences of sheep and the digestibility of such native tree/shrub fodder. Such knowledge could improve their use on smallholder farms. Multiple-choice feeding preference tests were conducted on six tree fodders (*Annona senegalensis*, *Blighia sapida*, *Cassia sieberiana*, *Gmelina arborea*, *Khaya senegalensis*, and *Mangifera indica*) to determine the best choice to feed the local rams and ewe Djallonke sheep. The cafeteria test involved four rams and four ewes. In addition, an in vivo trial using metabolic cages was conducted to evaluate the voluntary intake of dried woody leaves and the dry matter digestibility of diets containing these dried leaves. Preferences varied significantly ($p \leq 0.05$) according to the woody species. Based on relative intake values, sheep preferred, in decreasing order, the leaves of *M. indica*, *B. sapida*, *K. senegalensis*, *G. arborea*, *A. senegalensis*, and *C. sieberiana*. The apparent digestibility of dry matter was highest ($p \leq 0.01$) in the *G. arborea* diet (86.8%); all diets presented a value higher than 70%. This study provided helpful information about better resource utilization to improve animal productivity. Further study could evaluate the growth performance of sheep supplemented with tree fodder.

Keywords: forage trees; nutritive value; neutral detergent fiber; productivity; sustainable

1. Introduction

A challenge in ruminant production is meeting the forage requirements for livestock, especially in the context of specific climate conditions and land use changes. In recent decades, global environmental changes have severely affected traditional pastoral strategies in sub-Saharan Africa [1–3]. These changes affected pastoralist livelihoods due to a lower financial income from decreased animal productivity [4,5] and pastoralist resilience strategies because of the impacts on feed resources [2,6–8]. Farmers adopted various coping strategies to deal with climate disturbances and anthropic pressure. These strategies vary according to their prosperity level and economic resources [9,10]. Improving traditional pastoralism systems is needed as an adaptation and mitigation strategy to be used by smallholder farmers in Benin [10]. Small ruminants are kept on small-scale farms and play an important role in the livelihood strategies of resource-poor farmers [11,12], including income generation, insurance (sale for cash to meet unexpected expenditures), economic security (sale for cash to support foreseeable expenses), social/religious functions, and prestige in ownership [13]. Sheep rearing is particularly an important activity generating income for farmers due to the animal sale value in extensive production systems in rural areas and in fattening systems around cities [13,14].

Several studies investigated using woody plant leaves as feed in small ruminant farms [15,16]. Their permanent availability over the year and their palatability increase their use [12,17–19]. It has been found that when grasses and other herbaceous forage become scarce on rangelands during the dry season, the quantitative and qualitative imbalance in ruminant rations can be corrected by using one or more woody forage species [20]. Supplementing sheep with woody leaves results in good growth performance [2,17,21,22]. The potential reducing effect on greenhouse gas emission levels by ruminants consuming woody leaves containing some tannins has been reported [23]. Therefore, well-known and used tree species like *Moringa oleifera*, *Gliricidia sepium*, *Leucaena leucocephala*, *Khaya senegalensis*, and *Afzelia africana* are over-harvested [24,25], and some of their populations are declining [26,27]. It is also possible to explore the utilization of some less-used tree fodders in small ruminants' nutrition, particularly in semi-arid areas. It is thus necessary to investigate the possibility of using native species growing easily in semi-arid areas (e.g., *Annona senegalensis* and *Cassia sieberiana*) or species that could be cultivated (e.g., *Gmelina arborea*, *Mangifera indica*, and *Khaya senegalensis*) in order to reduce the pressure on the overused woody. This investigation could include the nutritional value of the fodder trees, animal preference, and feed digestibility. Ruminant feeding preference studies are important for designing new feeding systems to optimize the use of these feed resources and sustainably manage them [20,28]. The apparent digestibility value of a feed resource or diet for ruminants reflects their rumen's predisposition to use and digest it [29]. In Benin, little is known about the feeding preferences of ruminants, particularly sheep, for most of the native tree fodders and their digestibility. However, it is important to develop strategies for effective farm utilization to cope with specific climate conditions and land degradation. Therefore, this study aimed (i) to evaluate Djallonke sheep preference for six browse species using dry matter intake and (ii) to assess the dry matter digestibility of these tree/shrub fodders.

2. Materials and Methods

2.1. Study Area

The study was conducted at the research center of Ina (CRAN-Ina) from the National Institute of Agricultural Research of Benin (INRAB) in the municipality of Bembérékè (10°13′ N and 02°40′ E) in the northeast of Benin Republic (Figure 1).

The climate is dry tropical, characterized by one rainy season (from May to October) and one dry season (from November to March). The average annual rainfall over the last thirty years was 1114 mm. April is the hottest month (39 °C on average), and November is the coldest (25 °C on average) [30]. The vegetation is a tree and shrub savannah with some gallery forests [30]. The plant species found in this area include *Isoberlina doka*, *Khaya senegalensis*, *Gardenia ternifolia*, *Terminalia avicenniodes*, *Parkia biglobosa*, *Combretum nigricans*, *Detarium microcarpum*, *Gardenia erubescens*, and *Vitellaria paradoxa*. Ruminant farming is widespread and comprises cattle, sheep, and goats. These animals are raised in extensive systems with low inputs.

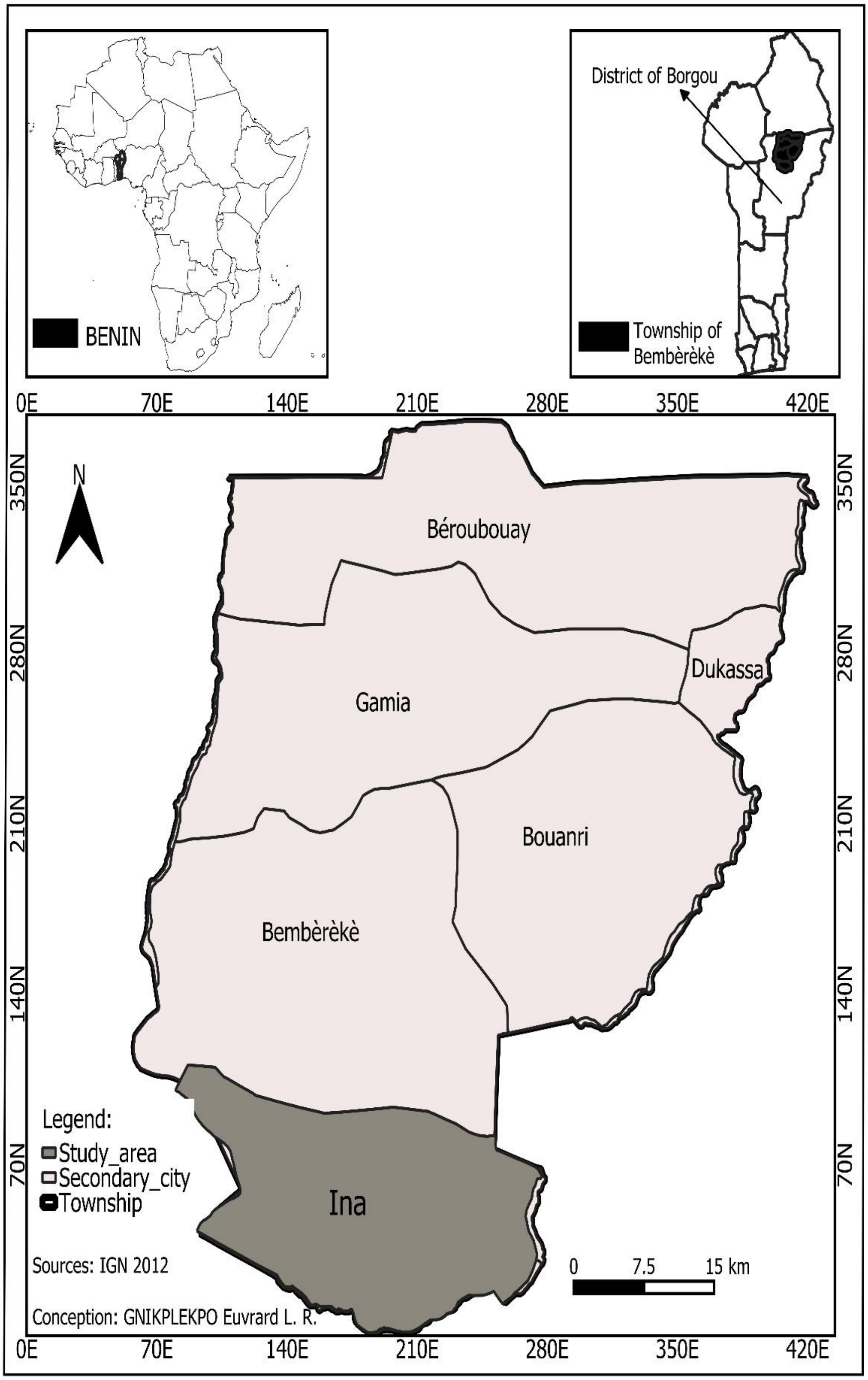

Figure 1. Map of study area.

2.2. Woody Plant Selection

The species investigated were *Annona senegalensis* (shrub, Annonaceae (AS)), *Blighia sapida* (woody species, Sapindaceae (BS)), *Cassia sieberiana* (woody species, Fabaceae (CS)), *Gmelina arborea* (woody species, Lamiacea (GA)), *Khaya senegalensis* (woody species, Meliaceae (KS)), and *Mangifera indica* (woody species, Anacardiaceae (MI)). Leaves from each tree and shrub were collected from three area exclures around Ina town. From each exclosure, leaves (about 1 kg per plant) from 15 phenologically similar (vegetative growth stage) mature plants of the respective species were collected by hand-clipping during the dry season of 2021 (between March and May). Immediately after collection, a mixture of different leaf samples was made per plant species, and a representative sample of 0.3 kg per plant species and leaves were air-dried under shade and stored in dry conditions for future analysis.

2.3. Experiment 1: Cafetaria Trial

2.3.1. Animal Management

Four mature rams and four mature ewes of similar age (2 $\pm$ 0.30 years) and weight (18.22 $\pm$ 0.78 kg) from the Djallonke breed were used. The animals were selected from the CRAN-Ina herd. They were housed in individual pens (1.5 m $\times$ 1.0 m) (Figure 2b) located next to each other in a closed, sufficiently ventilated, daylight dwelling. Three weeks before starting the trial, the animals were vaccinated against the Small Ruminant Plague. The animals were dewormed using Albenol® (albendazole), and treatment was made against external parasites using Cypertop® (cypermethrin, chlorpyrifos, and piperonyl butoxide).

(**a**) (**b**)

Figure 2. (**a**) sheep in metabolic cages; (**b**) individual pens for sheep.

2.3.2. Experimental Design

The animals were familiarized with the six dried woody plant leaves and were accustomed to eating them in six plastic feeders. The adaptation period lasted ten days, and the animals were offered simultaneously 50 g of dried leaves from each plant for 30 min in the morning. Each plant was randomly allocated to a plastic feeder during this period. Two observers were present during the adaptation period and positioned on the opposite side of the feeder row to accustom the animals to their presence. At the end of the 30-min adaptation, all leaves were removed, and the diet (*Panicum maximum* C1 hay ad libitum and maize bran (100 g)) was provided in a separate feeder positioned at the opposite side of the row of troughs. The trial lasted ten days. During this, 50 g of each browse species was provided daily at 9 am for 30 min. The location of a particular species in a trough was randomly determined each day to avoid conditioned learning (i.e., the association between feeder position and browse species), as Alonzo-Diaz et al. [31] suggested. The observation time was divided into three 10-min periods for intake measurement; the plants were thus weighed four times, at T0 and after each 10-min interval (T1, T2, and T3). Moreover, the two observers recorded the length of time a particular browse species was consumed, with two sheep observed alternating each day. The dried leaves were removed after the 30-min observation period, and a diet was offered.

2.3.3. Data Collection and Processing

The dried leaf intake (g) was calculated as the difference between the quantities offered and the remaining as measured. The dry leaf intake per visit (g) was calculated as the ratio between the total intake of a browse species and the total number of visits to this plant during the 30 min. Visits were recorded only when there was actual leaf consumption. The eating time (min) was recorded when sheep visited browse species, and actual consumption occurred. Intake rate (g/min) was calculated as the total amount of a specific browse species consumed during 30 min divided by the total time spent eating it. The relative intake (RI) was calculated according to the following formula:

$$\mathrm{RI_i} = \frac{\mathrm{qi}}{\mathrm{Q}} \times 100 \tag{1}$$

where Q is the sum of the quantities of all the woody dried leaves served (i.e., 300 g), and $\mathrm{q_i}$ is the quantity of the i type of woody.

The preference coefficient (*PC*) was calculated following the formula [32]:

$$PC = \frac{RI_i}{\sum RI_i} \tag{2}$$

where *RI* is the relative intake. Samples of each browse species, maize bran, and *Panicum maximum* C1 hay were collected daily until the end of the trial, pooled by species/feed type, ground to pass a 1-mm sieve, and stored at room temperature, awaiting chemical analysis.

2.4. Experiment 2: In Vivo Digestibility Trial

2.4.1. Experimental Design

The four woody plant leaves that were most preferred and easily cropped were selected for an in vivo digestibility trial conducted on twenty adult Djallonke sheep rams with a live weight of 16.5 ± 3.6 kg. These animals were divided into five groups of four, distributed in individual metabolic cages. Each animal group was randomly assigned to a diet. The amount of feed (g of dry matter (DM)) offered per animal was based on 4% of live weight, as suggested by Kearl [33]. The control diet (R0) comprised 70% *Panicum maximum* C1 hay and 30% maize bran. The four experimental diets were composed of 60% *Panicum maximum* C1 hay, 10% maize bran, and either 30% *B. sapida* (RBS), 30% *G. arborea* (RGA), 30% *K. senegalensis* (RKS), or 30% *M. indica* (RMI) dried leaves.

This study lasted 14 days: seven days of adaptation of the animals to the diet, and the metabolic cage (Figure 2a) and seven days of sampling. The diets were served in two steps: at 8 am and 4 pm. Each morning, the previous day's feed refusals were quantified before the first feed service of the day. Samples of feces (20% of total feces) were collected per animal. These samples were then pooled per group of animals (according to the diet and the sampling day), and a 300 g homogenized sample was collected for laboratory analysis to establish nutrient digestibility. The rams had free access to water and mineral lickstones throughout the study. Voluntary feed intake was calculated as follows:

$$\text{Nutrient ingested } (\mathrm{g \cdot d^{-1}}) = \text{Nutrient distributed } (\mathrm{g \cdot d^{-1}}) - \text{Nutrient refused } (\mathrm{g \cdot d^{-1}}) \tag{3}$$

The apparent digestibility (d_a) was calculated by balancing the nutrients ingested and excreted according to the formula:

$$d_a = \frac{\text{Ingested nutrients} - \text{Excreted nutrients}}{\text{Ingested nutrients}} \times 100 \tag{4}$$

2.4.2. Chemical Composition Analysis

Samples of dried leaves, *P. maximum* C1 hay, maize bran, and feces were chemically analyzed according to the Association of Official Analytical Procedures [34]. The samples were oven-dried for 48–72 h at 60 °C to determine the DM (AOAC procedure n° 967.03).

These samples were ground at 1 mm (Cyclotec de Tecator) for organic matter analysis (OM) (AOAC procedure n° 923.03). The contents of crude protein (CP) (AOAC procedure n° 978.04), neutral detergent fiber (NDF) (Van Soest), and acid detergent fiber (ADF) (Van Soest) were also determined. The spectrometric near-infrared method determined mineral contents (Ca, P, Mg, K, and Na).

2.5. Statistical Analysis

Descriptive statistics for means and standard deviation were calculated for the parameters. The discrimination of the woody plant leaves based on their chemical components was established using principal component analysis (PCA). The GLM procedure in SPSS 23.0 software was used to compare the DM intake during observation periods, relative intake, and preference coefficient between fodders according to animal sex for the first trial, and the DM and nutrient digestibility according to the diets for the second trial.

The model was: $Y_{ij} = \mu + T_i + E_{ij}$, where Y is the single data, μ is the mean, T is the tree leave effect (i = 6; AS, BS, CS, GA, KS, MI), the animal sex effect or the diet effect (i = 5; R0, RMI, RBS, RKS, RGA), and E is the error term. The Newman-Keuls test was used to explore the significance of differences at the 5% level.

3. Results

3.1. Chemical Composition of Dried Woody Plant Leaves

Table 1 shows the chemical composition of the various dried woody fodders studied. These dried leaves generally had a high dry matter content (85% to 92%). The neutral detergent fiber (NDF) and acid detergent fiber (ADF) varied from 410 g/kg DM in *G. arborea* leaves to 475 g/kg DM in *K. senegalensis* leaves and from 238 g/kg DM in *G. arborea* leaves to 335 g/kg DM in *B. sapida* leaves, respectively. However, the NDF value was the highest in *P. maximum* C1 hay (718 g/kg DM). The *C. sieberiana* leaves had the highest total CP (231 g/kg DM), while *M. indica* leaves presented the lowest value (83 g/kg DM). The *B. sapida* leaves had the highest Ca (35.5 g/kg DM) and Mg (4.1 g/kg DM) contents. The *C. sieberiana* leaves had the highest K (22.1 g/kg DM) and P (3.6 g/kg DM) contents. The principal component analysis bi-plot (Figure 3) showed two categories of woody resources according to their leaves' CP and mineral content. These were (i) resources rich in CP and potassium, such as *C. sieberiana* and *G. arborea* (cluster 1), and (ii) resources less rich in CP and high in calcium (cluster 2), which concerned other tree leaves studied. In addition to their high fiber contents (NDF and ADF), *P. maximum* c1 hay and maize bran, with the highest sodium and phosphorus contents, respectively, represented the third cluster. The two principal components explained about 75% of the total variation, with about 40% for PC1 and about 35% for PC2.

Table 1. Chemical composition of dried woody plant leaves.

Dried Woody Plant Leaves	DM	CP	NDF	ADF	Hem	Ca	P	K	Na	Mg
	(g/kg)					(g/kg DM)				
Annona senegalensis	860.0	85.0	450.0	277.9	172.5	18.1	1.1	9.8	0.1	3.0
Blighia sapida	890.0	98.0	506.3	334.6	171.7	35.5	1.5	12.0	0.2	4.1
Cassia sieberiana	897.0	231.0	417.8	245.4	172.4	8.7	3.6	22.1	0.2	2.2
Gmelina arborea	870.0	127.0	410.3	238.0	172.3	16.7	1.6	18.7	0.1	2.6
Khaya senegalensis	920.0	96.0	474.7	302.8	171.9	19.8	1.1	8.6	0.2	2.1
Mangifera indica	850.0	83.0	470.1	298.1	172.0	22.8	1.1	9.2	0.3	1.8
Other feed resources										
Panicum maximum C1 hay	840.0	34.0	718.3	422.0	296.3	6.3	1.5	3.7	3.1	2.9
Maize bran	660.0	128.0	650.5	620.6	29.9	0.2	8.7	10.6	---	3.2

DM: Dry Matter; CP: Crude Protein; NDF: Neutral Detergent Fiber; ADF: Acid Detergent Fiber; Hem: Hemicellulose; Ca: Calcium; P: Phosphorus; K: Potassium; Na: Sodium; Mg: Magnesium; ---: no value.

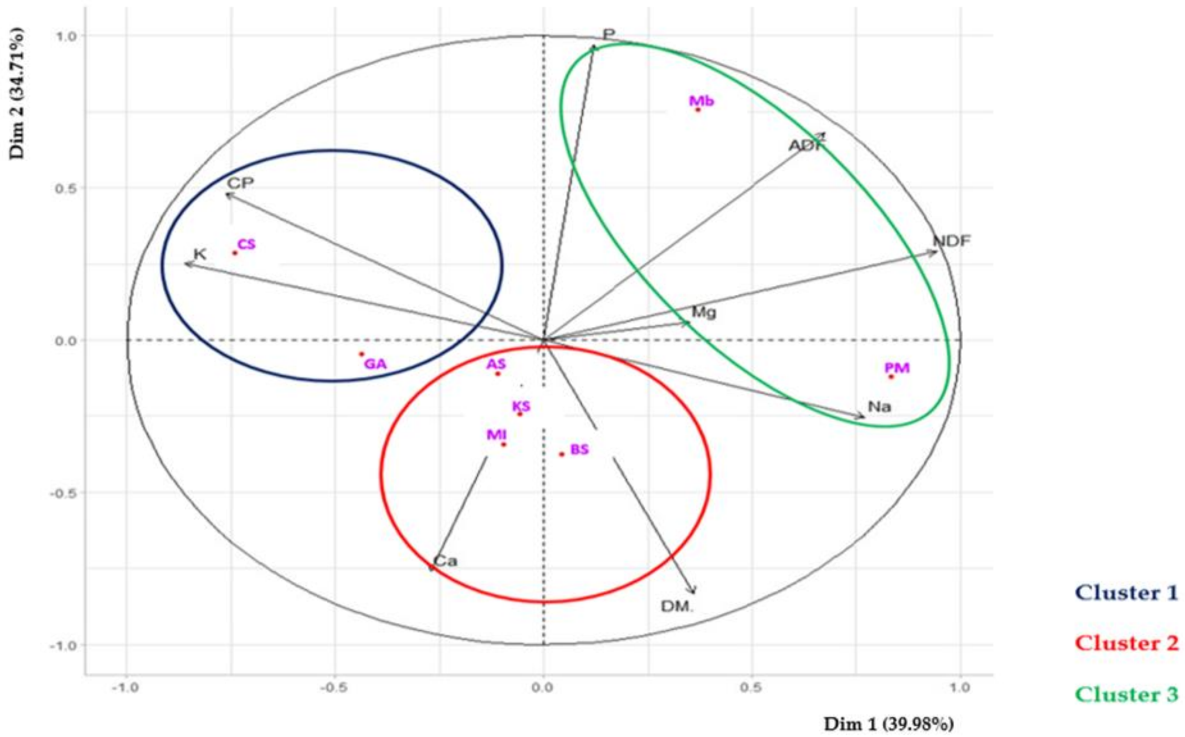

Figure 3. Chemical composition of feed resources projection on Principal Component Analysis axes. DM: Dry Matter; CP: Crude Protein; NDF: Neutral Detergent Fiber; ADF: Acid Detergent Fiber; Ca: Calcium; P: Phosphorus; K: Potassium; Na: Sodium; Mg: Magnesium; AS: *Annona senegalensis*; BS: *Blighia sapida*; CS: *Cassia sieberiana*; GA: *Gmelina arborea*; KS: *Khaya senegalensis*; MI: *Mangifera indica*; PM: *Pamicum maximum* C1 hay; Mb: Maize bran.

3.2. Dried Woody Plant Leaves Preference by Sheep

The relative intake (RI) values of dried woody plant leaves during the observation time time varied from 7% to 17% in females and 8% to 18% in males (Table 2). The highest relative intake values were found for *M. indica* leaves (17.7 and 17.3%) and the lowest for *C. sieberiana* leaves (8.1 and 7.4%) for rams and ewes, respectively. The preference coefficients (PC) of dried woody leaves followed a similar trend. The values recorded for this parameter varied from 0.01 to 0.23 in rams and ewes. Regarding real consumption time and number of visits (Table 3), differences ($p \leq 0.001$) were found for dried woody plant leaves. Irrespective of sex, sheep spent more time eating and visiting *B. sapida* than *C. sieberiana* leaves.

Table 4 shows the average dry matter intake of the dried leaves of each woody plant at 10 and 30 min, with significant variation ($p \leq 0.05$) according to animal sex and plant type. *M. indica* leaves were the most consumed by males and females during the first 10 min, with about 40 g DM, followed by *B. sapida* leaves; *C. sieberiana* leaves were the least ingested. After 30 min, the feed intake pattern was not different. The sheep consumed the same amount of *M. indica* and *B. sapida* leaves (47 g for the rams and 43 g for the ewes), followed by the same amount of *A. senegalensis*, *G. arborea*, and *K. senegalensis* leaves (36 g for the rams and 31 g for the ewes). The intakes by active consumption time (intake rate) and by visit showed significant variation according to dried woody plant leaves ($p \leq 0.001$) and the interaction ($p \leq 0.05$). The consumption per passage was higher for *M. indica* and *G. arborea* leaves for rams and for *C. sieberiana* leaves for ewes.

Table 2. Relative intake and preference coefficient of dried woody plant leaves by sheep according to sex.

Dried Woody Plant Leaves	Relative Intake (%)	Preference Coefficient
Ram		
Annona senegalensis	11.8	0.142
Blighia sapida	16.9	0.214
Cassia sieberiana	8.1	0.011
Gmelina arborea	14.4	0.171
Khaya senegalensis	13.9	0.173
Mangifera indica	17.7	0.212
Ewe		
Annona senegalensis	11.4	0.151
Blighia sapida	14.7	0.202
Cassia sieberiana	7.4	0.013
Gmelina arborea	11.9	0.163
Khaya senegalensis	11.4	0.154
Mangifera indica	17.3	0.233

Table 3. Real-time consumption and number of visits of dried woody plant leaves by sheep according to sex.

Dried Woody Plant Leaves	Real-Time Consumption (in Second/30 min)		Number of Visits (in 30 min)	
Ram	Mean ± Standard Deviation			
Annona senegalensis	164.5 ± 64.9 [ab]		5.1 ± 1.5 [b]	
Gmelina arborea	214.3 ± 82.6 [b]		5.4 ± 0.5 [b]	
Blighia sapida	353.1 ± 73.8 [a]		7.4 ± 1.1 [a]	
Cassia sieberiana	116.6 ± 81.4 [c]		3.6 ± 1.3 [d]	
Khaya senegalensis	267.9 ± 71.9 [ab]		6.1 ± 0.8 [b]	
Mangifera indica	196.3 ± 38.2 [ab]		4.1 ± 0.9 [c]	
Ewe	Mean ± Standard Deviation			
Annona senegalensis	251.6 ± 88.4 [ab]		6.4 ± 0.7 [b]	
Gmelina arborea	126.0 ± 30.3 [b]		5.8 ± 0.6 [b]	
Blighia sapida	303.2 ± 144.0 [a]		8.1 ± 2.2 [a]	
Cassia sieberiana	34.3 ± 28.4 [c]		1.8 ± 0.9 [d]	
Khaya senegalensis	199.4 ± 64.2 [ab]		6.1 ± 1.8 [b]	
Mangifera indica	240.6 ± 77 [ab]		4.3 ± 0.8 [c]	
	SEM	p	SEM	p
Tree leaves	27.03	0.001	0.42	0.001
Sex	15.60	0.242	0.24	0.808
Tree leaves × sex	38.23	0.126	0.60	0.184

[a–d:] Values with the same letter in a column mean that they are not different at a 5% level (test); SEM: Standard Error of Mean; p: Probability.

During the three successive observation time periods of 10 min, the behavior of the animals towards the woody plants differed (Figure 4). The maximum values of DM intake were recorded during the first 10 min for sheep ($p \leq 0.001$). During the second 10-min phase, almost all the woody material served was ingested. During the last 10-min phase, the woody plants less consumed during the previous phases were the most approached by the animals. So, during the third period, *C. sieberiana* leaves were the most ingested resource in ewes, while it was *A. senegalensis* leaves in rams ($p \leq 0.001$).

Table 4. Average intake values of dried woody plant leaves by sheep according to sex.

Dried Woody Plant Leaves	Intake (g DM/10 min)		Intake (g DM/30 min)		Intake Rate (g DM/TRC)		Intake (g DM/Visit)	
Ram	Mean ± Standard Deviation							
Annona senegalensis	12.9 ± 2.8 [de]		31.6 ± 8.1 [b]		0.2 ± 0.1 [abc]		6.3 ± 0.8 [c]	
Blighia sapida	28.9 ± 8.8 [b]		46.5 ± 3.4 [a]		0.1 ± 0.0 [c]		6.4 ± 1.2 [c]	
Cassia sieberiana	10.9 ± 4.8 [e]		21.9 ± 4.0 [c]		0.3 ± 0.1 [a]		6.6 ± 2.0 [b]	
Gmelina arborea	25.1 ± 6.7 [bc]		39.4 ± 3.6 [b]		0.2 ± 0.0 [ab]		7.3 ± 1.0 [bc]	
Khaya senegalensis	19.8 ± 6.9 [cd]		37.7 ± 5.5 [b]		0.2 ± 0.1 [bc]		6.3 ± 1.5 [bc]	
Mangifera indica	41.8 ± 2.7 [a]		47.8 ± 0.3 [a]		0.3 ± 0.1 [a]		12.1 ± 2.6 [a]	
Ewe	Mean ± Standard Deviation							
Annona senegalensis	16.0 ± 5.1 [de]		31.5 ± 4.9 [b]		0.1 ± 0.0 [abc]		4.9 ± 0.7 [c]	
Blighia sapida	20.6 ± 8.6 [b]		39.7 ± 10.5 [a]		0.1 ± 0.0 [c]		4.8 ± 0.3 [c]	
Cassia sieberiana	6.8 ± 1.4 [e]		20.2 ± 4.8 [c]		0.9 ± 0.7 [a]		10.4 ± 2.2 [b]	
Gmelina arborea	20.1 ± 9.2 [bc]		32.2 ± 6.4 [b]		0.3 ± 0.0 [ab]		5.6 ± 1.1 [bc]	
Khaya senegalensis	13.7 ± 1.1 [cd]		30.6 ± 6.1 [b]		0.2 ± 0.1 [bc]		5.5 ± 2.4 [bc]	
Mangifera indica	38.7 ± 7.7 [a]		46.7 ± 2.1 [a]		0.2 ± 0.1 [a]		11.3 ± 2.6 [a]	
	SEM	*p*	SEM	*p*	SEM	*p*	SEM	*p*
Tree leaves	2.2	0.001	1.98	0.001	0.076	0.001	0.63	0.001
Sex	1.3	0.031	1.15	0.019	0.044	0.086	0.51	0.434
Tree leaves × Sex	3.08	0.551	2.80	0.601	0.10	0.007	0.89	0.032

[a–e:] values with the same letter in a column mean that they are not different at a 5% level; SEM: Standard Error of Mean; *p*: Probability; DM: Dry Matter; TRC: Real Time of Consumption.

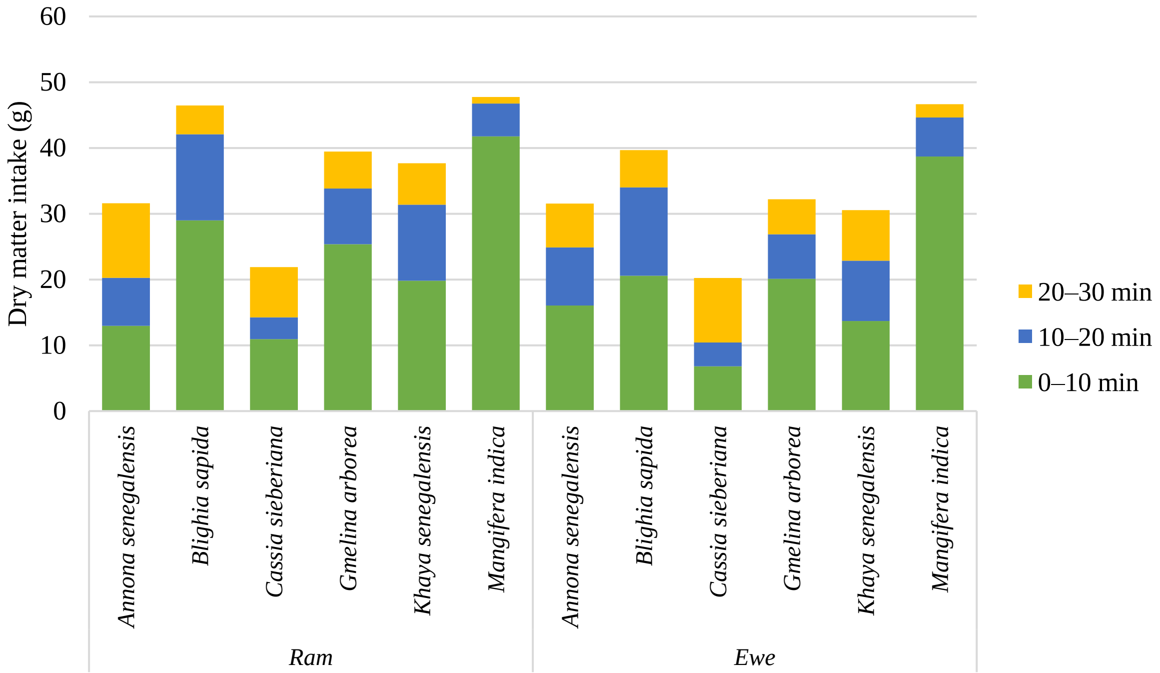

Figure 4. Dry matter intake of dried woody plant leaves by sheep according to sex across observation periods.

3.3. Voluntary Intake and Digestibility of Dry and Organic Matters of Dried Woody Plant Leaves by Sheep

Table 5 presents the intake and digestibility rates of the different studied diets in sheep. Both DM and OM intakes were higher with diets containing *K. senegalensis* et *M. indica* (708 g DM and 648 g OM) and lower with control and *G. arborea* diets (600 g DM and 525 g OM). The dry and organic matter digestibilities were significantly different: diets with *G.*

arborea diet (87% DM and 81% OM) and *B. sapida* diet (72% DM and 41% OM) at both ends, the remaining diet digestibilities, including the control diet, being intermediate.

Table 5. Voluntary intake and digestibility of dry and organic matters of diets supplemented with different dried woody plant leaves by sheep.

Diet	*Gmelina arborea*	*Blighia sapida*	*Khaya senegalensis*	*Mangifera indica*	Control	SE	*p*
Quantity of feed served (g DM)							
Woody leaves	180.6	186.6	183.2	182.4	0.0	--	--
Maize bran	130.4	130.4	130.4	130.4	173.8	--	--
Panicum maximum c1 hay	516.5	516.5	549.6	549.6	684.3	--	---
Total offered	827.5	833.5	863.2	862.4	858.1	--	--
Ingestion of diet (g)							
DM	606.6 [b]	693.4 [a]	716.1 [a]	700.8 [a]	594.5 [b]	12.1	0.001
OM	526.6 [b]	582.9 [b]	651.3 [a]	644.6 [a]	523.8 [b]	19.9	0.001
Digestibility of diet (%)							
DMd	86.8 [a]	72.3 [b]	81.7 [ab]	75.6 [ab]	73.1 [ab]	0.01	0.011
OMd	81.4 [a]	41.1 [b]	67.7 [ab]	58.3 [ab]	71.6 [ab]	0.02	0.017

[a,b]: values with the same letter in a line mean that they are not different at a 5%.

4. Discussion

4.1. Chemical Composition of Woody Plant Leaves

There is a diversity of local trees and shrubs, even at the mature plant stage, with higher protein and lower NDF and ADF contents than tropical grasses [35]. The studied woody plant leaves showed variation in nutritional values. The high DM content was because the samples were collected during the dry season, when there was less water in the leaves, and dried before being sent to the laboratory for analysis. However, several studies have reported good (more than 70%) DM content values for woody plant leaves on some browse leaves in Benin and Nigeria [25,36]. Regarding CP content, the levels were very variable from one leave to another but were for all higher than 8% DM, with 12% DM as the mean, near to the values obtained by Imorou et al. in North-East Benin [25], but lower than the average value of 15% reported by Koura et al. in subhumid zones of Benin [3]. The quantities of nutrients in the tree leaves vary according to the season [23], the various treatments the leaves may undergo [37], age at harvest [38], and types of soil [39]. The *C. sieberiana* leaves of the Fabaceae family had the highest CP content, followed by that of *G. arborea*; they also had lower levels of parietal structures (NDF, ADF, and hemicellulose). These characteristics are desirable from a nutritional point of view and make them a good feed that can be valorized in sheep farms [40]. Leaves of *M. indica*, *K. senegalensis*, *B. sapida*, and *A. senegalensis* have less interesting levels of CP and parietal constituents than *C. sieberiana* and *G. arborea* leaves, but their interest lies in their high calcium content, an essential nutrient involved in many valuable metabolic functions, particularly ruminal [41,42].

4.2. Preference of Dried Woody Plant Leaves by Sheep

In tropical regions, forage trees and shrubs are a major source of energy, protein, vitamins, and minerals for ruminant livestock during the dry seasons [20,23,25,43,44]. These kinds of woody plants in arid and semi-arid areas regenerate very fast during the rainy seasons, resulting in heavy vegetative masses, while during the lean (dry) period, the palatable vegetation, especially the grasses, deteriorates both in quality (low protein content) and quantity (low herbage biomass) [45,46]. Preference is positively related to palatability; it is the relationship between the feed's traits and animal post-ingestive feedback [20,47,48]. So, sheep with previous experience with *M. indica*, *B. sapida*, *G. arborea*, *K. senegalensis*, and *A. senegalensis* leaves could explain their strong preference for those resources. Animals used in the trial were purchased in an area where mango leaves are available. These animals had already been exposed to these resources and thus learned to consume them. In rural areas, browse species have a major role in the feeding of animals and alternative commendable typical uses [49]. In addition, the moderate CP content coupled with the low NDF and ADF contents in these leaves could favor this result [40]. Relative acceptance of browse leaves despite having traces of tannin was reported by some authors [40,50,51]. Tannins in tree fodder modify microbial fermentation in the rumen and lower the methane emission levels of ruminants [52]. The voluntary intake of a plant with a high tannin concentration could be attributed to the natural tendency of proline-rich protein in ruminants' saliva to attenuate tannin's negative effects [53]. On the other hand, some authors reported that the presence of calcium hydroxide in feed could be useful for enhancing shrub intake through decreased absorption and/or increased elimination of secondary compounds [41] and could be used as a nutritional strategy to improve growth rate and ruminal fermentation in fattening lambs [42]. Tree fodders are also known to be used in small ruminant farms to treat various diseases, more specifically gastrointestinal disorders [54–56]. The low consumption of *C. sieberiana* leaves was probably due to its organoleptic characteristics (bitter taste) and animal taste experience. In a similar study of woody leaf preference by Djallonke sheep in Nigeria, *C. sieberiana* leaves were also less appreciated [57]. The low number of visits by sheep to feeders containing *M. indica* leaves and their consumed quantity reinforce the idea that sheep are constantly interested in this resource, whereas the same indicator trend observed for *C. sieberiana* leaves reflects a lack of interest from sheep. Sheep depend on forage as their primary feed source; in the dry season, the forage supply falls, and the one available is fibrous and low in protein [17,58]. Unless the diet can be ameliorated, growth rate and lactation will decline, and in extreme cases, mortality, including in adults, will also increase, resulting in an immediate loss of income [58]. Indeed, Zanou et al. have shown that the market value of sheep is linked to their stoutness, which also represents a consumer choice criterion [14].

The intake measurements for the feed preference study were divided into three consecutive 10-min intervals to assess the behavior of the animals under different conditions. The first 10-min measurement was used to compare the preference between the different woody forage leaves served in equal amounts. The following 10-min periods express less animal preference because unequal amounts of woody forage were available in the feeders. Thus, the behavior of the animals changed according to the availability of feed resources and the needs of the animals [17]. It could be seen in the increase in the intake level of *C. sieberiana* leaves during the last two 10-min phases, whereas the animals ingested less of this resource during the first 10 min. The results of this study allowed us to classify according to the gradient ($p \leq 0.001$): less preferred as *C. sieberiana* leaves; preferred leaves like *K. senegalensis*, *G. arborea*, and *A. Senegalensis*; and highly preferred as *M. indica* and *B. sapida* leaves. The depletion of the served amount of *M. indica* and *B. sapida* leaves due to their heavy ingestion in the first 10 min probably induced the consumption of the other woody leaves for the rest of the observation time. Without the first choice of feed resources, the sheep had to content themselves with what was still available or, even better, with what would fulfill a specific need. The cumulative consumption curve illustrated this situation regarding the increase in the amount of *C. sieberiana* leaves consumed between the second and third observation periods. It gives an idea of the prioritization of woody leaves regarding main and alternative feed resources for sheep. Improving the palatability of *C. sieberiana* leaves by combining them with other fodder resources that are more palatable could facilitate their optimal use. The *K. senegalensis* leaves are a resource traditionally known to ruminant breeders. The increased use of this plant in recent years by ruminant farmers and for other purposes (firewood, carpentry, herbal medicine) has made it a vulnerable plant [59]. Maintaining this resource in the feeding strategy of small ruminants requires finding solutions for the promotion of its cultivation and the conservation of plants still present in the area.

4.3. In Vivo Digestibility

Although the animals receiving the control diet had a rather low feed intake, the diet's DM and OM digestibilities did not vary significantly compared to the other diets. However, some authors showed that *K. senegalensis* has a very low feed value due to the low digestibility of the organic matter and its composition of anti-nutritional elements, particularly tannin [60,61]. Indeed, under in vitro conditions, the amount of tannin influences digestibility in a diet; tannin acts on ruminal degradation microbes above a threshold [62]. Tannins found in some woody leaves form a complex with plant proteins that decreases their rate of digestion in the rumen, thereby decreasing rumen ammonia emissions [15]. On the other hand, feeding West African dwarf sheep with *P. maximum* supplemented with *G. arborea* leaves offers potential results in supplying fermentable nutrients needed to enhance a favorable rumen environment for effective microbial activities without any adverse effect on the rumen parameters status of the animals [63]. Introducing *G. arborea* leaves into small ruminant diets improved protein digestibility [64]. Moreover, *M. indica* leaves can be used in lambs' rations at a rate of 6% without any harmful effects [65], and *B. sapida* leaves are easily consumed by goats and have a high digestibility of DM and CP [66]. A study on browse leavf digestibility showed that nitrogen retention was positive for some browse species [67].

Briefly, depending on the species, tree woody foliage may be of lower nutritive value as a sole feed than as a supplement to other feeds, and the significance of anti-nutritive factors becomes more evident when woody foliage is the only feed consumed. In the present trial, the diets supplemented with dried woody leaves all had a DM digestibility above 70% and proved that they could be substituted for each other; the best results were obtained with *G. arborea*. So woody leaves had a great interest in small ruminants feeding, from the viewpoint of supplementing grass, which is hardly scarce in the dry season, particularly in semi-arid areas.

5. Conclusions

This study evaluated the feeding behavior of sheep for six dried woody plant leaves and the digestibility of diets containing these leaves. It was found that the different leaves studied had variable contents of different nutrients (crude protein and fibers), which could affect their valuation by animals. The Djallonke sheep preferred the leaves of *M. indica*, *B. sapida*, and *G. arborea* in priority, followed by *K. senegalensis* and *A. senegalensis leaves* in second, and lastly, *C. sieberiana* leaves. Except for *B. sapida* and *C. sieberiana*, which are less cultivated, techniques for growing other forage trees are well mastered in Benin. The digestibility of dry matter in all diets supplemented with woody leaves did not significantly differ from the control diet. Because of the increased pressure on certain feed resources, such as *K. senegalensis* leaves, this study proposes alternatives such as *M. indica* leaves, *B. sapida* leaves, or *G. arborea* leaves in small ruminant feeds to make up for the protein deficit in diets, especially in the dry season. This study was a step towards a better understanding of sheep behavior toward these woody leaves. It provided information to facilitate farmers' choice of woody leaves in sheep feed supplementation and thus increase farm productivity. This study suggested further investigations, such as evaluating the growth performance of animals fed rations containing these woody leaves. It encouraged further reflection and action to promote agroforestry and forage crops as sustainable feed resources for ruminant livestock.

Author Contributions: Conceptualization, methodology, software, E.L.R.G., B.I.K., P.D.A.L., J.-F.C. and M.R.B.H.; data collection, E.L.R.G., J.A. and A.Y.; writing original manuscript, E.L.R.G. and B.I.K.; manuscript review, A.Y., P.D.A.L., J.-L.H., J.-F.C. and M.R.B.H.; funding acquisition and project administration, J.-F.C. and M.R.B.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Kingdom of Belgium through the "Academy for Research and Higher Education" through the Project "Improvement of traditional small ruminant (sheep and goat) farming systems in a context of environmental and societal change in Benin".

Institutional Review Board Statement: Institutional Review Board Statement: This research was in compliance with the guidelines and animal experimentation protocol of the Committee of Animal Production and Biotechnology, Doctoral School of Agricultural and Water Sciences, University of Abomey-Calavi, Abomey-Calavi, Benin. Approval code n°0013-2021/UAC/EDSAE/D/DA/SA of 14 February 2021.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available upon request from the authors.

Acknowledgments: The authors would like to thank the Research for Development Project collaborators.

Conflicts of Interest: The authors declare no conflicts of interest.

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