ACTA AGRICULTURAE SCANDINAVICA, SECTION A — ANIMAL SCIENCE
https://doi.org/10.1080/09064702.2021.1919193

Taylor & Francis
Taylor & Francis Group

Check for updates

Evaluation of chemical composition and *in vitro* digestibility of stovers of different pearl millet varieties and their effect on the performance of sheep in the West African Sahel

Clarisse Umutoni[a], Vincent Bado[a], Anthony Whitbread[b], Augustine Ayantunde[c] and Prakash Gangashetty[a]

[a]The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Niamey, Niger; [b]The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), C/O- IITA East Africa Hub, Dar es Salaam, Tanzania; [c]International Livestock Research Institute (ILRI), Ouagadougou, Burkina Faso

ABSTRACT

The objective of this study was to assess the chemical composition and *in vitro* digestibility of residues of five pearl millet varieties and to investigate their effect on the performance of sheep. Thirty castrated male Bali-Bali sheep were randomly assigned to five treatments. Four dual-purpose millet varieties and one local variety-Somno were used. Sheep were fed *ad libitum* for 90 days with the stover of five millet varieties, complemented with cowpea hay. Stover of varieties ICMV167005 and ICMV167002 showed a tendency for a higher nitrogen content (1.0%) and in vitro digestibility (51.3% and 51.8%, respectively) compared to stover of other varieties. Significant differences were observed in average daily live weight gain. The animals fed with stover of the variety ICMV167005 in their diet had higher average daily live weight gain compared with others. We conclude that ICMV167005 is a promising variety for improving the productive performance of sheep.

ARTICLE HISTORY
Received 12 November 2020
Accepted 15 April 2021

KEYWORDS
Crop residues; dual-purpose millet; feed; growth performance; sheep; West African Sahel

Introduction

Pearl millet (*Pennisetum glaucum* (L.) R.Br.) is an important cereal for smallholder farmers in the West African Sahel, particularly in Niger. Pearl millets are drought tolerant, resilient to the extreme climatic and soil conditions, and are grown under extreme environmental conditions, which are poorly suited to the major crops of the world.

Millet grain is mainly consumed as food (78%), converted into drinks, or used for other purposes (20%) (Obilana, 2003). In addition to the use of millet grain in the human diet, millet stover is used as a basal diet for livestock such as small ruminants, especially during the dry season, when feed scarcity in the drylands of the Sahel worsens. Given its double benefit and the excellent tolerance to low rainfall, pearl millet is an option in the diet of ruminant in dry land where other sources of feed cannot develop well. Increasing quality-feed production for small farmers involved in agriculture and livestock requires more research for developing dual-purpose varieties with a double benefit: as food for humans and as fodder for livestock.

However, pearl millet breeding research programs are mostly focused on high grain and stover production, disease resistance, and water stress tolerance (Mason et al., 2015; Gangashetty et al., 2016; Debieu et al., 2018), while less attention has been paid to stover quality. Except for stover digestibility, other fodder quality traits, such as nitrogen (N) and energy contents, are generally ignored as selection criteria in millet breeding programs in West Africa.

For instance, some dual-purpose pearl millet varieties, with an in vitro digestibility of up to 51%, stay-green traits, and high grain yield, have been developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in collaboration with the International Livestock Research Institute (ILRI) and some of the national agricultural research institutions in the Sahel. However, very few studies (Bidinger & Blümmel, 2007; Blümmel et al., 2007, 2020) have been conducted to assess the nutritional value of these varieties as fodder for animals in vivo. For example, Blümmel et al. (2007) found Nitrogen concentration of 0.77–0.84%, 0.77–0.88% and 0.74–0.90% in stover of local landrace, dual-purpose and hybrid pearl millet varieties, respectively. The digestibility of various genotype tested by Blümmel et al. (2007) varied between 39 and 42%. Other study showed 0.46–0.77% N for millet stover (Nantoumé et al., 2000).

Most feeding trials in West African countries focus on protein-rich supplements, such as groundnut haulms or

CONTACT Clarisse Umutoni c.umutoni@cgiar.org
© 2021 Informa UK Limited, trading as Taylor & Francis Group

cowpea hay-based feed rations, comparing several cultivars in this regard (Savadogo et al., 2000; Ayantunde et al., 2008; Etela & Dung, 2011; Ansah et al., 2017). However, millet stover seems to be an important feed resource in the crop-livestock system, as it can support livestock production during critical periods of feed shortage, with some improved cultivars capable of out-performing local cultivars (Blümmel et al., 2007).

The available literature suggests that the nutrient composition of millet and other cereal stovers and their effect on livestock might be influenced by varietal differences (Blümmel et al., 2007, 2020). Nevertheless, little reliable information (Hiernaux & Ayantunde, 2004; Fernandez-Rivera et al., 2005; Abdou et al., 2011) is available on millet stover as animal feed in Niger. Hiernaux & Ayantunde (2004) and Fernandez-Rivera et al. (2005) revealed that a daily supplement of 300–600 g cowpea hay along with millet straw fattened sheep most profitably. However, variety of stover that provides optimal gain must be investigated. This provides justification for the current study with the hypothesis that millet nutrient composition and production performance of young sheep fed with stover of different variety of millet would differ. The objectives of this study were as follows: (i) Determine the chemical composition and in vitro digestibility of stover of four dual-purpose pearl millet varieties, compared to the local landrace; (ii) Evaluate the effect of stover of different pearl millet varieties on the feed intake and productive performance of young sheep

Materials and methods

Description of the study area

The feeding experiment was conducted with sheep at the ICRISAT research station at Sadoré (13° 14′ N, 2° 16′ E), Niger. Sadoré has a unimodal rainfall pattern beginning in late June and ending in early October. The dry season then extends from November to late May, with a period of warm dry conditions from March through May. The mean annual rainfall is 562 mm, and temperatures generally fluctuate between 12°C and 44°C, with a mean temperature of 29.4°C.

Animals and experimental design

The experiment was conducted during the dry season (January to April 2019) for 76 days, which were preceded by a 14 days period of adjustment to the environment, management and diets (90 days in total). Thirty castrated male Bali-Bali sheep aged between 18 and 24 months, with an average initial live weight of 27.1 ± 0.35 kg ($P > 0.05$) were used. The animals were bought locally at the livestock market and housed indoors in individual cages for the entire duration of the experiment. Animals were randomly assigned to five treatments (T0 = stover of local variety + cowpea hay; T1 = stover of Chakti + cowpea hay; T2 = stover of ICMV167005 +cowpea hay, T3 = stover of ICMV167006 +cowpea hay; T4 = stover of ICMV167002 +cowpea hay), with six replications per treatment (i.e. six sheep per treatment). All animals were vaccinated against three common small ruminant diseases in the study area, namely, Pasteurellosis, small ruminant plague, and sheep and goat pox (SGP). Animals were also de-wormed using Albendazole 300 and Ivermectine. In addition, animals received multivitamins (5 ml/sheep). Sheep were ear-tagged and randomly allotted to the dietary treatments.

Feeds and feeding

Animals were fed with stover residues from pearl millet together with cowpea hay. The stover residues were from four improved dual-purpose millet varieties (Chakti, ICMV167005, ICMV167006, ICMV167002), developed by ICRISAT for the semi-arid agro-ecological zone and released in Niger between the years 2017 and 2018, and the local landrace (Somno), commonly cultivated by farmers. Cowpea hay were from an improved variety of cowpea (TN578), which was provided alongside the millet varieties stover to complement the diet. The list of millet varieties and their main characteristics is shown in Table 1. The four improved dual-purpose varieties are characterized by higher grain yield potential (1.5–2.0 t/ha) than the local variety (1.0 t/ha) and a higher potential for stover production (Pasternak et al., 2012; ICRISAT, 2018). The cowpea variety typically shows a lifecycle of 75 days and the grain and fodder potential yields are 1.5 and 3t/ha, respectively (Baoua et al., 2013).

Stover residues were manually cut with a machete into ∼5 cm pieces to increase intake (Owen, 1994; Abdou et al., 2011) and offered to the sheep *ad libitum* (about 200% of the fresh intake of the previous day). Cowpea hay was offered separately in the afternoon (∼13:00 h) as a supplement. All animals received the same amount of cowpea hay (600 g/animal/day_ fresh weight), which was all completely consumed; thus, no refusal of cowpea hay was recorded throughout the experiment. The amount of cowpea hay offered was fixed based on the study conducted by Hiernaux and Ayantunde (2004), Fernandez-Rivera et al. (2005) and Abdou et al. (2011). Clean drinking water and mineral licks (Intromin block) were provided *ad libitum* to each animal throughout the duration of the experiment.

Table 1. Agrophysiological, chemical composition and in vitro organic matter digestibility of pearl millet stover and cowpea hay offered to sheep during feeding experiment conducted at Sadoré.

Parameter		Pearl millet variety					
		Somno	Chakti	ICMV167005	ICMV167006	ICMV167002	Cowpea
Life cycle (days)		90–120	50–65	80–90	80–85	80–85	75
Potential grain yield (t/ha)		1.0	1.5	2.0	1.5	1.5	1.5
Potential residue yield (t/ha)		3.5	5.0	5.0	6.0	6.0	3
Stover	DM (g/kg)	932	931	925	926	926	907
	Ash (g/kg DM)	82	65	84	113	88	79
	N (g/kg DM)	9	8	10	7	10	23
	NDF (g/kg DM)	738	757	688	667	676	469
	ADF (g/kg DM)	441	463	421	464	409	332
	ADL (g/kg DM)	43	47	46	53	38	63
	ME (MJ/kg DM)	7.4	7.3	7.6	7.1	7.7	8.94
	IVOMD (g/kg DM)	500	490	513	481	518	612
Stems	DM (g/kg)	932	927	915	929	922	–
	Ash (g/kg DM)	61	61	72	59	68	–
	N (g/kg DM)	5	6	7	3	6	–
	NDF (g/kg DM)	777	741	678	754	703	–
	ADF (g/kg DM)	499	477	415	504	442	–
	ADL (g/kg DM)	66	65	49	68	52	
	ME (MJ/kg DM)	6.9	6.8	7.6	6.7	7.6	–
	IVOMD (g/kg DM)	451	455	501	435	492	–
Leaves	DM (g/kg)	933	934	924	931	929	–
	Ash (g/kg DM)	84	66	132	112	99	–
	N (g/kg DM)	10	7	14	5	9	–
	NDF (g/kg DM)	740	769	598	730	687	–
	ADF (g/kg DM)	433	464	381	489	416	–
	ADL (g/kg DM)	39	44	35	42	35	–
	ME (MJ/kg DM)	7.5	7.4	7.9	7.2	7.4	–
	IVOMD (g/kg DM)	506	497	548	490	510	–

Notes: Somno is the local variety. ADF, acid detergent fiber; ADL, acid detergent lignin; N, nitrogen; DM, dry matter; IVOMD, in vitro organic matter digestibility; ME, metabolizable energy; NDF, neutral detergent fiber

Data collection and sampling

Sheep were adapted to the environment and the feeding management for 14 days before the start of data collection. The body weight changes of sheep in response to the experimental treatments were measured by taking the body weight of individual sheep at the beginning of the trial. This was then followed by individual weighing on a biweekly basis for three consecutive days until the end of the experiment. The final weight was recorded on the last day of the experiment. The weight measurements were performed in the morning before daily feeding.

Pearl millet stover and fecal data were collected during two periods of seven days each. The first period occurred after two weeks of adjustment to the feed and the second at the 8th week of the experiment.

For fecal data collection, each sheep was fitted with a fecal collection bag three days before each collection period. During the data collection period, the bags were removed two times per day, in the morning at 07:00 h and again in the evening at 17:00 h to collect and weigh fresh feces in order to determine fecal output. A composite sample of 100 g per sheep of fecal material was collected per day and air-dried for seven days to estimate the quantity of dry feces. At the end of the experiment, daily dried fecal samples from each sheep were pooled together and ground through 1 mm screen for chemical analysis.

To determine the intake of stover, the amounts of stover supplied and refused were recorded daily. Pearl millet stover offered to each sheep was weighed every morning at 08:00 h. The amount of leaves and stems offered were also recorded separately. Stover leftovers from the previous day were also measured every morning to determine voluntary intake. Moreover, millet stover leftovers were divided into leaf and stem refusal and weighed separately to enable the calculation of consumed leaves and stems. It is important to highlight that the components were still easily identified and separable. Stover offered was sampled every morning and stover samples were pooled together for each treatment. Two samples (leaf and stem) of stover offered were collected during each seven-day data collection period. All stover samples were ground through 1 mm screen for laboratory analysis.

Laboratory analysis

Feed samples were analyzed using near-infrared reflectance spectroscopy (NIRS) (Shenk & Westerhaus, 1991; Corson et al., 1999; Bidinger & Blümmel, 2007) for dry matter (DM) content, ash content, organic matter (OM) content, total N content, fiber components (neutral detergent fiber, NDF; acid detergent fiber, ADF; and acid detergent lignin, ADL), metabolizable energy (ME), and in vitro organic matter digestibility (IVOMD). Crude protein (CP) was estimated from N content (N × 6.25). Fecal samples were analyzed for DM, C, N and P.

Statistical analysis

Data analysis was performed using Genstat 19 software. Differences in feed and nutrient intake, weight gain, and fecal output were analyzed using the general linear model procedure for variance analysis. The average daily gain was estimated by performing a regression analysis of individual live weight data over time. Treatment effects were tested through analysis of variance (ANOVA). The Bonferroni tests were used to compare treatment means. Unless otherwise specified, the level of significance was set at $P < 0.05$.

Correlation analysis was used to evaluate the strength of the relationship between different variables while simple linear regression model was used to estimate the relationship between one independent variable and one dependent variable using a straight line.

Calculation

Voluntary feed intake was determined as the difference between the feed offered and leftovers. The variability in the results recorded for measured variables (weight gain, fecal output, concentration of nutrient in feces) was a result attributed to the variability in stover among the different pearl millet varieties, as all animals received the same amount of cowpea hay every day, which was completely consumed; thus, this part of the daily feed ration (cowpea hay) was considered as invariable.

Results

Chemical composition and in vitro organic matter digestibility of stover and stover fraction of dual-purpose millet varieties

The concentration of ash, N, NDF, ADF, ME, and IVOMD differed among the five varieties under study (Table 1). There was a tendency of a higher concentration of N in stover of ICMV167005 and ICMV167002 compared to stover of other varieties. The stover of Chakti showed a tendency of higher values for NDF and ADF. ME ranged from 7.1 to 7.7 MJ/kg DM while IVOMD value ranged from 490 to 518 g/kg DM. The leaves and stems of ICMV167005 showed a tendency of higher ash, N, ME, and IVOMD contents, but lower NDF and ADF contents. In contrast, the leaves of Chakti showed a tendency of higher NDF and ADL contents, while the tendency of lower N content was found in the leaves of ICMV167006.

Feed and nutrient intake

Overall feed intake varied from 1010 to 1066 g/day/animal. The intake of millet stover by sheep varied among varieties from 410 to 466 g/day/animal; and there were no significant differences in stover intake among varieties (Table 2). However, leaf and stem intake was variety-dependent ($P < 0.05$). Approximately 80% to 86% of the leaves fraction of pearl millet was consistently eaten by animals. The highest stem intake (19% and 22%) was observed for ICMV167005 and ICMV167006, respectively. A negative linear relation was observed between leaf and stem intake ($R^2 = 40.1$; $P < 0.05$).

Stover-N intake ranged from 2.8 to 4.1 g/sheep/day, with the highest N intake recorded among sheep fed with stover from Somno, ICMV167005 and ICMV002 (Table 2). Sheep fed with stover from ICMV167006 and Chakti showed the lowest stover-N intake. The NDF intake did not vary significantly among sheep fed with stover of different pearl millet varieties. Sheep fed with the stover of ICMV167006 showed higher ADF intake.

Fecal output and carbon, nitrogen and phosphorus concentration in feces

Fresh fecal output ranged from 0.9 to 1.2 kg/day/animal with significant differences ($P < 0.05$) among varieties (Table 3). The highest fecal outputs per day per animal were obtained with ICMV167006 and ICMV167005, while the lowest was obtained with ICMV167002. In contrast, there were no significant differences among varieties for dry fecal output. The concentration of carbon in feces ranged from 481 to 512 g/kg DM, with the highest concentration found in feces of sheep fed with stover of Chakti. The concentration of N in feces ranged from 19 to 21 g/kg DM, whereas that of P ranged from 4 to 7 g/kg DM (Table 3). Sheep fed with stover of local landrace Somno and Chakti showed the highest N content in feces, compared to the other varieties. The lowest N content in feces was obtained with ICMV167006 and ICMV167002. Sheep fed with ICMV167002 showed the highest P content in feces.

There was a linear trend ($P = 0.09$) between pearl millet stover-intake and fecal N excretion. Fecal N excretion tended to be positively correlated to stem

Table 2. Feed intake and nutrient intake by sheep fed with the stover of the local and four dual-purpose millet varieties and cowpea hay.

Parameter	Variety						Cowpea hay
	Somno	Chakti	ICMV 167005	ICMV 167006	ICMV 167002	P value	TN578
Proportion of stover fraction Intake (%)							
Leaves	83^a	86^a	85^a	80^a	84^a	0.357	–
Stems	12^a	10^a	19^b	22^b	14^a	<0.001	–
Intake of stover/straw as-fed basis (g/sheep/day)							
Leaves	374 ± 10^a	338 ± 10^a	304 ± 50^b	282 ± 70^c	374 ± 50^d	<0.001	–
Stems	78 ± 20^a	72 ± 80^a	146 ± 17^b	172 ± 15^b	93 ± 12^a	<0.001	–
Total intake	452 ± 16^a	410 ± 17^a	450 ± 19^a	454 ± 17^a	466 ± 11^a	0.162	600
Total feed intake as-fed basis (stover + cowpea hay)	1052 ± 16^a	1011 ± 17^a	1050 ± 19	1054 ± 17^a	1066 ± 11^a	0.177	–
Nutrient intake from pearl millet stover and cowpea hay_ dry matter basis (g/sheep/day)							
DM	424 ± 14^a	385 ± 14^a	417 ± 17^a	429 ± 11^a	433 ± 10^a	0.109	544.44
N	3.9 ± 0.1^b	3.0 ± 0.1^a	4.1 ± 0.2^b	2.8 ± 0.07^a	4.1 ± 0.10^b	<0.001	12.52
NDF	313 ± 11^a	291 ± 11^a	287 ± 12^a	286 ± 8^a	293 ± 7^a	0.161	255.51
ADF	187 ± 6.3^b	178 ± 6.5^a	176 ± 7.3^a	199 ± 5.2^c	177 ± 4.2^a	0.016	180.70
ADL	18.2 ± 0.62^a	18.0 ± 0.65^a	19.0 ± 0.79^a	22.6 ± 0.59^b	16.5 ± 0.39^a	<0.001	34.52
Total nutrient intake (pearl millet stover + cowpea hay) (g/sheep/day)							
DM	968 ± 14^a	929 ± 14^a	961 ± 17^a	973 ± 11^a	977 ± 10^a	0.109	
N	16.4 ± 0.1^b	15.6 ± 0.1^a	16.6 ± 0.2^b	15.3 ± 0.07^a	16.7 ± 0.10^b	<.001	
NDF	568 ± 11^a	546 ± 11^a	542 ± 12^a	541 ± 8^a	548 ± 7^a	0.161	
ADF	367 ± 6.3^b	359 ± 6.5^a	356 ± 7.3^a	379 ± 5.2^c	357 ± 4.2^a	0.016	
ADL	52.7 ± 0.62^a	52.5 ± 0.65^a	53.5 ± 0.79^a	57.1 ± 0.59^b	51.0 ± 0.39^a	<.001	

Notes: Means with different superscripts within rows are significantly different (P <0.05). ADF, acid detergent fiber; ADL, acid detergent lignin; N, nitrogen; DM, dry matter; NDF, neutral detergent fiber.

intake ($R^2 = 28.4$; $P = 0.02$). In contrast, fecal N and leaf-N intake were negatively correlated ($R^2 = 10.6$; $P = 0.04$). A negative linear relation was observed between leaf and stem intake ($R^2 = 40.1$; $P < 0.05$).

Live weight changes

Sheep live weight gain (LWG) over the 90-day period of the feeding experiment varied from 5.0 kg/sheep with Chakti to 8.3 kg/sheep with ICMV167005 (Table 4). Daily live weight changes among the cultivars were significantly different ($P < 0.05$). The animals fed with variety ICMV167005 had the highest ($P < 0.05$) average daily live weight gain compared with those fed with Chakti, ICMV167006, ICMV167002 and Somno varieties. No relationship was observed between stover intake and LWG. However, LWG was positively correlated with stover-N intake ($P < 0.05$; $r = 20.8\%$), indicating the beneficial effect of N content on LWG.

Discussion

The variation observed in Stover-N, NDF, ADF, ADL, ME, IVOMD content among the five varieties can be attributed to genetic variability and growth duration (Ball et al., 2001). Except for that of ICMV167006, the CP concentration values reported in this study were higher than the values reported in previous studies for some pearl millet varieties grown in arid and semi-arid cropping regions of Africa and India [Blümmel et al., 2007 (50 g/kg DM for the variety Raj 171 and local landrace); Blümmel et al., 2010 (40.3 g/kg DM for the variety GK 1044); Abdou et al., 2011 (48.1 g/kg DM)]. Furthermore, the stover CP concentrations were higher than those reported for other cereals, such as maize (38 g/kg DM, 43.5 g/kg DM), sorghum (36.4 g/kg DM), and rice (40 g/kg DM) by Singh et al. (1995, 1977) and Koralagama et al. (2008). Sarnklong et al. (2010) reported a higher value of CP in rice straw (64 g/kg DM in the early growing season). However, the CP concentration

Table 3. Fecal output and DM, Carbon (C), Nitrogen (N) and Phosphorus (P) concentration in feces excreted by sheep fed with stover of different pearl millet varieties, complemented with cowpea hay.

Parameter	Treatment					
	T0 (Somno + CH)	T1 Chakti + CH	T2 ICMV 167005+CH	T3 ICMV 167006+CH	T4 ICMV 167002+CH	P value
Feces output (kg/animal/day)						
Fresh feces	1.10 ± 0.03^{abc}	1.06 ± 0.02^{ab}	1.16 ± 0.05^{bc}	1.23 ± 0.04^c	0.96 ± 0.02^a	<0.001
Dry feces (dung)	0.46 ± 0.01^a	0.45 ± 0.01^a	0.44 ± 0.01^a	0.47 ± 0.03^a	0.45 ± 0.00^a	0.376
Fecal DM, carbon, nitrogen and phosphorus concentration						
DM (g/kg)	133.1 ± 3.4^a	119.1 ± 2.7^b	140.8 ± 3.5^a	171.9 ± 2.0^c	153.8 ± 2.0^d	<0.001
C (g/kg DM)	504 ± 1.9^c	512 ± 1.6^d	499 ± 2.0^c	481 ± 1.2^a	492 ± 1.2^b	<0.001
P (g/kg DM)	3.6 ± 0.1^a	4.3 ± 0.1 ^{b}	3.7 ± 0.2^a	4.4 ± 0.1^b	6.6 ± 0.1^c	<0.001
N (g/kg DM)	20.6 ± 0.4^b	20.3 ± 0.3^b	19.4 ± 0.3^{ab}	18.7 ± 0.3^a	18.5 ± 0.2^a	<0.001

Notes: Means with different superscripts within rows are significantly different (P < 0.05). CH, Cowpea hay; DM, dry matter.

Table 4. Weight gain by sheep fed with stover of local and four dual-purpose millet varieties, complement with cowpea hay.

Parameter	Treatment					
	T0 (Somno + CH)	T1 Chakti + CH	T2 ICMV 167005+CH	T3 ICMV 167006+CH	T4 ICMV 167002+CH	*P* value
Initial weight (kg)	26.9 ± 1.2[a]	27.5 ± 0.7[a]	27.2 ± 0.6[a]	26.6 ± 0.7[a]	27.4 ± 0.8[a]	0.980
Final weight (kg)	33.4 ± 0.8[a]	32.5 ± 0.7[a]	35.5 ± 0.9[a]	33.1 ± 0.6[a]	33.7 ± 0.8[a]	0.080
Weight gain (kg)	6.5 ± 0.7[a]	5.0 ± 0.6[a]	8.3 ± 0.5[c]	6.6 ± 1.0[b]	6.3 ± 0.6[b]	<0.001
Daily weight gain (kg)	0.083 ± 0.005[a]	0.065 ± 0.005[a]	0.102 ± 0.005[c]	0.076 ± 0.008[b]	0.077 ± 0.007[b]	<0.001

Notes: Means with different superscripts within rows are significantly different (P <0.05). CH, Cowpea hay.

reported by Sarnklong et al. (2010) in rice straw in other growing season was in the range reported in this study.

Similarly, the NDF and ADF fractions were all higher than the fractions of 679 g/kg DM (NDF) and 383 g/kg DM (ADF) reported by Singh et al. (1977). But, they were lower than the NDF (859 g/kg DM) and ADF (532 g/kg DM) content reported in stover of pearl millet varieties by Abdou et al. (2011) in Maradi (Niger). The tendency of a higher CP concentration found in stover of ICMV165005, may be an indication of its quality as feed, thus explaining the advantage in growth performance of sheep fed this variety. In contrast, the tendency for a higher NDF and ADF fractions found in Chakti stover suggests a relatively low digestibility of stover of this variety. As is well known, the digestibility of forage and their intake by ruminants are greatly influenced by NDF content (Harper & McNeill, 2015).

The NDF and ADF values are important because they relate to the ability of an animal to digest the forage; as ADF content increases, the ability to digest or the digestibility of the forage decreases. Thus, high ADF content has been associated with a slow rate of digestion (Riaz et al., 2014). Chakti is an early variety and was the first to be harvested, whereby, the length of the storage period might have affected the stover quality in this case (Gangashetty, 2018; Akakpo et al., 2020). Similarly, NDF content is used to predict intake potential of a feed. High NDF content (i.e. low digestibility) leads to low forage intake (Harper & McNeill, 2015). Our data clearly showed that there was a tendency of higher CP, IVOMD and ME and lower NDF, ADF and ADL contents in the leaves of pearl millet compared to stems, which implies that pearl millet varieties with relatively higher numbers of leaves or higher leaf: stem ratio are better quality fodder for sheep (Ball et al., 2001).

The lack of significant differences in daily stover DM intake of pearl millet varieties suggests that the concentration of structural carbohydrates in stover of different peal millet varieties did not affect significantly voluntary intake by sheep (Ansah et al., 2017). Further, despite the lack of any significant difference in daily DM intake, daily CP, ADF, and ADL intake from stover differed significantly among varieties. The high CP intake with ICMV167005 was probably due to a higher CP concentration in this variety.

The higher LWG observed in sheep fed ICMV167005 stover is a consequence of its higher CP, digestibility, and ME in the stover of this variety. Normally, animal performance and production efficiency are affected by feed digestibility and energy efficiency, both of which are positively correlated with feed intake and quality (Peripolli et al., 2011). The lower LWG observed in sheep fed Chakti stover may be an indicator of a lower rate of nutrient utilization from the residues of this variety and of its lower digestibility. This suggests that Chakti may be used as fodder in combination with supplements of a higher nutritional level. Indeed, several studies have reported the benefits of complementing cereal stover with cowpea hay or groundnut haulm (Zoundi et al., 2006; Ayantunde et al., 2008; Abdou et al., 2011; Etela & Dung, 2011; Ansah et al., 2017).

The lack of any relation between stover intake and LWG might be explained by the fact that weight gain is more closely associated with nutrient composition than with the total amount of feed consumed by sheep. This can explain the linear increase in weight with N intake, as the increase in N intake is generally associated with weight gain (Savadogo et al., 2000; Ayantunde et al., 2007). Nitrogen supports the rumen microbial population by increasing the activity of rumen microorganisms in order to maximize fiber digestion and optimize microbial protein synthesis. This explains the highest weight gain reported for sheep fed with ICMV167005. In contrast, sheep fed with Chakti showed a lower weight gain, and this might due to the lower N content in Chakti stover and its lower digestibility.

The fresh fecal output reported in this study laid within the range reported by Bloor et al. (2012) [0.5–2.8 kg/sheep/day], while the dry fecal output was below that reported in Zoundi et al. (2006) [0.53 kg /sheep/day]. The proportion of N in the fecal excretion of sheep fed with Chakti and local variety Somno complemented by cowpea hay was in the range reported in Bloor et al. (2012) [20–28 g/kg DM], while the proportion of N in fecal excretion from sheep fed with other the other varieties under study was below the range reported in Bloor et al. (2012).

The high concentration of N in the feces of sheep fed with stover of Chakti and Somno might be explained by the low digestibility of N in the rumen. According to Peyraud et al. (1995), N in ruminant solid feces is mainly in organic form, from undigested feed-N, micro-organisms, or N of endogenous origin, which means that the N content in the stover from Chakti and Somno were not highly degradable in the rumen of sheep. Lukas et al. (2005) and Peripolli et al. (2011) found that fecal N excretion is directly proportional to the digestibility of the diet and to the intake of a particular feed. This might explain the high N content in feces of sheep fed with Chakti, as well as the positive relationship between N excretion and millet stem intake, and the negative relationship between N excretion and millet leaf-intake. A high N content in feces reportedly has a negative impact on the environment (Nasiru et al., 2014; Singh & Rashid, 2017). Pearl millet varieties with large amounts of leaves can be considered as the best varieties, as they contain high N readily degraded in the rumen and absorbed by the organism, thereby limiting the concentration of N excreted in feces.

Conclusions

Chemical composition and in vitro digestibility of stover of different pearl millet varieties, and live weight gain by sheep in the feeding experiment indicated that, among the four dual-purpose pearl millet varieties promoted in Niger, ICMV167005 was the best under the experimental conditions used for the evaluation reported herein. The results of this study indicated that feeding sheep with stover of ICMV167005 along with cowpea hay allows higher weight gain. Therefore, we propose that ICMV167005 can be introduced in cropping systems to improve crop-livestock farming in the West African Sahel. In contrast, some of the dual-purpose millet varieties promoted performed below the local landrace used by farmers in the region.

Acknowledgements

The authors gratefully acknowledge the laboratory staff at ICRISAT and ILRI for their support with sample analysis using NIRS. The authors heartedly thank Dr. Michael Blummel for his useful criticism and suggestions.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Ethical standards

The experimental procedures adhered to the ARRIVE guidelines were conducted in accordance with the UK Animals (Scientific Procedures) Act 1986. The experiment was approved by the Ethics Committee on Animal Experimentation of the Faculty of Veterinary Medicine and Animal Science of Abdou Moumouni University of Niamey.

Funding

This research was funded by the United States Agency for International Development (USAID) under the Feed the Future Innovation Lab on Livestock Systems program [PTE Federal Award No: AID-OM-L-15-00003] and the CGIAR research program Grain Legumes and Dryland Cereals (GLDC) conducted with support from the CGIAR Trust Fund and through bilateral funding agreements. The funders played no role in the design of the study, the collection, analysis, or interpretation of the data, nor on the writing of the article, or the decision to submit the article for publication.

ORCID

Anthony Whitbread http://orcid.org/0000-0003-4840-7670

References

Abdou, N., Nsahlai, I. V. & Chimonyo, M. (2011). Effects of groundnut haulms supplementation on millet stover intake, digestibility and growth performance of lambs. *Animal Feed Science and Technology* 160, 176–184.

Akakpo, D. B., de Boera, I. J. M., Adjei-Nsiah, S., Duncand, A. J., Giller, K. E. & Oostinga, S. J. (2020). Evaluating the effects of storage conditions on dry matter loss and nutritional quality of grain legume fodders in West Africa. *Animal Feed Science and Technology* 262, 114419.

Ansah, T., Zanabongo, I. Y. & Nurudeen, A. R. (2017). Growth performance and hematology of Djallonké rams fed haulms of four varieties of groundnut (*Arachis hypogaea* L). *Animal Nutrition* 3, 406–410.

Ayantunde, A. A., Delfosse, P., Fernandez-Rivera, S., Gerard, B. & Dan-Gomma, A. (2007). Supplementation with groundnut haulms for sheep fattening in the West African sahel. *Tropical Animal Health and Production* 39, 207–216.

Ayantunde, A. A., Fernandez-Rivera, S. & Dan-Gomma, A. (2008). Sheep fattening with groundnut haulms and millet bran in the West African sahel. *Revue D'Elevage et de Médecine Vétérinaire des Pays Tropicaux* 61, 215–222.

Ball, D. M., Collins, M., Lacefield, G. D., Martin, N. P., Mertens, D. A., Olson, K. E., Putnam, D. H., Undersander, D. J. & Wolf, M. W. (2001). *Understanding Forage Quality* (Park Ridge, IL: American Farm Bureau Federation) Publication 1-01.

Baoua, I., Nouri, M., Saidou, A. K. & Amadou, L. (2013). *Quelques Nouvelles Variétés du Niébé Précoces Productives et Résistantes aux Ravageurs*. Technical Report. Niger: INRAN.

Bidinger, F. R. & Blümmel, M. (2007). Determinants of ruminant nutritional quality of pearl millet [Pennisetum glaucum (L.)

R. Br.] stover I. effects of management alternatives on stover quality and productivity. *Field Crops Research* 103, 119–128.

Bloor, J. M. G., Robert, P. J., Morvan, A. L. E. & Fleurance, G. (2012). Déjections des herbivores domestiques au pâturage: caractéristiques et rôle dans le fonctionnement des prairies. *INRA Production Animal* 25, 45–56.

Blümmel, M., Bidinger, F. R. & Hash, C. T. (2007). Management and cultivar effects on ruminant nutritional quality of pearl millet (*Pennisetum glaucum* (L.) R.Br.) stover II. Effects of cultivar choice on stover quality and productivity. *Field Crops Research* 103, 129–139.

Blümmel, M., Duncan, A. J. & Lenné, J. M. (2020). Recent Advances in dual purpose rice and wheat research: A synthesis. *Field Crops Research* 253, 107823.

Blümmel, M., Khan, A. A., Vadez, V., Hash, C. T. & Rai, K. N. (2010). Variability in stover quality traits in commercial hybrids of pearl millet (*Pennisetum glaucum* (L.) R. Br.) and grain-stover trait relationships. *Animal Feed Science and Technology* 10, 29–38.

Corson, D. C., Waghorn, G. C., Ulyat, M. J. & Lee, J. (1999). NIRS: forage analysis and livestock feeding. *Proceedings of the New Zealand Grassland Association* 61, 127–132.

Debieu, M., Sine, B., Passot, S., Grondin, A., Akata, E., Gangashetty, P., Vadez, V., Gantet, P., Fonce, D., Cournac, L., Hash, C. T., Kane, N. A., Vigouroux, Y. & Laplaze, L. (2018). Response to early drought stress and identification of QTLs controlling biomass production under drought in pearl millet. *PLoS ONE* 13, e0201635. doi:10.1371/journal.pone.0201635

Etela, I. & Dung, D. D. (2011). Utilization of stover from six improved dual-purpose groundnuts (*Arachis hypogaea* L.) cultivars by West African dwarf sheep. *African Journal of Food, Agriculture, Nutrition and Development* 11, 4538–4545.

Fernandez-Rivera, S., Hiernaux, P., Williams, T. O., Turner, M. D., Schlecht, E., Salla, A., Ayantunde, A. A. & Sangare, M. (2005). Nutritional constraints to grazing ruminants in the millet-cowpea livestock farming system of the sahel. In A. A. Ayantunde, S. Fernández Rivera & G. McCrabb (eds.) *Coping with Feed Scarcity in Smallholder Livestock Systems in Developing Countries* (Nairobi: ILRI), pp. 157–182.

Gangashetty, P. (2018). Pearl millet improvement program-WCA. Regional Pearl millet Convening, Thiess, Senegal, CERRAS.

Gangashetty, P. I., Motagi, B. N., Pavan, R. & Roodagi, M. B. (2016). Breeding Crop plants for improved human nutrition through biofortification: Progress and prospects. In J. M. Al-Khayri, S. M. Jain & D. V. Johnson (eds.) *Advances in Plant Breeding Strategies: Agronomic, Abiotic and Biotic Stress Traits* (Switzerland: Springer), pp. 35–76.

Harper, K. J. & McNeill, D. M. (2015). The role iNDF in the regulation of feed intake and the importance of its assessment in subtropical ruminant systems (the role of iNDF in the regulation of forage intake). *Agriculture* 5, 778–790.

Hiernaux, P. & Ayantunde, A. A. (2004). *The Fakara: A Semi-Arid Agro-Ecosystem Under Stress* (Niamey: ICRISAT, Desert Margins Programme), 95 p.

ICRISAT. (2018). *Fiches Techniques des Variétés* (Niger: ICRISAT).

Koralagama, K. D. N., Mould, F. L., Fernandez-Rivera, S. & Hanson, J. (2008). The effect of supplementing maize stover with cowpea (*Vigna unguiculata*) haulms on the intake and growth performance of Ethiopian sheep. *Animal* 2, 954–961.

Lukas, M., Südekum, K. H., Rave, G., Friedel, K. & Susenbeth, A. (2005). Relationship between fecal crude protein concentration and diet organic matter digestibility in cattle. *Journal of Animal Science* 83, 1332–1344.

Mason, S. C., Maman, N. & Palé, S. (2015). Pearl millet production practices in semi arid West Africa: A review. *Experimental Agriculture* 1, 1–21.

Nantoumé, H., Kouriba, A., Togola, D. & Ouologuem, B. (2000). Mesure de la valeur alimentaire des fourrages et sous-produits utilisés dans l'alimentation des petits ruminants. *Revue D'Elevage et Médicine Vétérinaire des Pays Tropicaux* 53, 279–284.

Nasiru, A., Ibrahim, M. H. & Ismail, N. (2014). Nitrogen losses in ruminant manure management and use of cattle manure vermicast to improve forage quality. *International Journal of Recycling of Organic Waste in Agriculture* 57, 1–7.

Obilana, A. (2003). *Overview: Importance of Millets in Africa*. Accessed 1 November 2019, available at: http://afripro.org.uk/papers/Paper02Obilana.pdf.

Owen, E. (1994). Cereal crop residues as feed for goats and sheep. *Livestock Research for Rural Development* 6.

Pasternak, D., Ibrahim, A. & Ayantunde, A. (2012). Evaluation of five pearl millet varieties for yield and forage quality under two planting densities in the Sahel. *African Journal of Agricultural Research* 7, 4526–4535.

Peripolli, V., Prates, E. R., Barcellos, J. O. J. & Braccini Neto, J. (2011). Fecal nitrogen to estimate intake and digestibility in grazing ruminants. *Animal Feed Science and Technology* 163, 170–176.

Peyraud, J. L., Vérité, R. & Delaby, L. (1995). Rejets azotés chez la vache laitière: effets du type d'alimentation et du niveau de production des animaux. *Fourrages* 142, 131–144.

Riaz, M. Q., Südekum, K. H., Clauss, M. & Jayanegara, A. (2014). Voluntary feed intake and digestibility of four domestic ruminant species as influenced by dietary constituents: A meta-analysis. *Livestock Science* 162, 76–85.

Sarnklong, C., Cone, J. W., Pellikaan, W. & Hendriks, W. H. (2010). Utilization of rice straw and different treatments to improve Its feed value for ruminants: A review. *Asian-Australasian Journal of Animal Sciences* 23, 680–692.

Savadogo, M., Zemmelink, G. A. J. & Nianogo, A. J. (2000). Effect of selective consumption on voluntary intake and digestibility of sorghum (*Sorghum bicolor* L. moench) stover, cowpea (*Vigna unguiculata* L. walp.) and groundnut (*Arachis hypogaea* L.) haulms by sheep. *Animal Feed Science and Technology* 84, 265–277.

Shenk, J. S. & Westerhaus, M. O. (1991). Population definition, sample selection and calibration procedures for near-infrared reflectance spectroscopy. *Crop Science* 31, 469–474.

Singh, R., Gupta, P. C., Singh, K. & Pradhan, K. (1977). Chemical composition of forages in relation to their nutritive value. *Indian Journal of Genetics and Plant Breeding* 37, 268–279.

Singh, A. & Rashid, M. (2017). Impact of animal waste on environment, its managemental strategies and treatment protocols to reduce environmental contamination. *Veterinary Science Research* 8, 1–12.

Singh, R. B., Sana, R. C., Singh, M., Chandra, D., Shukla, S. G., Walli, T. K., Pradhan, P. K. & Kessels, H. P. P. (1995). Rice straw – its production and utilization in India. In K. Singh & J. B. Schiere (eds.) *Handbook for Straw Feeding Systems* (New Delhi: ICAR), pp. 325–337.

Zoundi, S. J., Tiendrébéogo, J. P., Traoré, S. & Lalba, A. (2006). Embouche ovine en zone soudano-sahélienne du Burkina Faso: une alternative pour une amelioration de la sécurité alimentaire. In J. S. Zoundi, I. Butaré, J. N. Ndikumana & K. Adomefa (eds.) *Intégration Agriculture-élevage Alternative Pour une Gestion Durable des Ressources Naturelles et Line Amélioration de L'économie Familiale en Afrique de L'Ouest et du Centre* (Ouagadougou/Nairobi/Dakar: INERA/ILRI/CORAF/WECARD), pp. 151–159.