

Nutritional Value of Cereal and Legume Crop Residues Fed to Ruminant in Republic of Benin

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In sub-Saharan Africa, farmers use crop residues as livestock feeding strategy in small-scale-farms during the dry season. Due to the ignorance of the nutritional potential of the residues, the amounts of residues used are low and the operation remains rudimentary. The nutritive value of crop residues (cereal and legume) commonly used in ruminant feeding in Benin was determined to provide recommendation for their enhanced. The samples, collected in two agro-ecological regions areas of the country, were screened for their chemical composition and energy content, as well as for their *in vitro* fermentation characteristics (i.e., gas and volatile fatty acid production, organic matter degradability). Compared to legume residues, cereal residues showed lower energy (5.86 vs. 10.89 MJ/kg DM) and crude protein (4.16 vs. 11.77% DM) level and higher cell wall content (NDF: 84.98 vs. 56.12% DM), respectively. For both cereal and legume residues, the *in vitro* fermentation parameters were highly ($P < 0.01$) influenced by the residue type, while the study area significantly affected mainly cereal residues. Organic matter degradability ranged between 55.4 and 57.5% in cereal whereas between 53.2 and 89.6% in legume. The *in vitro* method utilized was helpful to evaluate the nutritive value and describe the fermentation kinetics of crop residues studied.

Keywords: Degradability, Fermentation Kinetics, *In Vitro* Gas Production, Volatile Fatty Acids.

1. INTRODUCTION

Feed scarcity remains the main constraint in ruminant production in African sub-Saharan area.¹⁻⁴ In many regions crop residues, while having low nutritive value, supply livestock for feed during dry seasons. These practices are widespread⁵⁻⁸ in Sahelian areas. A pre-requisite for making their best use is to accurately assess their availability and nutritive value especially in emerging countries.⁹ However, the nutritive value and particularly the fermentation characteristics of those feed resources are still less acknowledged. These characteristics are relevant, because the use of low-quality forages and byproducts in ruminant feeding is considered important for improving the environmental and economic sustainability of animal production in arid and semi-arid areas.¹⁰ Already since several years, the *in vitro* gas production technique (IVGPT) is proposed as a valid alternative method to determine the nutritive value of feedstuffs, because rate and extent of degradation and rumen fermentation can be easily determined; moreover, the measurement of cumulative gas production also

give a dynamic description of the feeds.¹¹ The IVGPT should be considered for use in nutritive evaluation also in developing countries, because the manual system does not require large financial resources and allows to analyze many samples simultaneously using small amounts of material.¹² At the same time, the IVGPT is highly reproducible and it is not a time-consuming method.

The main objective of the present investigation was to characterize the nutritive value of some cereal and leguminous crop residues cultivated in two areas of Benin. More specifically, this study aimed to determine the chemical composition and analyze the fermentation kinetics and characteristics (gas and volatile fatty acids production, organic matter degradability) of these feed resources using the IVGPT.

2. MATERIALS AND METHODS

Study Area

Crop residues were collected in two communes (Fig. 1) randomly chosen in two agroecological areas where residues are commonly fed to animals. The first commune,

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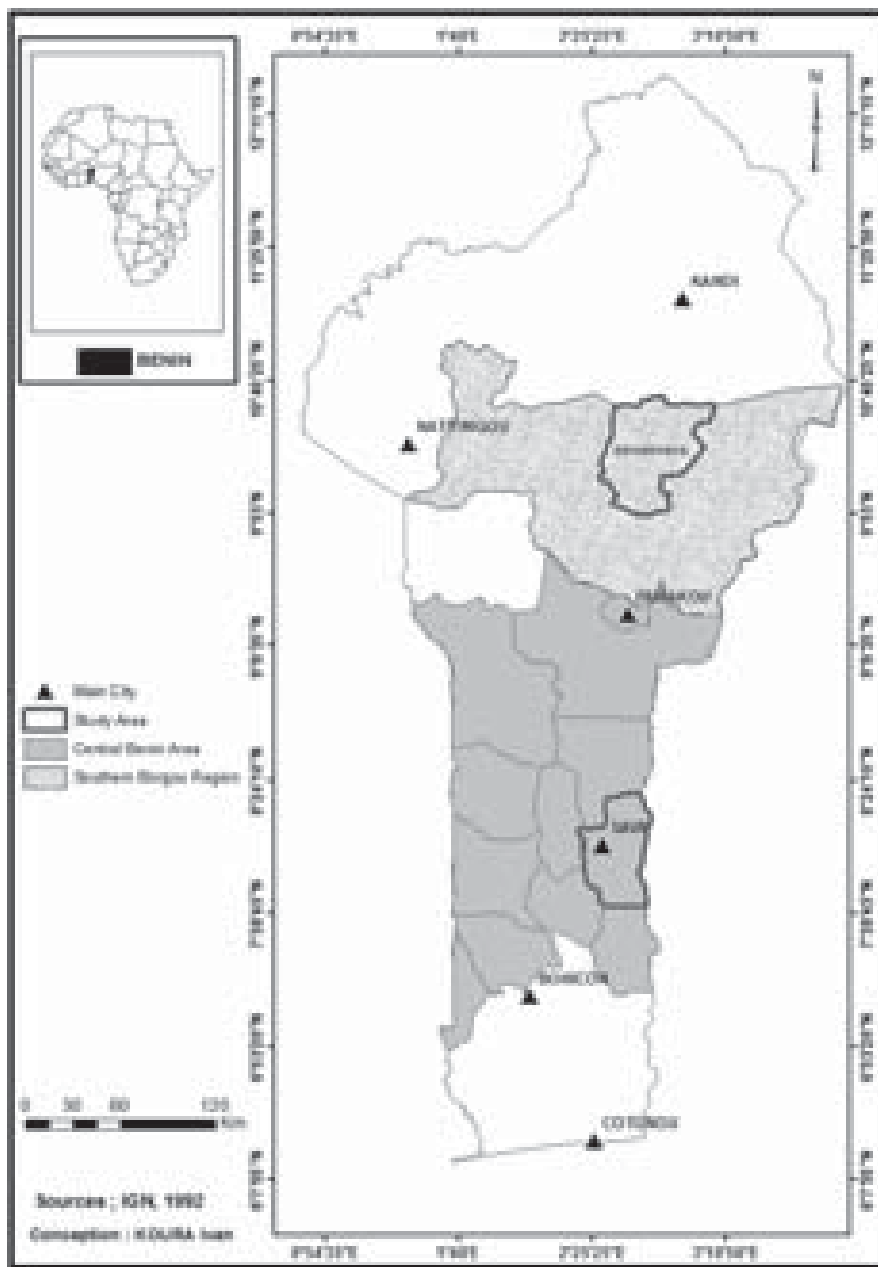


Fig. 1. Map of BENIN showing the two study areas, Study area: BEMBEREKE = Northern area; SAVE = Central area.

BEMBEREKE (Northern Area_N), was selected in the food cropping area of southern Borgou (agroecological region III) and the second, SAVE (Central Area_C), in the cotton cropping area of central Benin (agroecological region V). BEMBEREKE commune is located between 9.4° and 10.6° of latitude North and between 2° and 3.2° of longitude East. According to data recorded by the Agency for Aerial Navigation Safety in Africa and Madagascar (ASECNA) between 1981 and 2012, the annual rainfall

ranged from 900 to 1300 mm. The vegetation is dominated by shrubby and tree savannah¹³ and the soil is of leached tropical ferruginous with concretion type.¹⁴ SAVE commune is located at 8°01'59" Nord 2°29'01" Est. The average of rainfall amount recorded by ASECNA between 1981 and 2012 ranged from 600 to 1400 mm/year. The vegetation is constituted of savannah dotted with trees and shrubs¹³ and the soil is of impoverished tropical ferruginous type.¹⁴

Crop Residue Samples

Samples of four cereal residues [cob, husks and stalks from maize (*Zea mays* L.) and offal from sorghum (*Sorghum bicolor* L.) (M_C, M_H, M_S and S_O, respectively) and five samples of legume residues [haulms and pod shells from cowpea (*Vigna unguiculata* L.) and soybean (*Glycine max* L.), and haulms from groundnut (*Arachis hypogea* L.)] (C_H, C_PS, S_H, S_PS and G_H, respectively) were collected in the two cited areas during postharvest period, in November 2013 at the beginning of the dry season. All the samples were collected by single batch.

Chemical Composition

All the samples were ground to pass a 1 mm screen (Brabender Wiley mill, Brabender OHG, Duisburg, Germany) and analyzed for dry matter (DM), crude protein (CP), ether extract (EE) and ash as suggested by AOAC¹⁵ procedures (ID number: 2001.12, 978.04, 920.39 and 930.05 for DM, CP, EE and ash, respectively). Structural carbohydrate fractions were also analyzed: neutral detergent fiber (NDF),¹⁶ acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined.¹⁷

In Vitro Gas Production

The fermentation characteristics and kinetics were studied using the *in vitro* gas production technique (IVGPT), by incubating all the crop residues at 39 °C under anaerobic condition with buffered rumen fluid.¹¹ The substrates to test were weighted (1.0004 ± 0.0003 g) in triplicate in 120 ml serum flasks, where 74 ml of anaerobic medium were added. The rumen fluid was collected in a pre-warmed thermos at a slaughterhouse authorized according to EU legislation¹⁸ from six adult bovine (*Bos taurus*) fed a standard diet (NDF 45.5% DM and crude protein 12% DM). The collected material was rapidly transported to the laboratory, where it was pooled, flushed with CO₂, filtered through a cheesecloth and added in each flask (5 ml). Three flasks containing no substrate were incubated as blanks to correct for organic matter (OM) disappearance, and gas and volatile fatty acids (VFA) production.

Gas production of fermenting cultures was recorded 23 times (at 2–24 h intervals) during the period of incubation (120 h) using a manual pressure transducer (Cole and Palmer Instrument Co., Illinois, USA).

The fermentation was stopped at 120 h and the fermentation liquor was analyzed for pH with a pH-meter (model 3030 Alessandrini Instrument glass electrode, Jenway, Dunmow, UK) and sampled for VFA analysis. At the end of fermentation the extent of sample disappearance, expressed as organic matter degradability (dOM, %), was determined by difference of the incubated OM and the undegraded filtered (sintered glass crucibles; Schott Duran, Mainz, Germany, porosity #2) residue burned at 550 °C

for 5 h. Cumulative volume of gas produced after 120 of incubation was related to incubated OM (OMCV, ml/g) and to degraded OM (Yield, ml/g). For VFA determination, fermenting liquors were centrifuged at 12,000 g for 10 min at 4 °C (Universal 32R centrifuge, Hettich Furn Tech Division DIY, Germany). One milliliter of supernatant was then mixed with 1 ml of oxalic acid (0.06 mol). VFAs were measured by gas chromatography (Thermo Quest 8000 top Italia SpA, Rodano, Milan, Italy; fused silica capillary column 30 m, 0.25 mm ID, 0.25 μm film thickness), using external standard solution composed of acetic, propionic, butyric, isobutyric, valeric and isovaleric acids.¹⁹ Branched-chain fatty acids proportion (BCFA) was calculated as follows: (isobutyric + isovaleric)/tVFA.

Data Processing

The nutritive value of studied crop residues was estimated as metabolizable energy (ME, MJ/kg DM) using the equation:²⁰

$$ME = 2.2 + 0.1357 \times GP + 0.0057 \times CP + 0.0002859 \times CP^2$$

where CP is the content (g/kg DM) of crude protein and GP is the gas obtained *in vitro* (ml/200 mg incubated DM) after 24 h of incubation.

For each flask the gas production profiles were fitted to the sigmoid model:²¹

$$G = A \left[1 - \frac{B^{-C}}{1 + B^{-C}} \right]$$

where G is the total gas produced (ml/g of OM) at time t (h), A is the asymptotic gas production (ml/g of OM), B (h) is the time at which one-half of the asymptote is reached, and C is the switching characteristic of the curve. Maximum fermentation rate (R_{max} , ml/h) and the time at which it occurs (T_{max} , h) were also calculated according to the following formulas:²²

$$R_{max} = (A \times C^B) \times B \times [T_{max}^{-(B-1)}] / [(1 + C^B) \times (T_{max}^{-B})^2]$$

$$T_{max} = C \times \frac{B-1}{B+1}^{(1/B)}$$

Fermentation characteristics (OMCV, Yield, dOM, pH and VFA) and the model parameters (A, B, t_{max} , R_{max}) were subjected, separately for cereal and legume crop residues, to analysis of variance²³ to detect the differences between crop residues and study areas according to the model:

$$y_{ijk} = \mu + CR_i + SA_j + (CR \times SA)_{ij} + s_{ijk}$$

where y is the single data, μ is the mean, CR is the crop residue effect (i = 4 for cereals and 5 for legumes), SA the study area effect (j = Central and Northern for both cereal and legume crop residues) and s the error term.

Table I. Chemical composition (% DM) and nutritive value (MJ/kg DM) of crop residues in the two study areas.

	DM	Ash	CP	EE	NDF	ADF	ADL	ME
Cereal								
Central area								
Maize cob	94.2	3.62	4.99	0.37	84.9	47.4	8.72	6.48
Maize husks	94.4	2.52	3.31	0.49	87.4	46.9	5.01	6.38
Maize stalks	92.9	3.25	4.40	0.25	88.1	50.4	6.49	6.38
Sorghum offal	93.2	4.53	2.44	0.81	83.8	59.4	11.7	4.54
Northern area								
Maize cob	92.9	2.68	4.36	0.54	86.6	49.5	9.05	5.69
Maize husks	92.5	6.88	5.84	0.73	79.9	55.2	10.2	6.90
Maize stalks	92.2	6.79	4.07	0.55	87.7	62.6	14.6	5.26
Sorghum offal	92.0	5.64	3.89	0.88	81.5	52.0	8.82	5.26
Legume								
Central area								
Cowpea haulms	91.2	8.56	15.6	1.34	43.2	39.2	8.34	14.51
Cowpea pod shell	90.7	8.95	9.20	0.79	65.5	49.6	14.2	9.07
Groundnut haulms	90.5	13.4	18.1	3.43	54.0	49.9	16.0	16.3
Soybean haulms	91.1	12.6	9.63	5.35	52.8	47.5	13.4	8.10
Soybean pod shell	91.1	8.03	8.50	4.62	58.3	45.8	10.7	8.51
Northern area								
Cowpea haulms	90.5	11.7	18.8	1.81	39.2	32.9	8.34	17.0
Cowpea pod shell	93.6	4.06	8.84	0.60	68.7	54.3	10.7	8.63
Groundnut haulms	90.4	10.1	13.9	3.85	51.7	44.5	12.0	12.6
Soybean haulms	91.2	12.9	8.90	5.15	57.2	46.7	16.6	7.61
Soybean pod shell	91.1	6.16	6.23	4.09	70.62	56.9	13.4	6.62

Notes: DM = dry matter, CP = crude protein, EE = ether extract, NDF = neutral detergent fiber, ADF = acid detergent fiber, ADL = acid detergent lignin, ME = metabolizable energy calculated as suggested by Menke and Steingass (1988).

3. RESULTS

Table I shows the chemical composition and the nutritive value of both cereal and legume crop residues. As average cereal crop residues had higher structural carbohydrates (NDF: $84.98 \pm 2.34\%$ DM) and very low CP ($4.16 \pm 0.69\%$ DM) while legume residues were richer in

CP ($11.77 \pm 4.49\%$ DM) and had lower structural carbohydrates (NDF: $56.12 \pm 10.32\%$ DM), but more lignified (ADL: 9.33 ± 2.97 and $12.36 \pm 2.88\%$ DM for cereal and legume, respectively). Consequently, the energy content

was lower in cereal (ME: 5.86 ± 0.73 MJ/kg DM) than in legume (ME: 10.89 ± 3.89 MJ/kg DM) crop residues.

The chemical composition and the nutritive value appear few variable across cereal residues. Among legume residues, haulms from cowpea and groundnut showed the best characteristics in terms of CP, NDF and ME content. The lipid content appears quite high in groundnut haulms, soybean haulms and pod shell ranging between 3.43 and 5.35% DM. Comparing the study area, for cereals no linear trend was observed in the chemical parameters and energy content, whereas for legumes the samples collected in the Northern area presented more favorable characteristics.

Tables II and III show the *in vitro* fermentation parameters of cereal and legume residues, respectively. For both cereal and legume residues, all parameters were highly ($P < 0.01$) influenced by the residue crop type, while the study area significantly affected all parameters in cereal residues and only kinetics parameters in legume residues; also the interaction crop residues*study area resulted significant in most of parameters.

In cereal residues, OM degradability ranged between 55.4 and 76.3% in maize cob and maize husks, respectively; OMCV ranged between 219 and 303 ml/g, in sorghum offal and maize husks, respectively. Considering both sampling area, maize husks showed the highest ($P < 0.001$) OM degradability (71.67%) and OMCV (275 ml/g) while maize cob had the lowest values ($P < 0.001$) for dOM (59.65%) and sorghum offal the lowest value for OMCV (228 ml/g). In legume residues, OM degradability ranged between 53.2 and 89.6% in soybean pod shell and

Table II. *In vitro* fermentation characteristics for cereal crop residues.

	dOM (%)	OMCV (ml/g)	Yield (ml/g)	A (ml/g)	B (h)	t_{max} (h)	R_{max} (ml/h)
Central area							
Maize cob	63.9 ^C	253 ^C	39.7 ^A	287 ^C	26.8 ^C	12.4 ^{Bb}	6.59 ^{Ab}
Maize husks	76.3 ^A	303 ^A	398 ^A	327 ^{Cb}	28.7 ^{Cb}	15.2 ^{Ba}	7.23 ^{Aa}
Maize stalks	71.9 ^B	291 ^B	405 ^A	324 ^{Ba}	31.3 ^{Ba}	13.3 ^{Bab}	6.35 ^{Ab}
Sorghum offal	57.5 ^D	219 ^D	381 ^B	244 ^A	36.1 ^A	19.0 ^A	4.28 ^B
Northern area							
Maize cob	55.4 ^B	237 ^{Ab}	429 ^A	269	30.8 ^{Bc}	13.8 ^{ABb}	5.35 ^B
Maize husks	67.1 ^B	246 ^{Aa}	366 ^{Ba}	270	25.5 ^C	10.7 ^{Bc}	6.47 ^A
Maize stalks	64.8 ^A	228 ^B	352 ^{Bb}	263	35.4 ^{Aa}	15.7 ^{Ab}	4.59 ^C
Sorghum offal	64.4 ^A	236 ^{ABb}	367 ^{Ba}	261	33.1 ^{ABb}	17.6 ^{Aa}	5.00 ^{Bc}
Prob.							
Crop residues	***	***	***	***	***	***	***
Study area	***	***	***	***	***	**	***
Interaction	***	***	***	***	***	**	***
MSE	0.340	23.46	42.90	47.33	1.45	2.49	0.075

Notes: dOM = organic matter degradability (% of incubated OM); OMCV = cumulative volume of gas related to incubated OM; Yield = cumulative volume of gas related to degraded OM; A = potential gas production; B = time at which A/2 was formed; t_{max} = time at which maximum rate was reached; R_{max} = maximum fermentation rate. Means within a column, for each study area, with different superscripts are significantly different (A, B, C, D: $P < 0.01$; a, b, c: $P < 0.05$). MSE: Mean Square Error. **, ***: $P < 0.01$, $P < 0.001$.

Table III. *In vitro* fermentation characteristics for legume crop residues.

	dOM (%)	OMCV (ml/g)	Yield (ml/g)	A (ml/g)	B (h)	t _{max} (h)	R _{max} (ml/h)
Central area							
Cowpea haulms	72.9 ^{AB}	226 ^A	310 ^{AB}	228 ^{Aa}	13.9 ^{Cb}	7.51 ^A	10.5 ^A
Cowpea pod shell	59.1 ^B	199 ^{Bc}	342 ^A	207 ^{ABb}	14.6 ^C	6.19 ^{Bb}	8.67 ^B
Groundnut haulms	89.6 ^A	193 ^C	235 ^C	202 ^B	15.5 ^{Bca}	5.95 ^{Bc}	7.84 ^B
Soybean haulms	61.0 ^B	170 ^D	278 ^{Bc}	176 ^C	20.6 ^A	10.6 ^A	5.38 ^C
Soybean pod shell	59.1 ^B	209 ^B	353 ^A	228 ^A	16.8 ^B	7.76 ^B	8.47 ^B
Northern area							
Cowpea haulms	70.4	196 ^{Bc}	279 ^B	207 ^B	16.1 ^B	7.20 ^B	7.86 ^{Ba}
Cowpea pod shell	59.7	207 ^{AB}	347 ^A	216 ^{AB}	15.4 ^B	7.05 ^B	8.65 ^{Aa}
Groundnut haulms	71.5	218 ^A	304 ^{ABb}	229 ^A	15.3 ^B	6.11 ^B	9.11 ^A
Soybean haulms	59.7	168 ^D	281 ^B	173 ^C	21.0 ^A	12.3 ^A	5.40 ^C
Soybean pod shell	53.2	191 ^{CD}	358 ^{Aa}	194 ^B	20.0 ^A	11.5 ^A	5.67 ^C
Prob.							
Crop residues	**	***	***	***	***	***	***
Study area	NS	NS	NS	NS	***	**	***
Interaction	NS	***	NS	***	***	*	***
MSE	129	47.31	747	81.97	0.706	0.819	0.324

Notes: dOM = organic matter degradability (% of incubated OM); OMCV = cumulative volume of gas related to incubated OM; Yield = cumulative volume of gas related to degraded OM; A = potential gas production; B = time at which A/2 was formed; t_{max} = time at which maximum rate was reached; R_{max} = maximum fermentation rate. Means within a column, for each study area, with different superscripts are significantly different (A, B, C, D: *P* < 0.01; a, b, c: *P* < 0.05). MSE: Mean Square Error. NS, *, **, ***: not significant, *P* < 0.05, *P* < 0.01, *P* < 0.001.

groundnut haulms, respectively; OMCV ranged between 168 and 226 ml/g in soybean haulms and cowpea haulms, respectively. For both study area, the haulms of cowpea and groundnut showed the highest OM degradability compared to the others residues, but only in Central area the differences were statistically significant (*P* < 0.01). Regarding OMCV and considering both areas, the highest value was found in cowpea haulms (211 ml/g) and the lowest in soybean haulms (169 ml/g; *P* < 0.01).

Fermentation kinetics parameters (*B*, t_{max}, R_{max}) are shown in Tables II and III, and Figures 2 and 3. In cereal residues, the fermentation process was similar for most of the samples, starting within 6 h of incubation, reaching the maximum around 14 h and finishing gradually at 72 h. The slowest kinetics was observed in sorghum offal of the Central area (19.0 h and 4.28 ml/h, *P* < 0.01, t_{max} and R_{max}, respectively) whereas the fastest kinetics was observed in

maize husks of the Central area (R_{max}: 7.23 ml/h). Regarding legume residues, in the fermentation profiles it is possible distinguish three groups: the slowest (S_H Central and Northern, and S_PS Northern) that reaching the maximum fermentation rate (as average 5.48 ml/h) around 11 h and complete the process around 36 h; the fastest (C_H Central) with the highest R_{max} value (10.5 ml/h; *P* < 0.01) reached after 7.20 hours of incubation and all the others (C_H, C_PS and G_H from the Northern area and C_PS, G_H and S_PS from the Central area) characterized by intermediate t_{max} (6.61 h) and R_{max} (8.55 ml/h) values.

Tables IV and V presents the pH and volatile fatty acids produced after 120 hours of incubation for cereal and legume crop residues, respectively. The main effects (crop residues and study area) and their interaction affected all the parameters reported not clearly. The pH values ranged

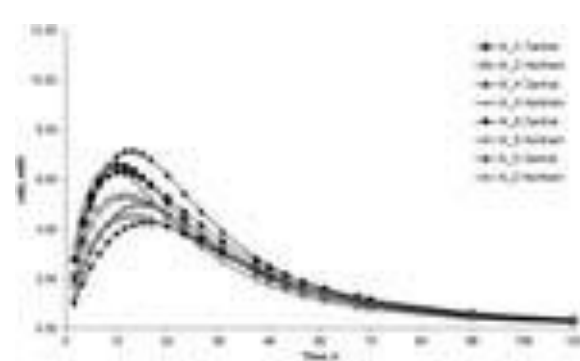


Fig. 2. *In vitro* fermentation rate over time for cereal crop residues, M_C: maize cob; M_H: maize husks; M_S: maize stalks; S_O: sorghum offal.

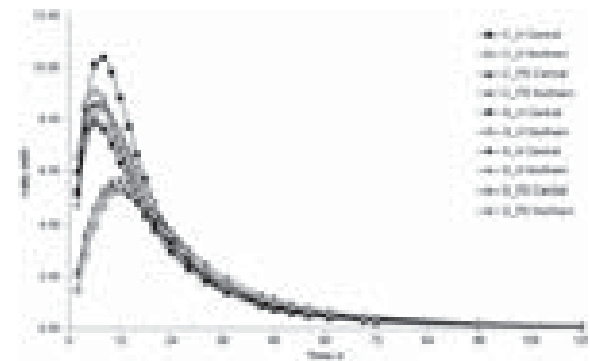


Fig. 3. *In vitro* fermentation rate over time for legume crop residues, C_H: cowpea haulms; C_PS: cowpea pod shell; G_H: groundnut haulms; S_H: soybean haulms; S_PS: soybean pod shell.

Table IV. Volatile fatty acids and pH at 120 h for cereal crop residues.

	pH	Acetate	Propionate	Isobutyrate	Butyrate	Isovalerate	Valerate	tVFA	BCFA
	(mM/g OM)								
	Central area								
Maize cob	6.58	46.44	15.14 ^{ab}	0.61 ^{AB}	6.27 ^{ABa}	0.91 ^A	0.79 ^a	70.16	0.033 ^a
Maize husks	6.42	40.97	14.90 ^{ab}	0.27 ^C	5.01 ^{AB}	0.63 ^B	0.61 ^a	62.39	0.024 ^b
Maize stalks	6.52	47.82	16.92 ^a	0.70 ^A	6.36 ^A	1.14 ^{Aa}	0.75 ^b	73.70	0.035 ^a
Sorghum offal	6.65	41.12	11.90 ^b	0.51 ^B	4.44 ^{Bb}	0.72 ^{ABc}	0.58 ^c	59.27	0.031 ^b
	Northern area								
Maize cob	6.61	36.31	11.47 ^b	0.35 ^b	4.27	0.61 ^b	0.52	53.52	0.027 ^{ABb}
Maize husks	6.61	45.17	16.51 ^a	0.42 ^{ab}	5.20	0.84 ^a	0.51	68.66	0.026 ^B
Maize stalks	6.63	35.83	13.60 ^{ab}	0.42 ^{ab}	4.65	0.80 ^{ab}	0.47	55.77	0.030 ^{AB}
Sorghum offal	6.66	37.80	11.33 ^b	0.51 ^a	3.98	0.74 ^{ab}	0.53	54.89	0.033 ^{Aa}
Prob.									
Crop residues	***	NS	*	***	NS	***	NS	NS	***
Study area	***	*	NS	***	***	NS	***	*	NS
Interaction	***	NS	NS	***	NS	***	NS	NS	*
MSE	0.000	33.52	4.874	0.006	0.609	0.012	0.009	77.71	0.000006

Notes: tVFA = total Volatile Fatty Acids; BCFA (branched chain fatty acids) = (isobutyric + isovaleric)/tVFA; Means within a column, for each study area, with different superscripts are significantly different (A, B, C: $P < 0.01$; a, b, c: $P < 0.05$). MSE: Mean Square Error. NS, *, **, ***: not significant, $P < 0.05$, $P < 0.01$, $P < 0.001$.

between 6.42 and 6.66 for cereal residues, and between 6.79 and 6.84 for legume residues. The average mean of total VFA was 62.30 and 56.50 Mm/g for cereal and legume residues, respectively. Regarding cereal residues, all the values except acetate and total VFA, were statistically different among substrates. As a whole, the highest value of total VFA was found in maize husks (mean value 65.53 Mm/g) and the lowest in sorghum offal (mean value 57.08 Mm/g), even if the differences were not statistically significant. By contrast, in legume residues, all the values were different among substrates. However, any clear trend was observed. The highest tVFA production was found in

soybean haulms (70.77 Mm/g, $P < 0.01$) in Central area, whereas in Northern area was registered in cow pea haulms (73.14 Mm/g; $P < 0.05$); the lowest tVFA values were recorded in cow pea haulms (49.09 Mm/g) and in soybean haulms (52.75 Mm/g), in Central and Northern area respectively.

Regarding the branched chain fatty acids (isobutyrate, isovalerate, valerate), cowpea haulms and groundnut haulms showed the higher proportion on tVFA (0.0626 and 0.0639, respectively).

To comparing sampling area the most important *in vitro* parameters (dOM, OMCV and VFA) are reported in

Table V. Volatile fatty acids and pH at 120 h for legume crop residues.

	pH	Acetate	Propionate	Isobutyrate	Butyrate	Isovalerate	Valerate	tVFA	BCFA
	(mM/g OM)								
	Central area								
Cowpea haulms	6.79 ^b	30.28 ^C	10.11 ^{Bb}	0.80 ^{abc}	5.65 ^{ABa}	1.48 ^A	0.77 ^{Ab}	49.09 ^{Bb}	0.062 ^A
Cowpea pod shell	6.84 ^a	37.09 ^{ABC}	9.56 ^{Bb}	0.60 ^c	3.45 ^C	0.99 ^{Bb}	0.50 ^B	52.18 ^{Bb}	0.040 ^B
Groundnut haulms	6.83 ^b	32.54 ^{BCb}	11.54 ^{ABb}	0.88 ^b	3.79 ^C	1.44 ^{ABa}	1.00 ^{Aa}	51.19 ^{Bb}	0.066 ^A
Soybean haulms	6.83 ^{ab}	48.81 ^{Aa}	15.14 ^{Aa}	0.79 ^{abc}	3.98 ^{BCb}	1.29 ^{AB}	0.76 ^{Ab}	70.77 ^A	0.040 ^B
Soybean pod shell	6.82 ^a	45.14 ^{ABa}	12.94 ^{ABa}	0.90 ^a	6.02 ^A	1.53 ^A	0.87 ^{Aa}	67.39 ^{ABa}	0.049 ^B
	Northern area								
Cowpea haulms	6.87 ^A	50.47 ^A	13.14	1.01 ^{Aa}	5.45 ^a	1.61 ^a	1.49 ^B	73.14 ^a	0.056 ^A
Cowpea pod shell	6.81 ^{Bb}	48.48 ^A	11.94	0.74 ^{Aa}	4.83 ^{ab}	1.30 ^a	0.69 ^C	67.98 ^b	0.040 ^B
Groundnut haulms	6.79 ^{Ba}	43.21 ^{AB}	14.05	0.87 ^{AB}	3.75 ^b	1.61 ^a	1.54 ^A	65.04 ^{abc}	0.062 ^A
Soybean haulms	6.82 ^{Bb}	34.67 ^B	12.26	0.59 ^{ABb}	3.67 ^b	0.94 ^b	0.63 ^C	52.75 ^c	0.041 ^B
Soybean pod shell	6.81 ^{Bb}	40.49 ^{AB}	12.30	0.67 ^{Bc}	4.39 ^{ab}	1.17 ^b	0.74 ^C	59.75 ^{abc}	0.043 ^B
Prob.									
Crop residues	NS	**	*	NS	**	**	***	**	***
Study area	NS	NS	NS	NS	NS	NS	**	NS	NS
Interaction	***	***	*	NS	NS	*	***	**	NS
MSE	0.0003	33.75	2.471	0.022	0.618	0.039	0.013	62.93	0.000027

Notes: tVFA = total Volatile Fatty Acids; BCFA (branched chain fatty acids) = (isobutyric + isovaleric)/tVFA; Means within a column, for each study area, with different superscripts are significantly different (A,B,C: $P < 0.01$; a, b, c: $P < 0.05$). MSE: Mean Square Error. NS, *, **, ***: not significant, $P < 0.05$, $P < 0.01$, $P < 0.001$.

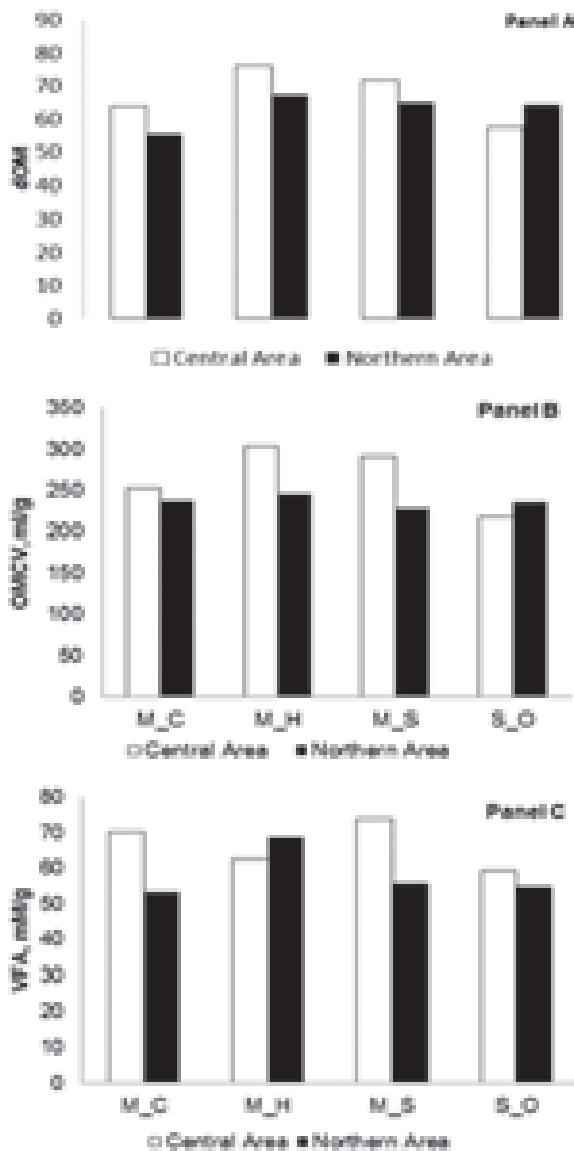


Fig. 4. *In vitro* fermentation characteristics: comparison among study area in cereal crop residues, M_C: maize cob; M_H: maize husks; M_S: maize stalks; S_O: sorghum offal, dOM = organic matter degradability, % of incubated OM, (Panel A); OMCV = cumulative volume of gas related to incubated OM (Panel B); VFA = total volatile fatty acids (Panel C). For each crop residue, with different superscripts are significantly different (A, B: $P < 0.01$; a, b: $P < 0.05$).

Figures 4 and 5. For cereal, the Central area showed in general best results in terms of dOM, gas and VFA production; however, this trend was very clear for maize cob: significant higher dOM ($P < 0.01$), OMCV ($P < 0.01$) and VFA ($P < 0.05$) in Central compared to Northern area. In legumes, less significant differences appear, and the area effect seems not linear and only for dOM the crop were ranged at the same way within the area.

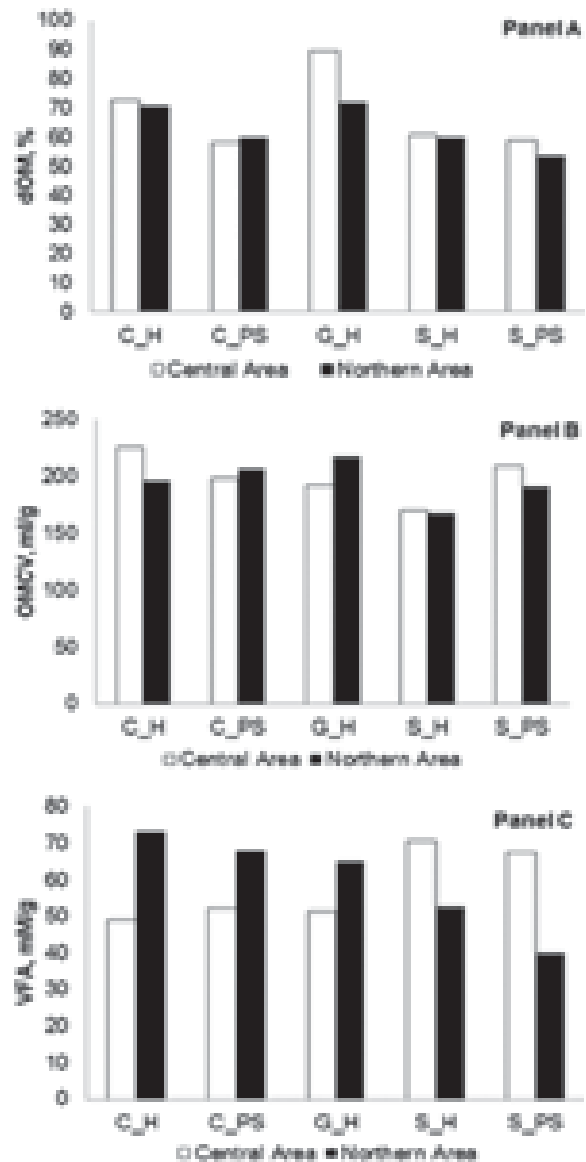


Fig. 5. *In vitro* fermentation characteristics: Comparison among study area in legume crop residues, C_H: cowpea haulms; C_PS: cowpea pod shell; G_H: groundnut haulms; S_H: soybean haulms; S_PS: soybean pod shell, dOM = organic matter degradability, % of incubated OM (Panel A); OMCV = cumulative volume of gas related to incubated OM (Panel B); VFA = total volatile fatty acids (Panel C). For each crop residue, with different superscripts are significantly different (A, B: $P < 0.01$; a, b: $P < 0.05$).

4. DISCUSSION

Crop residues represent important feedstuffs for livestock during dry season in sub-Saharan Africa.²⁴ The chemical composition and the *in vitro* parameters of all the crop residues studied appears quite diversified. However, some results were similar to those reported in previous studies.^{8, 25–30} As in most of the studies, where residues

were randomly collected, it is important to mention that not only the species, but also climate condition, sampling site, vegetative stage, collection and drying method, soil and cropping management can influence chemical composition and nutritive value of crop residues.^{28, 31}

Nutritional Characteristics of Crop Residues

Regarding crop residues chemical composition, part of the results were expected, i.e., the higher crude protein, lower structural carbohydrates and higher lignin contents in legume compared to cereal residues. Consequently, compared to legume, cereal residues showed a lower energy level. In general, the *in vitro* OM degradability resulted not very elevate, about 65% in the all residues types. The total volatile fatty acids produced, indicating the available energy for the animal, in cereal residues was more elevated compared to legume residues because of the higher content of carbohydrates in grass than in legumes. Regarding the kinetics, the great part of the fermentation process occurred within the first 72 h for grass and 48 h for legumes, to complete slowly in 96 h.

In particular for cereal crop residues, our results on chemical composition revealed low crude protein (24–58 g/kg DM), low energy content (ME: 4.5–6.9 MJ/kg DM), high structural carbohydrates level (NDF: more than 80% DM).²⁶ However, the OM degradability of our samples is slightly higher than the range (30–45%) reported in literature. The value of crude protein in maize residues is higher than data reported in literature,^{25–28} as well as the NDF content. Regarding maize husks, on average, the values obtained in terms of energy content, OM degradability, VFA production and fermentation kinetics are more favorable compared to the other cereal residues, unfortunately its utilization for feeding animals is little adopted. Maize cob was studied²⁸ in terms of *in vitro* organic matter digestibility (IVOMD) over 96 h and using rumen fluid from African female goat; according to our data, the authors reported a low IVOMD. Despite richer in crude protein than the others cereal residue, this crop is rarely used in ruminant feeding. Maize stalks or stovers, characterized by quite low nutritive value, is often fed as basal diet to ruminants, especially sheep and cow.³² The chemical treatment with ammoniac is used to improve its nitrogen content,³³ useful to maintain live weight in dry season in small ruminant. Previous works studied the IVOMD over 96 h of maize stalks/offal collected in a teaching and research farm.⁸ The OM digestibility reported was lower than ours (49 vs. 68%), while the gas production after 24 h is higher in their experiment (31.33 vs. 21.12 ml/g) compared to our samples. The animal specie donor of rumen fluid used can explain the difference observed in the two investigations: goat and cow. Regarding sorghum offal, in our study it resulted the cereal crop residue with the lowest OM degradability, gas and VFA production and the slowest fermentation kinetics. However, the crude protein value

reported in literature²⁷ is quite higher compared to our, but the energy content was lower than ours. Despite poor in crude protein and energy compared to maize stalks, this residue is more palatable for ruminant, probably due to its low cell wall content.

The legume residues are often supplemented to small ruminants,⁶ so it is important to know their chemical composition and nutritive value to formulate adequate diet for animal requirements. Soybean haulms are less rich in nutrients, less easy to find and less used than haulms from other legumes, and showed characteristics closed to legume pod shells. Cowpea and soybean pod shells, despite their low nutritive value, were highly used in ruminant feeding as good fibrous source for rumen microbial functioning. In legume crop residues, on the contrary to cereal ones, the values found in literature were diversified for all the residues studied. According to some authors^{8, 27, 29, 30} the crude protein content for cowpea haulms, cowpea pod shells and groundnut haulms range from 90 to 220 g/kg DM; on the other hand, for legume tops and haulms our results are in agreement with literature.²⁶ The OM degradability for these residues resulted quite high, as also reported in literature,^{8, 26} in agreement with their low cell wall content. In general, legume haulms showed better nutritive characteristics compared to pod shells, the latter having high structural content. In particular, in both soybean residues (haulms and pod shell), which nutritive value is little known, though it is the most produced legume crop in southern Africa, we found a lower crude protein content (70 to 90 g/kg DM) compared to the other legume residues. Throughout higher than cereal residues; also for metabolizable energy, OM degradability, gas and VFA production we observed low value and the fermentation kinetics resulted quite slow. These results may in part be explained by the high lignin level. Groundnut haulms, with its high nutritive value (crude protein 21.2 and NDF 37.9% DM) are the most used crop residues as animal feed in Africa.³⁰ Groundnut haulms also showed interesting *in vitro* parameters: high OM degradability and gas production, and fast fermentation kinetics. Cowpea haulms are known to be good feedstuffs for ruminants in sub-Saharan Africa, but a low DM degradability has been reported³⁴ using the nylon bag technique. In our study cowpea haulms showed better characteristics compared to pod shell, in terms of crude protein, structural carbohydrates and metabolizable energy content and, consequently in terms of *in vitro* parameters (in particular OM degradability and VFA production).

Comparing the two areas of collecting samples, the results are not easy to explain. Regarding the fermentation characteristics, residues collected in the two regions were significantly different ($P < 0.01$) for t_{max} and R_{max} for both cereal and legume crop residues. Moreover, for most of cereal residues in the Central area showed better values in terms of OM degradability and gas production, compared

to the Northern area; for VFA production the results are no so clear. For legume residues less differences appear between the two collecting area and the results are clear only for groundnut haulms: higher dOM and lower OMCV and VFA, in Central compared to Northern area. These results might be due to the differences in soil characteristics (impoverished soil vs. leached soil with concretion), climate condition [one raining season of about 6 months (May–October) versus two raining seasons (a big one from April–July and a small one from October to November)] of BEMBEREKE (Northern area) and SAVE (Central area) commune, respectively, but also to the different in crop production system, monoculture in the Northern and association of culture in the Central. However, during the transhumance period there are the mobility of cattle from their original area (Northern) when feed is rare (during dry season) to another area (Central and Southern) where feed is more available. When condition becomes good in their original area, those transhumant return back. So for both areas, it is very important to know the characteristics of the crop residues.

In Vitro Gas Production

Most of the work found in the literature on crop residues focused on their chemical composition, thus the use of the *in vitro* gas production technique to appreciate fermentation characteristics of crop residues is uncommon in sub-Saharan Africa. Later in the past,^{35, 36} it was showed that the *in vitro* gas production method appears to be a suitable technique for the evaluation of the nutritive value of forages in developing countries, where financial resources are limited. This method gives useful information about the fermentation kinetics (i.e., fermentation rate), and final products (i.e., VFA).³⁵

In this study, the final gas production recorded (OMCV) was similar to the potential value estimated by the adjusted model (A) indicating that the incubation time (120 h) is adequate to complete the fermentation process of these kinds of substrates. Moreover, in line with the chemical composition, less gas production at similar OM degradability was observed in legume compared to cereal residue crop due to the higher crude protein content; as well as slower fermentation kinetics was found in cereals compared to legumes due to the higher structural carbohydrates level. The results obtained using cow rumen fluid were quite lower than data reported for OM degradability with goat rumen fluid.⁸ The volatile fatty acids produced during the incubation give information about the energy released by carbohydrates during fermentation and directly available to the animal. In the experimental condition all the feedstuffs produced moderate levels of total VFA, however the proportion among the most important acids (acetate, propionate, butyrate) reflects that one produced in the rumen with mixed forage/concentrate ratio:³⁷ 67, 20, 7.5 and 67, 22, 8.0% of tVFA in grass and legume crop residues respectively.

5. CONCLUSION

The *in vitro* method utilized was helpful to evaluate the nutritive value and describe the fermentation kinetics of most commonly fed residues from cereal and legume. The information reported could help to better fed ruminant during the dry season in African sub-Saharan using crop residues in order to increase the productivity in small-scale farms.

Conflict of Interest

There is no conflict of interest.

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