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In vitro digestibility and fermentation kinetics of agricultural and agro-industrial by-products used in ruminant feeding in Benin Republic

Marthe Montcho [1*], Sévérin Babatounde [1], André B. Aboh [2,4], Valerie Bougouma-Yameogo[3], Guy A. Mensah [4]

[1] Zootechnical Laboratory, Faculty of Agronomic Sciences, University of Abomey-Calavi, 01 BP 526 Cotonou, Benin Republic.

[2] National University of Agriculture, BP 43, Kétou, Benin Republic

[3] Institute of Rural Development (IRD), Polytechnical University of Bobo-Dioulasso (UPB), 01 BP 1091 Bobo-Dioulasso, Burkina Faso.

[4] Center of Agricultural Research of Agonkanmey, National Institut of Agricultural Researches of Benin (INRAB), 01 BP 884 Recette Principale, Cotonou 01, Benin Republic

[*]Corresponding author: Marthe Montcho. E-mail: marthemontcho@gmail.com

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ABSTRACT

Objective: The global energy value of the feed remains essential in the choice of raw materials used in ruminant feeds.

Methodology and results: This study analyzes the variability *in vitro* of degradation parameters in the presence of rumen juice from agricultural and agro-industrial by-products. It reveals that the tuber by-products very rich in starch have a high fermentation efficiency. The by-products poor in fiber and rich in sugars are quickly degraded by the rumen microbes.

Conclusion and application of results: The estimation of the digestibility of agricultural and agro-industrial by-products through the *in vitro* feed incubation methodology in the presence of rumen juice is an effective way to categorize feeds used in small ruminant feeding in Benin republic. The digestibility of the by-products studied is related to the volumes of gas produced during the incubation. More digestible is By-product, the more gas it produces. This study strengthens the rationing tables. The By-products which is more digestible must be prioritized for production targets for fattening. Beyond the feed degradation, other constraints must be considered in the choice of agricultural and agro-industrial by-products in the development of the ruminant rations.

Keywords: by-products, digestibility, Benin Republic, rumen juice, ruminant.

INTRODUCTION

The rumen is a strict anaerobic ecosystem where a variety of microbes allows the degradation of ration constituents (Dehority, 2003). The method of producing *in vitro* gas from Menke *et al.,* (1979) is widely used today to estimate the digestibility and metabolizable energy of feed for ruminants. Measures using rumen juice, "in Sacco E method" (Orskov and Donald, 1979) and "fermentability" *in vitro* (Demarquilly, 1978) probably give a more accurate picture of degradation in the rumen. This method allows to quickly evaluate the nutritive value of feeds and to highlight the presence of elements with anti-nutritional properties in their composition. Previous studies indicate that tannins can influence *in vitro* gas production and digestibility due to their inhibitory effect on extracellular enzymes secreted by bacteria. Tannins affect the permeability of the bacterial wall by acting on the cell membranes of bacteria (Arhab, 2007) and on the efficiency of microbial growth. Moreover, the nutritive value of ruminant feed is determined by the content of the chemicals and by the rate and extent of their degradation determinate by the gas or other fermentative metabolites (Getachew *et al.,* 2004). Therefore, the measure of the degradation in the rumen of parietal constituents of concentrated feeds and agro-industrial by-products is a good predictor of the indigestible parietal fraction of feeds, which is the main determinant of their energy value in ruminants (Chapoutot *et al.,* 2010). Most publications report that *in vitro* gas production is negatively influenced by the fibrous content of feeds (Larbi *et al.,* 1998, Getachew *et al.,* 2004). This justifies the great variability of the degradation parameters of the parietal constituents of concentrated feeds and agro-industrial by-products. Evaluation of degradation of constituents in rumen is an essential step to quantify ruminal proteolysis in digestible protein systems of ruminants (Nozières *et al.,* 2007). *In vitro* "test gas" methods have acceptable repeatability and reproducibility (Rymer *et al.,* 2005a). Their cost depends on the level of automation of the system. Moreover, these methods are quick and easy to implement (Coles *et al.,* 2005). They allow the simultaneous evaluation of a large quantity of substrates. *In vitro* methods appear to be an interesting alternative to the in situ method for the study of soluble or small particle feeds. Several authors propose the evaluation by the kinetics of fermentation and degradability in presence of rumen juice to assess the power of congestion of the feed (Offner *et al.,* 2003 ; Offner and Sauvant, 2004). The criteria for fibrosity and congestion, assessment of the fast fermentable carbohydrate content, the buffering capacity and short-term *in vitro* acidogenicity as well as the short-term degradation of dry matter can be determined by Kinetic measures (Sauvant *et al.,* 2005). Furthermore, little study has been done on the degradation of parietal constituents of agricultural and agro-industrial by-products compared to fodder. This study investigated the kinetic parameters of fermentation and degradation of some agricultural and agro-industrial by-products in order to understand the factors determining their digestibility or indigestibility.

MATERIAL AND METHODS

Animal equipment and rationing: During this study, which was carried out in the laboratory of zootechnics of the Faculty of Agricultural Sciences of the University of Abomey-Calavi, four (4) West Africa dwarf goats, of about thirty kilograms were used. They were operated and a rumen cannula insert which was used to extract the rumen juice (Rumen Fistula). During the test, the animals were kept in stable and maintained with a *Panicum maximum var. C1* and concentrate ration (cotton seeds and cassava peelings) at a rate of 50 g DM/kg PV distributed in two (2) spaced cakes of 8 hours. This ration was distributed in the pre-experimental and experimental periods. The percentage composition of the diet is as follows: 70% of fresh *Panicum maximum var. C1* + 30% of concentrate (35 g/kg PV of fresh *Panicum maximum var. C1* ; 7.5 g DM/kg body weight of cotton seed and 7.5 g DM/kg body weight of cassava peelings per cake. This proportion was generally used in degradability studies in Sacco (Michalet-Doreau and Ould-Bah 1992). The cotton seeds were distributed in the morning and the cassava peelings in afternoon. The animals had permanently a mineral licking block and water.

Preparation of incubation equipment: Agricultural and agro-industrial by-products (Root and tuber by-products, fruit by-products, seeds and oilcake, pulse by-products, cereal by-products) inventoried and collected in the field in small ruminant farms were studied. A sample of 250 mg DM was taken per syringe. The incubation was carried out in 100 ml glass syringes graduated in 1 ml steps. Each syringe was equipped of stopcock with three (3) valves. The pistons were lubricated with vaseline before each incubation. The fermentations in syringe were carried out using the inoculum of Menke et *al.,* (1979). The composition area recommended by this author is 10 ml of rumen juice plus 20 ml of inoculum. Solution D is indicative of redox and solution E is a reducing solution. Solution E was prepared just before its use. The other solutions were however prepared in advance. The distilled water and the first four solutions were poured into a berlin. The addition of the reducing solution was carried out under a continuous flow of CO_2 in the solution through a join. The solution color was slightly bluish at the beginning, passed by reddish coloration and finished by a colorless state. One liter of rumen juice was taken in equal quantities from each sheep before the first manipulation. The rumen juice was transferred to a thermos flask before being transported quickly to the laboratory. The sample was immediately filtered with a 246 µm riddle and mixed with the solvent solution. The rumen juice ratio and the inoculum was 1/2. The mixture was maintained at 39°C in paddle of CO_2 during the manipulation.

Incubation technique

Step 1: Preparation of samples of agricultural and agroindustrial by-products to incubates

Samples weighing and syringes filling up were realized the day before incubation. The syringes were held vertically, neck down, on a wooden support.

Step 2: Incubation of by-products in the presence of rumen juice. During incubation, 30 ml of the fermentation mixture was injected into the syringe via the valve with three (3) stopcocks. The valve was opened by a track and the piston was pushed back to allow the air contained in the syringe to be expelled. After filling up, the syringes were placed horizontally in a drying oven initially heated to 39°C. Four (4) replicates of the same feed were systematically carried out. The temperature of the drying oven was maintained at 39°C ± 0.5°C throughout the incubation period.

Step 3: Reading the volume of product gas

The initial volume V_o was read after closing the valve. The piston position was read at hours 0, 2, 4, 6, 8, 12, 24, 48, 72, 96, 120, 144 and 168. Three syringes ''blanco'' containing only the rumen and inoculum were associated with each incubation. The average gas production in these syringes is called the ''blanco value''. It shows how much gas comes from the fermentation of the rumen juice components. It is used to correct the production of gas. The fermentability efficiency measures in syringes were all repeated during a second period following the previous protocol. This allowed for deviations associated with uncontrollable factors, such as variability of rumen juice and environmental factors.

Determination of kinetic parameters: mathematical model (France *et al.,* 1993)

The volume of gas produced at time t per g of DM of the feed is determined by the following formula:

$$V_{(t)} = \frac{\left[(V_{lu(t)} - V_{(to)}) - (V_{b(t)} - V_{b(to)})\right] \times 1000 \times 100}{(PE \times \%MS)}$$

Where: $V_{(t)}$: volume of gas produced at time t (ml) per g of DM

$V_{lu\,(t)}$: volume read at time t (ml)

$V_{(to)}$: initial volume (ml) read before the start of incubation

$V_{b\,(t)}$: volume produced by syringes blanco at time t (ml)

$V_{b\,(to)}$: initial volume of syringes blanco (ml)

DM: percentage of dry matter (%)

PE: test portion (mg).

The kinetics of gas production has been adjusted to the mathematical model of France et *al.,* (1993). The model equation establishes a theoretical kinetic curve from the observed values of gas volume. The calculation was carried out by successive iterations until the sum of the squares of the residual deviations was minimized. The parameters resulting from the modeling are the theoretical volumes, the final volume, the latency time and the fractional rates of gas production.

Statistical analysis of data: The descriptive statistics such as mean, minimum, maximum and coefficient of variation were used on the kinetic parameters of gas production data. The gas production data of agricultural and agro-industrial by-products incubated in syringes were adjusted by the mathematical model of France *et al.,* (2000). The Student Newman and Keuls test were used for the multiple comparison of means. The differences were considered significant at 95% confidence level ($p < 0.05$). These statistical analyzes were performed using software SAS version 8.02 (SAS inc; 2008).

RESULTS

Fermentation in syringes and kinetic parameters for gas production of agricultural and agro-industrial by-products in the presence of rumen juice: The kinetic parameters of gas production of agricultural and agro-industrial by-products presented in table 1 show that the time required for the adherent microbial population to grow and increase its enzyme concentration (latency time) was very low. The majority of by-products took less than half an hour to begin fermentation, namely root and tuber by-products (cassava peelings, yam peelings, potato peelings, cassava peelings or cassava sharps) which latency time is almost null. On contrary, agricultural by-products constituted of straws and stalks have a higher latency time than other by-products. Thus, the fermentation process took place very quickly, as shown by the fractional rates of gas production. Moreover, no significant difference ($p>0.05$) existed between the values obtained for the latency time. However, the time T/2, the final volume of gas produced after (Vfinal) and the potential gas production (Y) varied significantly ($p <0.001$). In general, some by-products studied have had a rapid and high production of gas. Yet, low value was recorded for rice husks, papaya peelings, *Parkia biglobosa* husks. A theoretical degradation (TD) value greater than 40% was recorded for the majority of agricultural and agro-industrial by-products studied. The level of rapidly degraded DM, corresponding to the soluble fraction, is very high with a value greater than 50% for the by-products powder of *Parkia biglobosa* ; manioc peelings; "Garigo" cassava sharps; breadfruit peelings "blèfoutou"; sweet potato peelings and banana peelings. The theoretical degradation of dry matter (DM) remains low (20-30%) for by-products sorghum husks and sorghum stalks. In general, root and tuber by-products have a high theoretical degradation average (TD) (50.55%) more than other by-product groups. By-products of legumes and by-products of cereals have an average theoretical degradation approximate (43.52% and 39.63%). The TD (47.52%) recorded at the level of fruit by-products and cakes are approximate with the respective values of 47.52 and 46.57%.

Table 1: Fermentation in syringes and kinetic parameters for gas production of agricultural and agro-industrial by-products in the presence of rumen juice

Feed resources	Latency time (h)	Time $T_{/2}$ (h)	Fractional rate $T_{/2}$ (% h)	V_{final} (ml)	Y (ml/g DM)	TD (% DM)
Root and tuber by-products						
Cassava peelings	0,00 c	7,00 b	0,100 b	307,05 a	383,81 b	51,14 a
Sharps of cassava "Garigo"	0,18 b	6,84 b	0,121 a	356,61 a	445,77 a	52,12 a
Yam peelings	0,33 a	8,37 a	0,103 b	340,72 a	425,90 a	48,38 a
Sweet potato peelings	0,16 b	7,42 b	0,110 b	362,46 a	453,08 a	50,57 a
Average	**0,16**	**7,40**	**0,10**	**341,71**	**427,14**	**50,55**
CV (%)	*7,57*	*6,80*	*3,39*	*5,88*	*5,88*	*2,20*
Fruit by-products						
Breadfruit skin	0,83 a	6,82 a	0,120 a	310,83 a	388,54 a	52,07 a
Banana peelings	0,90 a	7,22 a	0,093 a	312,24 a	390,30 a	50,39 a
Papaya peelings	0,66 b	7,32 a	0,095 a	140,00 c	175,00 c	49,09 a
Orange peelings	0,61 b	9,21 a	0,095 a	319,14 a	398,92 a	46,47 a
Pineapple peelings	0,58 b	6,78 a	0,063 b	308,86 a	386,07 a	47,09 a
Cocoa bowl	0,32 c	10,82 a	0,039 c	181,74 b	227,17 b	40,00 b
Average	**0,65**	**8,03**	**0,084**	**262,14**	**327,67**	**47,52**
CV (%)	*59,00*	*16,50*	*26,09*	*25,75*	*25,75*	*6,31*
Seeds and oilcake						
Soybean crushed	0,65 a	7,33 c	0,102 a	254,95 b	318,69 b	50,18 b
Cottonseed cake	0,44 b	10,23 b	0,054 c	214,86 c	268,58 b	42,61 b
Kernel cake	0,37 c	10,00 b	0,086 b	207,69 c	259,61 b	44,74 b
Soybean cake	1,02 a	14,06 a	0,067 c	252,34 b	315,42 b	37,27 b
Peanut cake	0,75 a	15,62 a	0,05 c	145,33 d	221,99 c	35,22 b
Copra cake	0,82a	9,25 b	0,12 a	322,01 a	402,52 a	63,38 a
Shea cake	1,16 a	7,00 c	0,17 a	132,46 d	165,57 d	52,61 b

Average	**0,74**	**6,48**	**0,09**	**218,52**	**278,91**	**46,57**
CV (%)	*22,73*	*13,45*	*21,73*	*8,60*	*8,60*	*6,31*
Pulse by-products						
Parkia biglobosa powder	0,54 b	15,45 b	0,185 a	378,88 a	473,59 a	56,71 a
Husk of *Parkia biglobosa*	0,06 d	10,96 c	0,041 c	163,09 d	178,86 d	41,02 b
Husk of soybean	0,04 d	12,25 c	0,050 c	203,33 b	254,16 b	40,42 b
Peanut coat	0,26 c	24,24 a	0,026 c	180,04 c	225,05 c	29,91 c
Dried of cowpea	0,59 b	10,78 c	0,084 b	352,91 a	441,14 a	43,19 b
Cowpea top	0,59 b	14,99 b	0,036 c	193,47 c	241,83 b	43,15 b
Peanut top	0,79 a	17,07 a	0,041 c	225,4 b	281,73 b	50,27 a
Average	**0,41**	**15,10**	**0,06**	**242,44**	**299,88**	**43,52**
CV (%)	*89,91*	*31,86*	*52,17*	*30,30*	*30,30*	*13,73*
Cereal by-products						
Maize bran	0,24 b	12,66 b	0,063 b	314,35 a	392,94 a	39,70 b
Rice bran	1,52 a	10,37 b	0,069 b	232,44 b	290,54 b	43,76 b
Dried of tchoukoutou	0,53 a	8,05 b	0,086 b	278,07 b	347,59 b	48,53 a
Sharps of rice	0,82 a	7,88 b	0,106 a	333,00 a	416,25 a	49,48 a
Husk of rice	1,53 a	8,65 b	0,075 b	111,52 d	139,40 d	44,82 b
Husk of sorghum	0,94 a	37,16 a	0,02 c	217,74 c	272,18 c	20,25 c
Stalk of sorghum	0,77 a	18,83 a	0,046 c	218,61 c	273,27 c	30,89 b
Average	**0,90**	**14,8**	**0,06**	**243,67**	**304,59**	**39,63**
CV (%)	*88,46*	*52,54*	*30,61*	*24,78*	*24,78*	*17,00*
F-value	*0,93^{ns}*	*7,23***	*1,81^{ns}*	*6,12****	*6,95****	*0,97^{ns}*

*T/2: time required to produce half of the total volume; µT/2: fractional rate of gas production at T/2; TD: theoretical degradability; Y: potential gas production at time t; CV: coefficient of variation. Ns: not significant (p>0.05); *=P<0.05; **=p<0.01; ***=p<0.001. The values followed by the same letter in the same column are not significantly different according to the Student Newman-Keuls test at the threshold of p<0.05.*

Evolution of gas production in agricultural and agro-industrial by-products: Figure 1 shows that there is very little variation in gas production between tuber by-products at the beginning of the experiment (p>0.05). The high gas production is practically reached about 48-72 hours of incubation. There is a resemblance of sweet potato peelings and sharp of cassava from volume of potential gas produced. However, very high variation of final volumes from 307.05 to 362.46 ml/g of DM is noted.

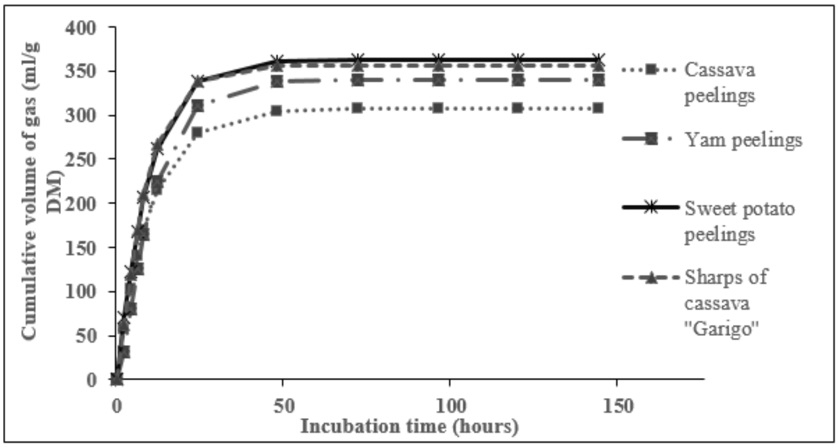

Figure 1: Cumulative gas production of root and tuber by-products at different incubation times

Figure 2 and 3 show the evolution of gas production from cake and seed by-products. It shows that gas production at the level of grain by-products is less than that of tuber by-products and ranges from 207.69 to 254.95 ml/g DM with a high value recorded in level of soybeans. On contrary, there is no significant difference between gas production and degradation of cotton and palm kernel cake (p>0.05).

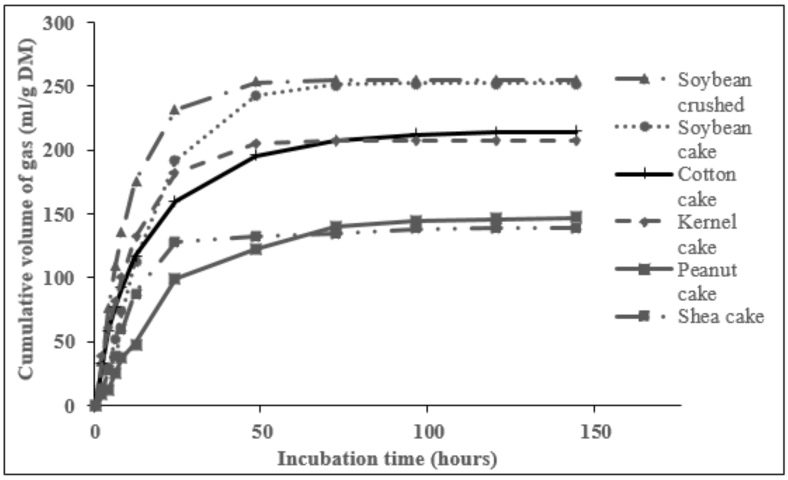

Figure 2: Cumulative gas production of cake by-products at different incubation times

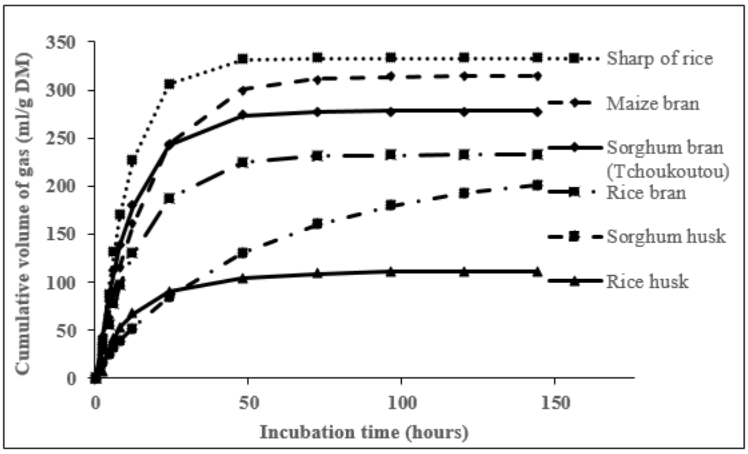

Figure 3: Cumulative gas production of cereals by-products at different incubation times

Figure 4 shows the evolution of gas production from leguminous by-products. Strong degradability has been recorded for by-products of cereal *Parkia biglobosa* powder and dried of cowpea. Moreover, by-products of peanut coats are very slightly attacked and digested by the microbes of rumen.

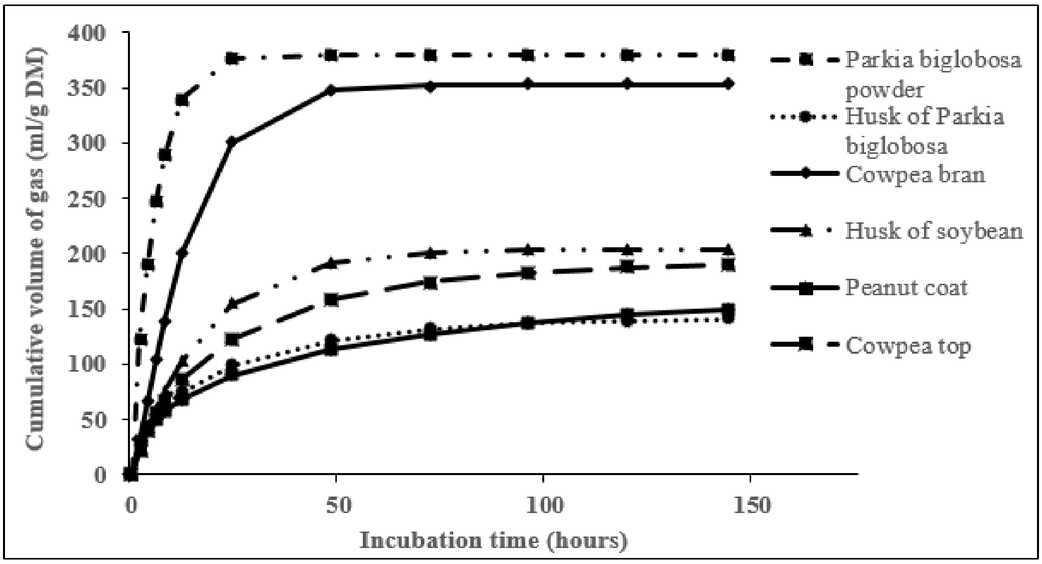

Figure 4: Cumulative gas production of pulse by-product at different incubation times

Figure 5 shows the evolution of gas production of fruit by-products. It shows that at the end of the digestion of the fruit by-products by the microbes of the rumen, there is no significant difference between the orange peelings by-products; bread fruit peelings; banana peelings and pineapple peelings. Moreover, during digestion, precisely between 20h and 100h, degradability or ruminal digestion of pineapple peelings is lower compared to banana, orange and breadfruit by-products, which have remained very high throughout of incubation.

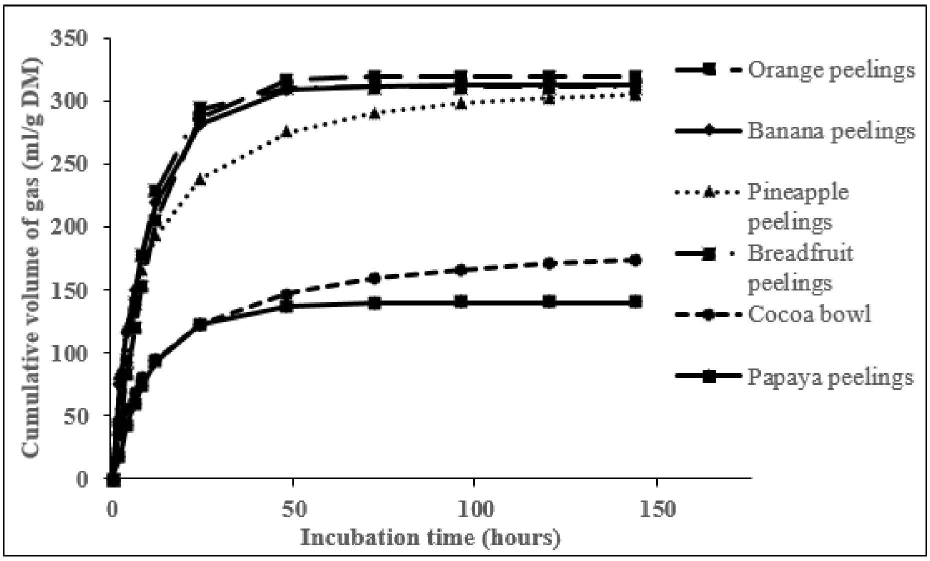

Figure 5. Cumulative gas production of fruit by-products at different incubation times.

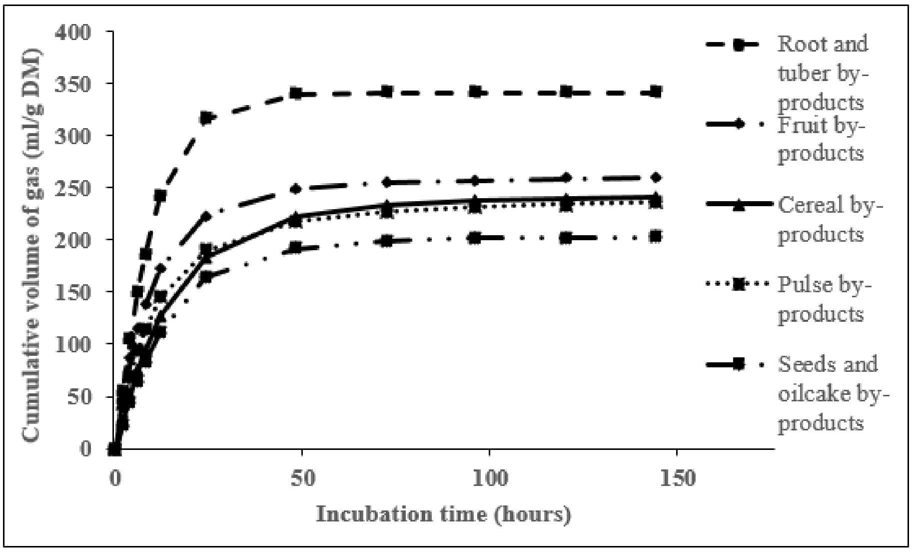

Figure 6. Evolution of gas production of different groups of by-products

DISCUSSION

Fermentation in syringes and kinetic parameters for gas production of agricultural and agro-industrial by-products in the presence of rumen juice: For the majority of the agricultural and agro-industrial by-products studied, a latency period is noted at the beginning of the fermentation. According to several authors, the almost null volume of gas production at the start of fermentation is the result of a latent phase during which microbes attach and colonize feed particles before eventual degradation (Bernard *et al.,* 2001). This finding is also reported by several authors working *in vitro* and in Sacco (El hassan *et al.,* 2000 ; Medila *et al.,* 2015). Moreover, a high degradability for tuber by-products was remarked. This is due to the high fermentation capacity of the starch contained in the tubers. Tuber starch is fermented by rumen bacteria much more quickly than coarse fodder fibers (Brindelle and Buldgen, 2004). On contrary, the low degradability or fermentability rate noted for some by-products (sorghum stalk, *Parkia biglobosa* husk) is due to their high content of parietal constituents. Indeed, the lay-out and the configuration of the parietal polysaccharides in the cell wall can affect the degradability of a substrate. High levels of fiber and secondary compounds can reduce gas production. Differences between substrates may also be due to the extent of lignification of NDF (Hervas *et al.,* 2003). Fiber content (Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), Acid Detergent Lignin (ADL)) is an important component of ruminant feed. It is the most difficult fraction to digest and when present in a large amount of feed, the fibers appear to deteriorate metabolism and fermentation in the rumen. Moreover, attachment of microbes to fibers is very rapid, but several factors such as microbial accessibility to the substrate and the chemical and physical nature of the fibers affect the speed and extent of digestion of parietal fractions (Chen *et al.,* 1987). In addition, there is a significant positive correlation between carboxy methyl cellulasic activity and *in vitro* gas production. The low theoretical degradability value (TD) noted in soybean cake (37.27%) is due to the presence of tans. The latter compounds of anti-nutritional substances can act directly on the ruminal microbiota by modifying its composition and the permeability of the bacterial membrane, as they can inhibit the enzymes involved in the degradation of cellulose compounds (Hervas *et al.,* 2003). Total condensed tans appear to have a negative correlative effect towards the end of fermentation. It should be noted that the differences between the kinetic parameters of gas production mean differences in nutritive value, which is generally closely related to the chemical composition of the substrates.

Evolution of gas production in agricultural and agro-industrial by-products: The low value of data of gas evolution obtained in the husk of rice and sorghum in the estimation of fermentable organic matter from *in vitro* degradability in the presence of rumen juice is due to the presence of hardly digestible fibers, which are degraded more slowly (Sauvant *et al.,* 2005). For the same author, these by-products such as beet pulp, rice husk, are difficult to be processed by rumen microbes, against fat rich products are overestimated unless a specific correction is made. Moreover, these high fiber feeds are also important for ruminants. Sauvant *et al.,* (2005) stresses that the lack of obstruction in rations can be a risk factor for digestive pathology and concentrated feeds and co-products can be criticized for their lack of congestion. Our results show that the volumes of gas registered at the cereal by-products are lower than those recorded for tuber by-products. This could be explained by the type of starch and the technological treatments applied during the process. It is thus possible to distinguish "slow" starch (maize, sorghum) which is poorly soluble and slowly degradable (Nozière *et al.,* 2010). Based on simple criteria, it can also be stated that the measure of the density of the treatment constitutes a good criterion to assess the degradability of the starch of maize and sorghum having undergone different types of hydrothermal treatments (Offner *et al.,* 2003). About the rice by-products, we noted a highly significant difference between the rice sharp and rice bran. Michalet-doreau *et al.,* (2010) published that during the operation of rice bleaching which aims to rid the grain of the various layers of the pericarp that envelop it, the flour is impoverished in fiber and is enriched with starch. It explains the variation in the degradability of these flours. According to the same author, the study of the chemical composition (crude cellulose content) of these by-products makes it possible to distinguish two populations, the big bran as one category, the fine bran and the sharp as second category. This distinction is found in the degradability of feed nitrogen. Indeed, the degradability of the bran depends essentially of the diagram of the initial cereal ground. It increases significantly by 76% for a big bran to 84% for a fine bran or a white sharp. The volume of very high gas observed in certain fruit by-products could be explained by their fewer parietal constituents and richness in easily fermentable sugars. Wang and Eastridge, (2001) showed that fodders are naturally fibrous and rich in NDF and ADF and are known to negatively affect digestibility and in particular the production of gas in vitro. For Schmidely and Sauvant, (2001), cottonseed cake contains cyclopropenoic fatty acids (malvalic and sterculic acids) which are potent inhibitors of the Δ9 desaturase enzyme activity involved in the transformation of fatty acids and degradation. Cottonseed cake is mainly valued in ruminants but contains an antinutritional factor, gossypol which has intrinsic toxicity and also decreases the biological value of proteins (Gamboa *et al.,* 2001a, 2001b ; Azman and Yilmaz, 2005), by its fiber content (Gamboa *et al.,* 2001a ; Ojewola *et al.,* 2005). The use of cottonseed cake in animal production is limited by antinutritional factors such as gossypol, which is present in the seed coats. It is therefore not recommended to use this product in equal quantities with other protein feeds such as soybean and groundnut cake (Diaw *et al.,* 2011). According to Hervas *et al.,* (2003) the high final volume of soybeans is related to the high degradability of soybeans. Sauvant *et al.,* (2005) underline a high degradability of oleaginous and products rich in lipid during management in the rumen. Indeed, their low lignified insoluble fraction is easily accessible to the ruminal microbiota (Gihad *et al.,* 1989). Michalet-Doreau *et al.,* (2010) in his study on "Concentrated ruminant feeds: in situ degradability in rumen" has made an overall classification of raw materials and classifies protein and oilseed grains as feeds whose nitrogen fraction is highly degradable. According to the same author, the by-products of proteinaceous and oleoproteaginous seeds have a strong fermentable capacity in the presence of rumen juice. This justifies the high volume of gas recorded in soybeans.

CONCLUSION

This study on important number of different agricultural and agro-industrial by-products allowed to show a high variability of their degradation kinetic in presence of rumen juice. It also enabled us to highlight the main factors that make it possible to understand the variations observed in these various by-products. The lignin, fiber, sugars and fat contents are the essentially factors which determine the agricultural and agro-industrial by-products degradation by rumen microbes during *in vitro* digestibility in the presence of rumen juice. The lignin, fiber, sugar and lipid content are among the factors that determine the degradation of agricultural and agro-industrial by-products by rumen microorganisms during in vitro digestibility in the presence of rumen juice.

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Appendix: Chemical composition of agro-industrial by-products

Feed resources	DM	CT	OM	CP	NDF	ADF	CF	GM
Root and tuber by-products								
Yam peelings	88,99 ± 0,02 **c**	5,50±0,27 **b**	93,97±0,25 **b**	7,99±0,01 **a**	75,31±0,31 **a**	66,19±0,02**a**	4,44±0,15 **c**	0,32± 0,01**c**
Cassava peelings	92,75 ± 0.05 **a**	5,45±0,10 **b**	94,67±0,02 **b**	5,26±0,08 **b**	60,89±0,03 **c**	49,36±0,66**c**	9,96±0,02 **a**	1,80±0,08 **a**
Sweet potato peelings	88,80±0,15 **c**	7,56±0,24 **a**	92,82±0,14 **c**	8,04±0,04 **a**	53,59±0,25 **d**	43,20±0,49**d**	5,51±0,02 **b**	0,87±0,03 **b**
Sharps of cassava "Garigo"	90,60 ± 0.07 **b**	0,92 ±0,02 **c**	99,25±0,10 **a**	1,69±0.09 **c**	66,77± 0,05 **b**	57,77±0,025**b**	2,15±0,05 **d**	0,91±0.05 **b**
Average	90,28±0,59 **B**	4,85±0,92 **C**	95,18±0,92 **A**	5,74±0,98 **B**	64,14±3,01 **A**	54,13 ±3,3**AB**	5,51±1,07 **C**	0,97±0,20 **B**
Minimum	**88,65**	**0,90**	**92,68**	**1,60**	**53,34**	**42,71**	**2,15**	**0,31**
Maximum	**92,80**	**7,80**	**99,35**	**8,08**	**75,63**	**66,22**	**9,98**	**1,88**
CV (%)	**1,87**	**53,58**	**2,74**	**48,29**	**13,27**	**17,14**	**54,98**	**58,13**
Fruit by-products								
Banana peelings	85,99±0,29 **d**	14,87±0.02 **b**	85,13 ±0.04 **d**	6,66 ±0,05 **c**	53,29 ±0,10 **e**	46,99 ±0,05 **e**	9,84 ±0.21 **d**	4,59 ±0.07 **a**
Orange peelings	92,89±0,01 **a**	9,84±0,001 **d**	90,35 ±0,18 **b**	6,87 ±0,02 **c**	63,22 ±0,03 **d**	41,19 ±0,04 **f**	14,03±0,05 **b**	2,88 ±0,03 **b**
Pineapple peelings	91,39±0,16 **b**	10,10 ±0,01 **c**	89,94 ±0,03 **c**	6,39 ±0,16 **d**	62,64 ±0,09 **d**	54,96 ±0,02 **c**	12,17±0,10 **c**	1,44 ±0,22 **d**
Breadfruit peelings	93,11±0,39 **a**	7,73 ±0,12 **e**	92,47 ±0,08 **a**	7,12 ±0,09 **b**	69,43 ±0,43 **c**	50,77 ±0,04 **d**	8,76 ±0,01 **e**	1,99 ±0,02 **c**
Papaya peelings	91,13±0,03 **b**	31,30±0,02 **a**	68,77 ±0,04**e**	1,77 ±0,02 **e**	92,96±0,005 **a**	56,19±0,02 **b**	8,95 ±0,01 **e**	3,15±0,10 **b**
Cocoa bowl	85,99 ± 0,10 **c**	7,55 ± 0,01 **e**	92,61 ±0,15 **a**	31,97 ±0,01 **a**	91,30 ± 0,05**b**	66,39±0,04 **a**	38,56± 0,03 **a**	0,97 ±0,01 **e**
Average	90,6733±0,72**B**	13,56±2,49 **A**	86,54±2,51 **C**	10,13±2,99 **B**	72,14±4,49 **A**	52,75±2,3 **AB**	15,4 ±3,17**AB**	2,50±0,36 **B**
Minimum	**85,97**	**7,54**	**68,73**	**1,75**	**53,27**	**41,15**	**8,75**	**0,96**
Maximum	**93,51**	**31,32**	**92,77**	**31,99**	**92,97**	**66,44**	**39,60**	**4,66**
CV (%)	**2,78**	**63,82**	**10,04**	**102,45**	**21,58**	**15,62**	**71,49**	**50,31**
Cereal by-products								
Sorghum bran	93,98±0,035 **b**	13,70 ±0,03 **b**	81,87 ±0,09 **f**	19,50 ±0,12 **a**	64,74 ±0,09 **d**	50,90 ±0,05 **f**	15,15 ±0,01 **d**	10,13 ±0,08 **b**
Maize bran	92,75 ±0,015 **d**	5,13 ±0,03 **f**	94,93 ±0,03 **b**	14,84 ±0,05 **c**	65,56±0,035 **c**	62,61 ±0,02**d**	6,70 ±0,02 **f**	1,60 ±0,02 **d**
Husk of sorghum	92,61 ±0,075 **e**	4,49 ±0,26 **g**	95,65 ±0,02 **a**	4,05 ±0,015 **e**	87,33 ±0,09 **b**	82,66 ±0,01 **b**	29,19±0,00 **c**	2,98 ±0,05 **c**
Husk of rice	93,57±0,03 **c**	24,77 ±0,04 **a**	75,21 ±0,03 **g**	1,89 ±0,025 **g**	87,24 ±0,05 **b**	76,22 ±0,02 **c**	37,68 ±0,08 **b**	0,98 ±0,01 **e**
Stalk of sorghum	94,53 ±0,015 **a**	6,56 ±0,23 **e**	93,69 ±0,01 **c**	3,29 ±0,15 **f**	91,59 ±0,04 **a**	89,88 ±0,03 **a**	45,18 ±0,02 **a**	0,64 ±0,025 **f**
Sharps of rice	90,10 ±0,005 **g**	7,49 ±0,035 **d**	92,57 ±0,01 **d**	10,72 ±0,04 **d**	48,05 ±0,01**e**	62,04 ±0,01 **e**	1,68 ±0,15 **g**	0,29 ±0.002 **g**
Rice bran	91,49 ±0,002 **f**	11,52 ±0,01 **c**	88,55 ±0,04 **e**	17,14 ±0,01 **b**	45,51 ±0,001 **f**	29,10 ±0,01**g**	10,11 ±0,14**e**	12,80 ±0,01 **a**
Average	92,72 ± 0,39 **A**	10,54 ±1,8**AB**	88,92±1,97**BC**	10,20±1,84 **B**	70,006±4,9 **A**	64,774±5,3 **A**	20,8±4,27 **AB**	4,206±1,30 **B**
Minimum	**90,10**	**4,33**	**75,18**	**1,87**	**45,50**	**29,09**	**1,67**	**0,28**
Maximum	**94,55**	**24,82**	**95,67**	**19,60**	**91,63**	**89,91**	**45,20**	**12,81**
CV (%)	**1,58**	**64,83**	**8,31**	**67,76**	**26,23**	**30,63**	**76,77**	**116,35**
Pulse by-products								
Husk of soybean	93,66± 0,045 **a**	5,6±0,030 **e**	94,77±0,05 **c**	5,90±0,015**e**	89,12±0,010 **a**	77,31±0,07 **a**	49,11±0,066**a**	0,65±0.015**f**

Husk of *Parkia biglobosa*	85,81±0,04 **g**	5,80±0,015 **d**	94,26±0,05 **d**	0,32±0.008**g**	72,34±0,055 **c**	59,32±0,1**b**	21,77±0,05**d**	1,11±0,024**d**
Parkia biglobosa powder	88,59±0,065 **e**	5,00 ±0,045 **f**	95,15±0,10 **b**	4,49±0.06**f**	33,80±0,015 **g**	24,31±0,02 **g**	10,82±0,04**g**	0,96±0.001**e**
Dried of cowpea	92,07±0,040 **c**	3,96±1.90 **g**	96,04±0,015**a**	17,29±0,015**b**	76,96±0,035 **b**	53,64±0,01 **d**	14,87±0,03**e**	0,97±0.016**e**
Cowpea top	92,01±0,05 **d**	11,66±0,015 **a**	88,46±0,015 **g**	13,48±0,035d	71,44±0,04 **d**	56,28±0,02 **c**	30,50±0,05**b**	2,15±0.01**c**
Peanut top	86,92±0,025 **f**	6,57±0,025	93,46±0,03 **e**	15,48±0,18**c**	65,63±0,10 **f**	43,52±0,05 **f**	22,09±0.035**c**	10,45±0.035**b**
Peanut coat	92,36±0.04 **b**	11,19±0.01 **b**	88,81±0.038 **f**	20,42±0.019**a**	67,27±0,30 **e**	46,54±3.80 **e**	12,98±0,025**f**	14,14±0.41**a**
Average	90,20±0,78 **B**	7,11±0,78 **BC**	93±0,79 **AB**	11,07 ±1,91 **B**	68,08 ± 4,36 **A**	51,56 ±4,17 **B**	23,17±3,40 **A**	4,35±1,42 **B**
Minimum	**85,77**	**3,95**	**88,40**	**0,30**	**33,79**	**24,29**	**10,82**	**0,65**
Maximum	**93,71**	**11,72**	**96,06**	**20,44**	**89,13**	**77,33**	**49,12**	**14,17**
CV (%)	**3,25**	**41,28**	**3,18**	**64,80**	**23,97**	**30,26**	**54,95**	**122,78**
Seeds and oilcake								
Cottonseed cake	92,9 ±0,01 **c**	7,35±0,015 **b**	92,68±0,02 **e**	33,43±0,01 **c**	63,45±0,035 **e**	51,37±0,01 **c**	13,57±0,04 **c**	16,85±0,01 **d**
Kernel cake	93,06±0.015 **c**	4,45±0.02 **f**	95,59±0,02 **a**	19,78±0,067**g**	62,76±0,39 **f**	43,84±1.02 **f**	10,49±0.11 **f**	22,05±0.25 **b**
Soybean cake	93,29±0,025 **c**	7,85±0.11 **a**	92,22±0,045 **f**	31,51±0,03 **d**	73,58 ±0,19 **a**	46,13±0,11 **e**	17,68±0.65 **a**	20,72±0,08 **c**
Copra cake	91,9±0.42 **d**	5,40±0.08 **e**	94,41±0,21 **b**	22,94±0.035**f**	65,15 ±0,04 **d**	58,32±0.32 **b**	0,96±0.002 **g**	44,89±0,02**a**
Shea cake	95,16±0.085 **b**	7,78±0.050 **a**	92,38±0.11 **ef**	27,43±0.15 **e**	68,86±0.025 **c**	60,23±0.05 **a**	11,17±0.07 **e**	14,26±0.03 **f**
Peanut cake	90,97±0.40 **e**	6,11 ±0.001 **d**	93,94±0.001 **c**	54,28±0.99 **a**	39,67±0.17 **g**	17,91±0.77 **g**	16,50±0.13 **b**	0,89±0.00 **g**
Soybean crushed	96,12±0.075 **a**	6,77±0.66 **c**	93,46±0.22 **d**	34,81±0.01 **b**	72,15±0.01 **b**	50,45±0.01 **d**	11,65±0.002**d**	16,26±0,04 **e**
Average	93,34±0,45 **A**	6,53±0,32 **BC**	93,52± 0,31 **A**	32,04±2,89 **A**	63,66±2,92 **A**	46,89±3,61 **B**	11,71±1,4 **CB**	19,41±3,38 **A**
Minimum	**90,92**	**4,43**	**92,19**	**19,78**	**39,64**	**17,81**	**0,90**	**0,88**
Maximum	**96,20**	**7,90**	**95,62**	**54,33**	**73,70**	**60,28**	**17,75**	**44,91**
CV (%)	**1,84**	**18,88**	**1,25**	**33,76**	**17,16**	**28,85**	**44,84**	**65,25**
Valeur de F	***4,67****	***3,83****	***3,77***	***15,39****	***0,57**	***2,27***	***3,40***	***11,64****

DM: Dry Matter; CP: Crude Protein; CF: Crude Fiber; OM: Organic Matter; GM: Grass Matter. The values followed by the same letter in the same column are not significantly different according to the Student Newman-Keuls test at the threshold of p<0.05.
Source: Montcho et al., 2016