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CHEMICAL COMPOSITION, DEGRADABILITY AND METHANE EMISSION POTENTIAL OF BANANA CROP RESIDUES FOR RUMINANTS

[COMPOSICIÓN QUÍMICA, DEGRADABILIDAD Y POTENCIAL EMISIÓN DE METANO DE RESIDUOS DE CULTIVO DE BANANA UTILIZADOS EN LA ALIMENTACIÓN DE RUMIANTES]

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SUMMARY

Banana leaf hay (BL), banana pseudostem hay (BP), coast-cross hay (CC), 50% coast-cross hay with 50% banana leaf (BLCC) and 50% coast-cross hay with 50% pseudostem hay (BPCC) were evaluated for chemical composition, cumulative gas production, dry matter degradability and methane emission potential. Inoculums from sheep and cattle were collected to tests. The experimental design was completely randomized in a factorial arrangement of 5 x 2, being data analysed by variance analysis and the means compared by Tukey test (5%). The crude protein levels for the substrates BL, BP, CC, BLCC and BPCC were respectively 13.8%, 3.5%, 8.6%, 9.7% and 6.1%. Despite its low protein level, the BP substrate had higher content of non-fibrous carbohydrates (28.4%), followed by BL (23.4%), BPCC (23.4%), BLCC (20.0%) and CC (13.3%). The highest cumulative gas production was observed for BP ($P < 0.05$), reflecting their greater effective degradability (76.3%). This substrate showed the largest emissions of methane (34,16 mL/g DMD).

Keywords: food evaluation; semi-automated *in vitro* gas production technique; alternative forages; banana plant; methane.

RESUMEN

Para determinar la composición química, cantidad de gases producidos, degradación de la material seca y potencial producción de metano, muestras de Heno de hojas de bananera (BL), heno de pseudotallos de bananera (BP), heno de coast-cross (CC), 50% de heno de coast-cross y 50% de heno de hojas de bananera y finalmente, 50% de heno de coast-cross e 50% de heno de pseudotallos de bananera, fueron analizados. Muestras de líquido ruminal de ovejas y bovinos fueron obtenidas para los análisis. El diseño experimental fue totalmente aleatorio en esquema factorial de 5x2, los resultados obtenidos fueron sometidos al análisis de varianza y las medias encontradas comparadas por el método de Turkey (5%). Las concentraciones de proteína bruta para BL, BP, CC, BLCC y BPCC, fueron respectivamente, 13.8%, 3.5%, 8.6%, 9.7% e 6.1%. Apesar de presentar bajas concentraciones de proteína, el tratamiento con BP presentó alta concentración de carbohidratos no fibrosos (28.4%), seguido por BL (23.4%), BPCC (23.4%), BLCC (20.0%) y CC (13.3%). La alta producción acumulada de gas fue observada en BP ($P < 0.05$), esto como resultado de eficiente degradabilidad (76.3%). Este alimento presentó las mayores emisiones de metano. La substitución de 50% de heno de coast-cross por heno de hojas de bananera o por heno de pseudotallos de bananera mejoraron la fermentación del pasto, se observó un aumento de 22.9-36.0% y 11.9-59.1% en la degradación efectiva y potencial máximo de producción de gas, respectivamente, sugiriendo la posibilidad de uso de estos residuos en la alimentación de rumiantes.

Palabras clave: análisis de alimentos; técnicas semiautomáticas de producción de gas *in vitro*; forrajes alternativos; bananeira; metano.

INTRODUCTION

Ruminant production in tropical countries is characterized by the use of grass as the main nutritional source. This food is usually offered as pasture, predominantly in extensive systems, subjecting the animals to periodic shortages of forage (Alencar and Pott, 2003).

The reduction in supply along with the low nutritional value of grasses in the dry season affect animal performance negatively and increase methane emissions from enteric fermentation, a concerning factor from today's environmental point of view.

To minimize problems caused by seasonal pasture supply and reduce production costs, the use of agricultural residues in the diet of ruminants has been proposed. The use of crop residues can bring benefits to the ruminant's diets and in many cases ensure an increase in food availability, improved production efficiency and an economic and appropriate disposal of these subproducts (Araújo and Alves, 2005; Moraes, 2007).

Characterized by a high production of residues, which can reach 200 tons / hectare / year of fresh matter (Moreira, 1999), the banana plant (*Musa* spp.) has a great potential for ruminant feeding. According to Manica (1997), the leaves and upper two-thirds of the pseudostems, which constitute the major part of the subproducts resulting from the cultivation practices of banana, can be incorporated into diets for the animals.

The chemical composition of banana varies, depending mainly of the cultivar and the plant structure. In studies conducted by Bezerra *et al*. (2002), the chemical analysis of leaf and pseudostem of bananas showed levels of 12. 1% and 3. 3% of crude protein, respectively.

As well as being a potential feeding alternative for ruminants in the dry season, the banana is characterized by the presence of tannins in different cultivars (Kimambo and Muya, 1991; Olivo *et al*., 2007) that can promote a reduction in methane emissions resulting from enteric fermentation, since this polyphenol substance has been associated with reduced methanogenic activity in the digestive process of ruminants (Waghorn, 2007; Woodward *et al.*, 2001).

In addition to the chemical analysis, a more accurate evaluation the ruminant's diet requires an estimation of kinetic ruminal fermentation and degradability values, which can be obtained by the semi-automated *in vitro* gas production technique (Theodorou *et al*, 1994). With this technique, the gas chromatography allows to estimate the volume of methane produced during forage's fermentation process.

Thus, the aim of this study is to evaluate the fermentation kinetics and ruminal degradability of leaf and pseudostem hays of the banana plant, pure and in inclusion levels of 50% coast-cross hay, comparing the inoculum from sheep and bovine.

MATERIAL AND METHODS

Banana plants of the Prata Anã variety, at the stage of harvest, were randomly selected at the Agricultural Sciences Institute of the Federal University of Minas Gerais (UFMG), located in Montes Claros, Minas Gerais state, Brazil, latitude 16°44'06"S and longitude 43°51'43"W. The leaves and the upper two thirds of the pseudostem of these plants were collected and cut mechanically in particles between 2 and 3 cm, followed by sun drying until the humidity levels were between 10% and 12%. The coast-cross hay (*Cynodon dactylon*) was purchased commercially in the region for comparison and to test the replacement levels in relation to banana crop residues.

Laboratory tests were conducted at the Laboratory of Animal Nutrition of Clean Water Farm, University of Brasilia (UNB), located in Vargem Bonita, Federal District, Brazil, latitude 15°94'49.23"S and longitude 47°93'15.44"W, and at Center for Nuclear Energy in Agriculture, University of São Paulo (USP), located in Piracicaba, São Paulo state, Brazil, latitude 22°70'75.12"S and longitude 47°64'46.69"W.

Hay samples were crushed in a Willey Mill with a sieve of 1 mm. The dry matter's content was then determined and the following substrates were prepared for analysis: banana leaf hay (BL), banana pseudostem hay (BP), coast-cross hay (CC), and coast-cross hay with the inclusion level of 50% banana leaf or pseudostem hays (BLCC and BPCC).

The five substrates were subjected to chemical analysis to determine the following: dry matter (DM) at 105°C, crude protein (CP) using the Kjeldahl method (AOAC, 1995), neutral detergent fiber (NDF), acid detergent fiber (ADF), neutral detergent insoluble protein (NDIP) and acid detergent insoluble protein (ADIP) by the sequential method (Van Soest *et al.*, 1991), ether extract (EE) by the Soxhlet process and mineral matter (MM) according to AOAC (1995).

The total carbohydrates (TC) were estimated according to the equation proposed by Sniffen *et al*. (1992), CT = 100 - (%CP + %EE + %MM), while the content of non-fiber carbohydrates (NFC) was calculated by the difference between the levels of TC and NDF, taking into account mineral matter and protein values (NDFmp), according to Hall *et al*. (1999).

In accordance to the methodologies described by Matos (1997) and Mouco *et al*. (2003), qualitative phytochemical tests were performed for the detection of tannins in the banana leaf hay, pseudostem hay and coast-cross hay.

The semi-automated *in vitro* gas production technique proposed by Theodorou *et al*. (1994) and modified by Mauricio *et al*. (1999) was used to determine the ruminal kinetics fermentation and degradability of the substrates. For this purpose, one male bovine and two sheep (all adult, male and castrated) from UNB were used as inoculums donors. The bovine was maintained in pasture (*Brachiaria brizantha*), while the sheep remained in the stable receiving fresh tifton (*Cynodon nlemfuensis*). Both groups were receiving mineral mixture and water *ad libitum* and sheep received an extra of 150g / animal / day of concentrated supplement.

A 1.0g Samples of the substrates were weighed and sealed in ANKOM® bags, which were introduced in glass bottles with measured capacity of 160mL, previously identified and filled with CO_2 in order to maintain the anaerobic environment (Beuvink and Spoelstra, 1992). 90mL of media tamponant culture were added to the bottles (Theodorou *et al.*, 1994) and 10mL of ruminal inoculum, and the bottles were once again filled with CO_2 and sealed with rubber stoppers. After manual shaking to mix the contents, the flasks were randomly placed in a drying oven with forced air convection at 39°C.

A total of 196 flasks were incubated, 16 containing only ruminal fluid and the media tamponant culture as control, used to determine the production of gas from the rumen content for the correction of the net production of gases by substrates fermentation. The 180 remaining bottles corresponded to three repetitions per treatment (BL, BP, CC, BLCC and BPCC) for each inoculum (sheep and bovine), with six replicates used to determine the dry matter degradability (DMD) at different intervals.

The pressure readings were taken at 2, 4, 6, 8, 12, 16, 20, 24, 30, 36, 48, 72 and 96 hours after incubation with a pressure transducer (Press Data model) connected to a valve of three outputs, being one output connected to the transducer, the second to a 25 mm x 0. 7 mm needle and the third output was used to remove the gas after reading.

The pressure data obtained in PSI was used to calculate gas volume with the equation described by Guimarães Jr *et al*. (2008), for the conditions of temperature and atmospheric pressure of Planaltina, Federal District, Brazil: Volume (mL) = 4.50231 * pressure (PSI) + 0.05164 * pressure^2 (R^2 = 0.996).

The kinetics of gas production in each treatment was determined by the model described in France *et al*. (1993) using the Solver tool in Microsoft Excel 2010 software:

$Y = A \{1 - \exp^{[-b*(t-L) - c*(\sqrt{t} - \sqrt{L})]}\}$:

Y = cumulative gas production (mL),

A = maximun gas production potential (mL),

L = lag time (h),

b (h^{-1}) e c ($h^{-0,5}$) = fractional rate constants, and

t = time (h).

The average fractional rate (h^{-1}) of gas production (μ) was calculated by:

$\mu = b + c / (2\sqrt{t})$, being μ = gas production rate (h^{-1}).

After pressure readings 24 and 48 hours post-incubation, six bottles of each treatment were collected, three per inoculum, to determine the concentration of methane. The percentage of methane was determined through a flame ionization detector (FID) in a Shimadzu GC-14A gas chromatograph (GC) using a standard methane gas (50%) at 240°C for the detector and at 60°C for the shincarbon ST micro packed column.

After reading and collecting the gas at 2, 6, 12, 24, 48 and 96 hours post-incubation, six bottles of each treatment, three per inoculum, were removed and placed on ice to stop fermentation. The bag containing the degraded sample was removed from each flask, which was washed multiple times with distilled water and then washed with acetone solution and rinsed to remove microbial mass. They were then dried at 105°C for 24 hours and the degradable fraction of the dry matter was determined by the relationship between the percentage of material initially incubated and the residue obtained in each period.

The effective degradability (ED), using a passage rate of 2% / h, was calculated by the equation proposed by France *et al*. (1993), using the Solver tool in the Microsoft Excel 2010 software:

$ED = S_0 e^{-kT} (1 - kI) / (S_0 + U_0)$:

k = passage rate,

S_0 = initially fermentable fractions,

U_0 = unfermentable fractions,

$I = \int L^{\infty} \exp -[(b + k)(t - T) + c(\sqrt{t} - \sqrt{T})]dt$

The experimental design adopted consisted of complete randomization in a 5 x 2 factorial, with the factors representing the substrates (BL, BP, CC, BLCC, and BPCC) and inoculum (sheep and bovine). Data for cumulative gas production, DMD and methane volume produced per gram of degraded dry matter, obtained at different time intervals, was subjected to variance analysis and the means compared by the Tukey test at a 5% significance level, through of SAS software (2000).

RESULTS

The chemical composition of banana leaf hay (BL), banana pseudostem hay (BP) and coast-cross hay (CC), and inclusion levels of 50% banana leaf or pseudostem hays to coast-cross hay (BLCC and BPCC) is showed in Table 1.

According to methodologies described by Matos (1997) and Mouco *et al*. (2003), the phytochemical analysis of the banana leaf and pseudostem hays indicated the presence of hydrolysable and condensed tannins, which were not observed in the coast-cross hay.

Table 2 shows the results of dry matter degradability of the substrates after 24, 48 and 96 hours fermentation. A significant interaction (P = 0,0327) between the substrate and the donator species was observed only in the period of 48 hours incubation, with the CC and BLCC showing higher fermentation in sheep inoculum when compared to the bovine inoculum.

In all the intervals the banana pseudostem hay showed the highest degradability averages, while the coast-cross hay had the lowest rates of dry matter disappearance, with the exception of the 48 hours post incubation period in sheep inoculum. The Table 2 showed also that inclusion of banana leaves and banana pseudostem hays increased the degradability of coast cross.

The *in vitro* ruminal fermentation kinetic parameters of the substrates, adjusted to the model described by France *et al*. (1993) are shown at Table 3.

Table 1. Chemical composition of banana leaf hay (BL), banana pseudostem hay (BP) and coast-cross hay (CC), and inclusion levels of 50% banana leaf or pseudostem hays to coast-cross hay (BLCC and BPCC).

SUBST.	DM (%)	CP (%)	MM (%)	EE (%)	NDF (%)	ADF (%)	NDIP (%)	ADIP (%)	TC (%)	NFC (%)
BL	92.7	13.8	9.7	5.2	61.1	38.7	54.3	21.2	71.1	23.4
BP	93.0	3.5	12.4	1.3	64.6	36.2	66.2	20.2	82.6	28.4
CC	92.5	8.6	5.5	3.8	77.8	45.1	56.0	25.8	82.0	13.3
BLCC	92.6	9.7	7.2	4.3	69.1	42.4	55.8	26.0	78.7	20.0
BPCC	92.8	6.1	8.3	2.3	69.2	40.6	61.6	22.9	83.2	23.4

Dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), neutral detergent insoluble protein (NDIP), acid detergent insoluble protein (ADIP), ether extract (EE), mineral matter (MM), total carbohydrates (TC) and non-fiber carbohydrates (NFC).

Table 2. *In vitro* dry matter degradability (%) after 24, 48 and 96 hours fermentation of banana leaf hay (BL), banana pseudostem hay (BP) and coast-cross hay (CC), and inclusion levels of 50% banana leaf or pseudostem hay to coast-cross hay (BLCC and BPCC) in ruminal inoculum from sheep and cattle.

SUBSTRATE	24 h	48 h		96 h
		sheep	cattle	
BL	40.1 B	57.3 Ba	53.0 Ba	58.5 C
BP	48.3 A	64.1 Aa	65.3 Aa	77.8 A
CC	32.8 C	50.6 Ba	38.2 Cb	46.3 D
BLCC	38.4 B	54.1 Ba	46.8 Bb	55.6 C
BPCC	40.4 B	51.8 Ba	52.6 Ba	63.0 B
CV (%)	6.7	7.2		3.5

Means followed by different capital letters in the same column or different lower case letters in the line, in each interval, differ from each other by Tukey test ($P < 0.05$).

Table 3. Kinetic parameters of dry matter fermentation of the banana leaf hay (BL), banana pseudostem hay (BP) and coast-cross hay (CC), and inclusion levels of 50% banana leaf or pseudostem hays to coast-cross hay (BLCC and BPCC) in ruminal inoculum from sheep and cattle.

SUBSTRATE	ED (%)	A (mL/gDM)		L (min)		μ (%/h)	
		sheep	Cattle	sheep	cattle	sheep	cattle
BL	58.2	120.0	112.0	49	61	2.1	3.5
BP	76.3	271.1	257.9	318	324	4.5	6.3
CC	46.3	117.0	122.6	207	150	3.6	4.5
BLCC	57.0	175.3	137.3	52	122	3.6	3.6
BPCC	63.0	186.2	189.1	178	90	4.4	4.1

ED = effective degradability calculated for passage rate of 2%/h, A = maximum gás production potential, L = lag time, e μ = gas production rate.

The banana pseudostem hay had higher results when compared to other substances in the effective degradability analysis. When 50% of banana leaf or pseudostem hay were added, the coast-cross presented, respectively, an increase of 22.9% and 36.0% in the effective degradability when compared to pure coast-cross hay. The same effect was observed in the maximum potential gas production, where the addition of banana crop hay residues caused an increase in this parameter.

The Table 4 presents the cumulative gas production averages after 24, 48 and 96 hours of fermentation, being that in all times there was a significant interaction (P = 0,0001; P = 0,0003; P = 0,0034; respectively) between substrate and inoculum.

According to the Table 4, the inclusion of 50% of banana leaf hay to coast-cross hay caused a significant increase in gas production when using the sheep inoculum. This effect, however, did not occur when using the bovine inoculum

The volume of methane produced after 24 and 48 hours of fermentation differed between treatments, as can be seen in Table 5. At 24 hours of incubation there was also a significant interaction (P = 0.0021) between the factors evaluated. Regarding the difference in methane production between the inoculum for the substrates CC, BLCC and BPCC, only the second showed a higher volume of methane for the ovine species.

Table 4. Cumulative gas production averages (mL/gDM) after 24, 48 e 96 hours of fermentation of banana leaf hat (BL), banana pseudostem hay (BP) and coast-cross hay (CC), and inclusion levels of 50% banana leaf or pseudostem hay to coast-cross hay (BLCC and BPCC) in ruminal inoculum from sheep and cattle.

SUBSTRATE	24h		48h		96h	
	sheep	cattle	sheep	Cattle	sheep	cattle
BL	35.6 Ca	45.8 Ca	66.7 Ca	78.6 Ca	100.1 Ca	105.9 Da
BP	89.2 Ab	115.1 Aa	181.6 Ab	198.9 Aa	259.1 Aa	260.7 Aa
CC	37.5 Cb	52.8 Ca	71.6 Ca	86.1 Ca	109.1 Ca	119.7 CDa
BLCC	78.7 Aba	53.0 Cb	127.5 Ba	93.0 Cb	168.0 Ba	129.5 Cb
BPCC	70.0 Bb	88.7 Ba	127.1 Ba	138.7 Ba	180.8 Ba	186.4 Ba
CV (%)	11.5		7.6		6.4	

Means followed by different capital letters in the same column or different lower case letters in the line, in each interval, differ from each other by Tukey test (P < 0. 05).

Table 5. Methane volume produced per gram of dry matter degraded (mL/gDMD), during 24 and 48 hours of fermentation of banana leaf hay (BL), banana pseudostem hay (BP) and coast-cross hay (CC), and inclusion levels of 50% banana leaf or pseudostem hay to coast-cross hay (BLCC and BPCC) in ruminal inoculum from sheep and cattle.

SUBSTRATE	24h		48h
	sheep	cattle	
BL	4.5 Ca	6.2 Ca	11.9 D
BP	16.1 Aa	17.5 Aa	34.1 A
CC	4.3 Cb	8.7 Ca	15.8 CD
BLCC	12.0 Ba	6.6 Cb	19.4 C
BPCC	8.9 Bb	12.8 Ba	24.4 B
CV (%)	19.		11.2

Means followed by different capital letters in the same column or different lower case letters in the line, in each interval, differ from each other by Tukey test ($P < 0.05$).

DISCUSSION

The crude protein content of banana pseudostem hay (3.56%), even with the added 50% coast-cross hay (6.10%), performed poorly. Similar results have been reported in other studies for this part of the banana tree, according to research conducted by Andrade (1984). According to Minson (1990), CP levels below 7% may compromise the maintenance of ruminal microbiota, resulting in a lower degradability of food and reducing the consumption of dry matter, and reducing the animal's performance. The other samples showed CP levels similar to those found in the main tropical forages (Euclides and Medeiros, 2003), especially the banana leaf hay, whose CP approaches to the nutritional requirements for bovine and sheep feeding (NRC, 2000, NRC, 2007).

The NDF values found for all substrates, except for the coast-cross, approaches those described for *Panicum* grasses, 65-75% (Euclides, 1995), *Brachiaria*, 55 to 77% (Miles *et al.*, 1996) and *Cynodon*, 65 to 74% (Cecato *et al.*, 2001), being these some of the main forages used for ruminants in tropical countries. According to Allen (2000), higher levels of NDF in food are related to a lower dry matter intake and this limitation, caused by the rumen fill, is evidenced in diets with NDF content above 60% (Berchielli *et al.*, 2006).

The 77.82% NDF content found in coast-cross hay, although high, is in agreement with the research of Melo *et al*. (2001), who found values ranging from 71.2% to 85.0% depending on the time of year the material was collected. The ADF was also higher for the coast-cross hay, with the value of 45.11% in this present study being slightly less than that described by Gonçalves *et al*. (2003) for tifton hay (*Cynodon nlemfuensis*), ranging from 46.6% to 50.4%, with cutting ages from 28 to 84 days after regrowth.

The neutral detergent insoluble protein is slowly degraded in the rumen, and it is also important to correctly estimate the value of non-fiber carbohydrates (NFC). The acid detergent insoluble protein is a protein fraction unavailable to the animal and is associated with lignin and other compounds of hard degradation (Licitra *et al.*, 1996). Both the NDIP and ADIP were high on all substrates evaluated in this study, corresponding to an average of 58.8% and 23.2% of the CP, respectively. Reis Jr *et al*. (2011) found NDIP and ADIP values of 50.7 and 16.6%, respectively, in the coast-cross hay, which is below what was observed in this study for the same food. According to Euclid and Medeiros (2003), in tropical forages which had no thermal treatment at temperatures above 60°C, the proportion of protein attached to NDF is generally 40-50% of CP, while the fraction of the protein complexed to ADF ranges from 5 to 10% of CP.

The observed values of total carbohydrate present is within the standards used in ruminant diets (Berchielli *et al.*, 2006). As for the non-fiber carbohydrates, the 13.36% content in coast-cross hay was slightly higher than that found by Cabral *et al*. (2000) for this hay (12.79%), being lower, however, when compared to the values found for other substrates in this study. The banana pseudostem hay had the highest percentage of NFC (28.45%). The values observed for this substrate are close to those observed by Campos *et al*. (2010) in sorghum silage, 27.3%, and corn, 29.9%. The NFC are important because they constitute the primary source of energy for rumen microorganisms and, consequently, for ruminants, present in sugars and starch their cell content and by pectin, which, despite present in the plant cell wall, is totally soluble in neutral detergent and of an extensive and fast degradation (Mizubuti *et al.,* 2011; Van Soest, 1994).

Regarding the degradability of the substrates, the highest values were found in banana pseudostem hay, which can be attributed to its lower percentage of cell walls, with higher levels of NFC than most tropical grasses. According to Kimambo and Muya (1991), the lower degradability of banana leaves, when compared to the pseudostems, is also related to the higher content of tannins in the leaves, making fractions of carbohydrate and protein for fermentation unavailable for ruminal microorganisms.

The 40.16% of degradability obtained in 24 hours of fermentation for banana leaf hay approaches that found by Keir *et al*. (1997), who observed in the same period a rate of 40.2% degradability for fresh banana leaves, using the *in situ* technique in bovine. However, with 48 hours of incubation the study shows a rate of 48.4% degradability, which is slightly below to the average of 55.1% found in this present study.

The cumulative gas production observed with 24, 48 and 96 hours fermentation of banana leaf hay was lower than the values found by Keir *et al*. (1997), who evaluating the same parameter with the same periods of incubation of fresh banana leaves in ruminal inoculum from bovine found values of 71.0, 99.5 and 123.0mL/gDM. In the present study, however, showed that the addition of 50% of coast-cross hay to banana leaf hay improved the fermentation process, possibly due to dilution levels of tannin, resulting in a cumulative gas production of 78.7, 127.5 and 168.0mL/gDM in sheep ruminal inoculum and 53.0, 93.0 and 129.5mL/gDM in bovine inoculum, with 24, 48 and 96 hours of fermentation. This significant difference found between species in the fermentation of the BLCC substrate, with higher cumulative gas production in sheep, can be attributed to its major tolerance to the anti-nutritional effects of tannins when compared to the bovine species.

According to Tomich *et al*. (2003), assuming that the gas production reflects the degradation of the tested sample, the rate and the maximum potential of gas production are the main factors for evaluating the quality of forages. Taking these parameters into account, we can infer in this study that the banana pseudostem hay presented better fermentative quality since its maximum potential and its rate of gas production in both inoculums were higher than in other substrates.

The lag time represents the time between the start of incubation and the microbial action on the substrate evaluated, with its reduction due to the presence of soluble compounds and physical and chemical characteristics of the food's cell wall (Tomich *et al*. 2003). Thus, despite the higher non-fiber carbohydrate content, we can suggest that the concentration of soluble carbohydrates in banana pseudostem hay is lower than that found in the banana leaf hay and coast-cross hay, which would explain the colonization being slower in that substrate.

A higher content of non-fiber carbohydrates and lower concentrations of NDF and ADF, both characteristic of higher quality forages, are generally related to a lower proportion of dietary energy converted to methane (Blaxter and Clapperton 1965, Machado et al., 2011). However, in this study, the volume of methane produced by banana pseudostem hay did not reflect their better fermentative quality and chemical composition. Similar results were observed by Canesin *et al*. (2010), who found higher values of methane production per gram of dry matter degraded in a diet with lower concentrations of NDF and ADF using the *in vitro* semi-automated gas production technique to evaluate the methane production from marandu grass (*Brachiaria brizantha* cv Marandu) supplemented with different percentages of concentrate, and linked this result to higher fermentation rates.

The condensed tannins have been frequently mentioned as an inhibitor compound of methanogenic activity. Woodward *et al*. (2001) and Puchala *et al*. (2005) observed that small ruminants fed with forages rich in condensed tannins emitted lesser volumes of methane than those who received plants with lower levels of these metabolites. Although in this paper the methane production did not differ significantly between the coast-cross hay and banana leaf hay, we can suggest that the lower emissions of methane by the latter can be associated with the presence of condensed tannins, due to the fact that their higher degradability did not cause an increase in gas production

CONCLUSIONS

The banana leaf and pseudostem have nutritional characteristics that allow their use as alternative forage in ruminant feed, like a high content of non-fiber carbohydrates, and crude protein level above the average of tropical grasses, for the leaf.

The inclusion of 50% of banana leaf or pseudostem hay can improve the standard of ruminal fermentation in diets based on grass, increasing the effective degradability of the diet.

Despite the higher levels of non-fibrous carbohydrates and better standard of ruminal fermentation, the pseudostem hay showed methane production higher than the other tested substrates, which represents a greater loss of dietary energy.

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