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Chemical-bromatological composition and *in vitro* ruminal kinetics of sugar cane silage with maniçoba

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ABSTRACT. The objective this study was to evaluate the effect of maniçoba supplementation in sugar cane silage with respect to chemical-bromatological composition and the *in vitro* degradation kinetics of the silage. This experiment was conducted in a completely randomized design with four treatments (maniçoba levels: 0, 20, 30, and 40%) and six repetitions. Silage samples were analyzed for their chemical-bromatological composition, digestible energy, metabolizable energy, total digestible nutrients, *in vitro* gas production and degradability parameters. The silage with higher inclusion level had better bromatological composition ($p < 0.05$) than the silage without maniçoba for CP, NDF, ADF and MM (6.49, 56.64, 38.66 and 4.52% *versus* 2.21, 70.96, 49.95 and 2.78%). Higher ME content (2.35 MJ kg^{-1} MS *versus* 1.85 MJ kg^{-1} MS), DE (2.87 Mcal kg^{-1} MS *versus* 2.25 Mcal kg^{-1} MS) and TDN (65.16% *versus* 51.11%), respectively. The highest values for gas production were also observed in silage with added maniçoba due to higher NFC content (34.87%). With an increase in the proportion of maniçoba, there was an increase in the soluble *a* fraction, *b* fraction, and thus a higher effective degradability of dry matter (46.56%). The addition of maniçoba improves the nutritive value of sugarcane silage.

Keywords: degradation; forage conservation; gas production; *Saccharum officinarum*.

Composição químico bromatológica e cinética ruminal *in vitro* em silagens de cana de açúcar com maniçoba

RESUMO. O objetivo do presente trabalho foi avaliar a inclusão de maniçoba à silagem de cana de açúcar na composição químico bromatológica e cinética de degradação *in vitro*. Foi elaborado experimento em delineamento inteiramente casualizado com quatro tratamentos (níveis de inclusão: 0, 20, 30 e 40%) e seis repetições. As silagens foram analisadas quanto à sua composição químico bromatológica, energia digestível, energia metabolizável, nutrientes digestíveis totais, produção de gases *in vitro* e determinação dos parâmetros de degradabilidade. A silagem com maior nível de inclusão apresentou melhor composição bromatológica ($p < 0,05$) que a silagem sem maniçoba para PB, FDN, FDA e MM (6,49, 56,64, 38,66 e 4,52% *versus* 2,21, 70,96, 49,95 e 2,78%). Maior conteúdo de EM (2,35 MJ kg-1 MS *versus* 1,85 MJ kg-1 MS), ED (2,87 Mcal kg-1 MS *versus* 2,25 Mcal kg-1 MS) e NDT (65,16% *versus* 51,11%), respectivamente. Os maiores valores de produção de gás também foram observados em silagens com adição de maniçoba em função dos maiores conteúdos de CNF (34,87%). À medida que se aumentou a proporção de maniçoba, houve incremento da fração *a*, da fração *b* e, consequentemente, maior degradabilidade efetiva da matéria seca (46,56%). A adição de maniçoba melhorou o valor nutritivo da silagem de cana de açúcar.

Palavras-chave: conservação de forragem; degradação; produção de gás; *Saccharum officinarum*.

Introduction

Sugar cane is regarded as an alternative feed for the dry season. The daily cutting of sugar cane for use as fresh forage, however, demands a large amount of manpower. As a result, producers have opted for sugar cane silage as an alternative (Fortaleza et al., 2012). Besides improving the efficiency of harvesting, sugar cane silage ensures forage availability during periods of food scarcity. However, sugar cane has limited use because of its low crude protein (4%) and minerals, and high alcoholic fermentation when ensiled, compromising the nutritional quality of the food (Nussio, Susin, Mendes, & Amaral, 2009).

The nutritional deficiencies of sugar cane forage can be reduced with the addition of forage of higher nutritive value, such as maniçoba (*Manihot pseudoglaziovii*), which has a higher protein content of 20.6% (Silva et al., 2011). Maniçoba is native to semiarid environments and so is resistant to hot and dry climatic conditions. The cyanogenic glycosides that maniçoba contains are easily volatilized by hay and silage processing. Studies conducted by Carvalho, Queiroz, Silva, and Voltolini (2014) demonstrate the importance of using maniçoba in sugar cane silage to improve the fermentative dynamic. Furthermore, the use of maniçoba represents a better utilization of the forage resources available.

The nutritional quality of food is related, among other factors, to its digestibility. Many attempts have been made to predict the quality of food using laboratory techniques that simulate the process of digestion. Among these, the technique of cumulative gas production provides an estimation of digestibility, the rate of fermentation of different food fractions, and ruminal microbial synthesis (Muniz et al., 2012). It is a low-cost technique, capable of evaluating a large amount of substrate, and it presents a high correlation with *in vivo* digestibility.

This study aimed to evaluate the chemical-bromatological composition, the kinetics of *in vitro* gas production, and the parameters of ruminal degradation in sugar cane silage with increasing levels of maniçoba.

Material and methods

This study was conducted at Embrapa Semiárido and at the Laboratory of Bromatology and Animal Nutrition/Univasf in Petrolina, PE, Brazil. To prepare the silage, 24 silos consisting of plastic buckets of 25 liters' capacity were used. The experiment was conducted in a completely randomized design with four treatments (levels of inclusion of maniçoba: 0, 20, 30, and 40%) and six replications.

The forage was harvested by hand at a phenological stage of 18 months for the sugar cane and 8 months for the maniçoba. It was then separately chopped to particle sizes smaller than 2 cm and compacted by trampling, while maintaining the proper proportions (0, 20, 30, and 40% maniçoba by shoot area throughout to replace the sugar cane, based on the natural matter of both). Each silo was then sealed with a cover and adhesive tape, and kept in a protected area at room temperature.

After 90 days of storage the silos were opened, the ends were discarded, and the material was sampled. The samples were dried in an oven with forced air (55°C for 72h) and ground in a knife mill with a 1-mm sieve, the dry matter content (DM) was determined. Chemical-bromatological analyses of mineral matter (MM) (Association of Official Analytical Chemists, AOAC, 2005) (942.05), crude protein (CP) (AOAC, 2005) (954.01) and ether extract (EE) (Am 5-04: American Oil Chemists' Society, AOCS, 2009) were as a percentage of dry matter. The ratio of acid detergent insoluble nitrogen to total nitrogen (ADIN/TN), and acid detergent insoluble protein (ADIP) were made following the procedures of Licitra, Hernandez, and Van Soest (1996). Measurements of neutral detergent fiber (NDF), neutral detergent fiber free from ashes and protein (NDFap), and acid detergent fiber (ADF) were performed according to Van Soest, Robertson, and Lewis (1991), and hemicellulose (HEMI) was calculated as the difference between NDF and ADF.

A chemical-bromatological analysis of the sugar cane and maniçoba before ensiling was performed according to the methods described below (Table 1).

Table 1. Chemical-bromatological composition of the sugar cane and maniçoba used in the production of silage.

Forage	DM	MM	CP	EE	NDF	ADF
	--------g kg^{-1} DM--------					
Sugar cane	290.0	17.0	21.3	10.5	651.0	308.0
Maniçoba	335.0	61.0	123.8	34.0	450.0	284.3

The total carbohydrate content (TC) was calculated by the equation:

$$[100 - (\mathrm{PC} + \mathrm{EE} + \mathrm{MM})]$$

as proposed by Sniffen, O'Connor, Van Soest, Fox, and Russell (1992). The non-fibrous carbohydrates (NFC) were estimated by the equation:

$$[100 - (\mathrm{CP} + \mathrm{NDFap} + \mathrm{EE} + \mathrm{MM})]$$

as proposed by Mertens (1997).

To determine gas production *in vitro*, it was used the method described by Theodorou, Williams, Dhanoa, McAllan, and France (1994), modified by Mauricio et al. (1999). Rumen fluid was collected through a fistula from two Holstein cattle with an average weight of 500 kg, after the animals had been kept on the diet of forage (sugar cane) *ad libitum*, along with concentrate (based on corn and soybean meal) containing 10% CP to meet the requirement for maintenance of cattle according to NRC (2001).

To estimate gas production and degradation,1-g samples of silages were packed in nylon bags of known weight and added to fermentation flasks (160 mL) that had been previously injected with CO_2 (three bottles per treatment). To each flask, 90 mL of culture medium (pH 6.9–7.0) and 10 mL of ruminal fluid and filtrate were added (Mauricio et al., 1999). Bottles containing only rumen fluid and culture medium were used as controls. The flasks were sealed with rubber stoppers and then incubated. From that point, the pressure of the gases produced by the fermentation of the substrate and accumulated in the bottles was measured using a pressure transducer at 2, 4, 6, 8, 10, 12, 15, 19, 24, 30, 36, 48, 72, 96, and 120h, and the pressure measurements were converted to volumes.

In order to estimate the gas production kinetic parameters of the silage we used the bicompartmental logistic model proposed by Schofield, Pitt, and Pell (1994), adjusted to cumulative gas production curves, according to equation:

$$V(t) = \frac{Vf1}{[1 + e^{(2-4m1(L-T))}]} + \frac{Vf2}{[1 + e^{(2-4m2(L-T))}]}$$

where: V = total volume of gases; Vf_1 = maximum volume of gas production from the fraction of non-fiber carbohydrates; m_1 = degradation rate (%/h) of the fraction of non-fiber carbohydrates; T = incubation time (h); L = lag time (h); Vf_2 = maximum volume of gas production from the fraction of fibrous carbohydrates; and m_2 = degradation rate (%/h) of the fraction of fibrous carbohydrates.

Pressure readings were taken more frequently during the initial fermentation. The degradability of DM was estimated at 2, 6, 12, 24, 48, 96, and 120h of incubation *in vitro*. To evaluate the potential degradation of dry matter we used the equation $PD = a + b(1 - \exp^{c \times t})$ proposed by Mehrez, Ørskov, and McDonald (1977). To determine the effective degradation we used the expression:

$$ED = a + (b \times c)/(c + K_p)$$

from Ørskov and McDonald (1979). The passage rate was assumed to be 5% h^{-1}.

Metabolizable energy (ME) was calculated according to Robinson, Givens, and Getachew (2004) as follows:

$$ME\ (MJ\ kg^{-1}\ DM) = 1.25 + (0.0292 \times gas_{24}) + (0.0246 \times EE) + \big(0.0143 \times (PB - ADIP)\big),$$

where gas_{24} is the gas production over 24 h of *in vitro* incubation (mL 0.2 g^{-1} DM). The values of crude protein (CP), ether extract (EE), and mineral matter (MM) were expressed in g kg^{-1} DM. Subsequently, the digestible energy (DE) and total digestible nutrients (TDN) were estimated according to NRC (2001) as follows:

$$DE\ (Mcal.Kg^{-1}) = ME/0.82, \text{ and}$$

$$TDN\ (\%) = DE/4.409 \times 100.$$

The results were analyzed by the Statistical Analysis System (SAS, 2003) computer program (Version 9.1), and normality was previously verified by the Shapiro-Wilk test (Proc Univariate); variances were compared by orthogonal contrasts at a significance level of 5% using Proc GLM. As the levels were not equidistant between treatments, PROC IML was used to generate the vectors for each contrast (linear, quadratic, and quadratic deviation). PROC REG determined the parameters of the regression equations if contrast analyses were significant.

Results and discussion

The addition of maniçoba increased ($p < 0.05$) the content of DM, MM, EE, and CP of the silages compared to the control, with maximum values of 284.7, 45.2, 20.7 and 64.9 g kg^{-1} DM, respectively, in silage with the highest (40%) maniçoba inclusion levels (Table 2).

Table 2. Chemical-bromatological composition (g kg^{-1} DM) of sugar cane silage with maniçoba: dry matter (DM), mineral matter (MM), ether extract (EE), crude protein (CP), ratio of acid detergent insoluble nitrogen to total nitrogen (ADIN/TN), acid detergent insoluble protein (ADIP), neutral detergent fiber (NDF), ash and protein-free neutral detergent fiber (NDFap), acid detergent fiber (ADF), and hemicellulose (HEMI).

	Maniçoba level (%)					P Value	
Variable	0	20	30	40	SEM	L	Q
DM	252.0	266.4	273.1	284.7	0.447	<.0001	0.6544
MM	27.8	36.1	40.6	45.2	0.091	<.0001	0.7156
EE	14.3	13.5	20.7	20.7	0.164	<.0001	0.2488
CP	22.1	43.7	56.3	64.9	0.053	<.0001	0.2298
ADIN/TN	3.0	3.8	3.3	3.9	0.024	0.0501	0.7082
ADIP	6.3	16.4	18.7	25.2	0.109	<.0001	0.8871
NDF	709.6	693.4	645.4	566.4	0.764	<.0001	0.0002
NDFap	695.5	670.5	618.5	520.6	0.442	<.0001	<.0001
ADF	492.5	452.3	430.7	386.6	0.515	<.0001	0,0623
HEMI	217.0	241.2	214.8	17.98	0.443	0.0346	0.0047

	Regression Equation	R^2
DM	$\hat{y} = 251.2 + 0.79x$	0.63
MM	$\hat{y} = 27.7 + 0.432x$	0.93
EE	$\hat{y} = 13.1 + 0.19x$	0.89
CP	$\hat{y} = 22.3 + 1.09x$	0.99
ADIP	$\hat{y} = 6.34 + 0.46x$	0.88
NDF	$\hat{y} = 709.4 + 2.04x - 0.14x^2$	0.92
NDFap	$\hat{y} = 695 + 2.19x + 0.16x^2$	0.97
ADF	$\hat{y} = 497.5 - 25x$	0.90
HEMI	$\hat{y} = 217.5 + 3.07x - 0.1x^2$	0.94

SEM = standard error of the mean; R^2 = coefficient of determination.

The DM content of the fresh maniçoba was higher (320 g kg^{-1}) than the DM content of the sugar cane before ensiling (290 g kg^{-1}), and it provided an increase of 0.08% in DM for each 1% inclusion. However, the dry matter content of the silage was less than in the forage. According to Schmidt et al. (2007), sugar cane contains high levels of soluble carbohydrates and an epiphytic yeast population responsible for alcoholic fermentation, and this cause excessive loss of DM. Carvalho et al. (2014) succeeded in reducing DM losses by adding maniçoba to sugar cane silages, corroborating the importance of the use of this supplemental forage.

With the addition of maniçoba, the MM content increased linearly. For each 1% addition, MM increased 0.04%. This can be explained by the higher MM content observed in the maniçoba (Table 1), which is evidenced by the major difference between NDF and NDFap (Table 2) when maniçoba is included in the silage. The inclusion of maniçoba also linearly increased EE content because the maniçoba presented higher EE content before ensiling. Souza et al. (2010) found values of 43 g kg^{-1} DM and 27 g kg^{-1} DM of EE in fresh maniçoba and in maniçoba as silage, respectively. Before ensiling, maniçoba showed greater crude protein (CP) than cane, which resulted in a linear increase in this nutrient in the silage. For every 1% inclusion, there was an increase of 0.11% in protein content, so with the addition of 40% maniçoba, the silage showed a CP content of 64.7 g kg^{-1} DM.

As a result of higher crude protein, silage with greater percentages of maniçoba had higher concentrations of ADIP: 25.2 g kg^{-1} DM, as against the 6.3 g kg^{-1} DM found in silage made exclusively of cane. However, the amount of nitrogen available for the animals, as measured by ADIN/NT, was not influenced ($p > 0.05$).

The highest levels of NDFap (702.4 g kg^{-1} DM) were estimated by the regression equation for silage with 6.7% maniçoba, and this variable may have influenced the content of hemicellulose, which in turn showed its highest value (24.0 g kg^{-1} DM) with 15.2% maniçoba.

ADF content decreased linearly ($p < 0.05$) with increasing maniçoba content: for each additional percentage point of included maniçoba, the ADF content decreased 0.25%. However, even for silage with higher maniçoba content, the ADF values were higher than with sugar cane alone. According to Pedroso et al. (2007), fibrous components become more concentrated in sugar cane silage dry matter due to the loss of soluble carbohydrates during ensiling. Rezende et al. (2009) also observed a linear ADF relationship in sugar cane silage with the addition of potato scrap (0, 7, 14, 21, and 28%). In this case, each percentage unit of added potato reduced ADF by 0.81%.

Cumulative gas production was influenced by the addition of maniçoba (Figure 1), and the highest values were observed in silage with a higher proportion of maniçoba, indicating potentially more degradation by faster fermentation of NFC and slower of fiber fraction.

There was a difference between treatments ($p < 0.05$) in the total carbohydrate content (TC) and non-fiber carbohydrate content (NFC) (Table 3). The lowest value of NFC (219.0 g kg^{-1} DM) was estimated for silage with 11.7% maniçoba. The total carbohydrate content (TC) decreased by 0.17% for each 1% of maniçoba added. This can be explained by the similar decrease in the carbohydrate components already mentioned (ADF and NDF), and by the subtraction of the MM values when calculating CT.

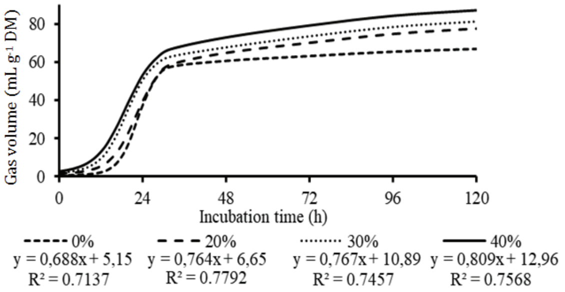

Figure 1. Estimation of gas volume according to incubation time for different levels of maniçoba in sugar cane silage.

Table 3. Maximum volume of gas production from non-fiber carbohydrates, fibrous carbohydrates and total (Vf1; Vf2; V, in mL g^{-1} DM); rate of gas production from non-fiber carbohydrates and fibrous carbohydrates (m_1; m_2, in mL g^{-1} DM h^{-1}); lag time (L, in h); total carbohydrate and non-fiber carbohydrate (TC; NFC, in g kg^{-1} DM) of sugar cane silage with maniçoba.

	Maniçoba level (%)				SEM	P Value	
Variables	0	20	30	40		L	Q
Vf_1	63.08	60.16	58.19	62.14	1.77	0.3934	0.5562
Vf_2	12.15	20.16	23.75	25.28	0.37	<.0001	0.0623
V	75.23	80.32	81.95	87.42	1.65	0.0011	0.4271
m_1	0.09	0.07	0.07	0.06	0.004	<.0001	0.4211
m_2	0.01	0.01	0.01	0.01	0.0002	0.0720	<.0001
TC	935.7	906.8	882.4	869.3	0.18	<.0001	0.4276
NFC	240.2	236.3	263.9	348.7	0.56	<.0001	<.0001

	Regression Equation	R²
Vf_2	$\hat{y} = 12.78 + 0.3391x$	0.96
V	$\hat{y} = 74.78 + 0.2868x$	0.73
m_1	$\hat{y} = 0.09 - 0.001x$	0.64
m_2	$\hat{y} = 0.01 + 0.0001x - 0.000002x^2$	0.70
TC	$\hat{y} = 93.68 - 0.1703x$	0.97
NFC	$\hat{y} = 24.12 - 0.37x + 0.0158x^2$	0.93

SEM = standard error of the mean; R^2 = coefficient of determination.

Sugarcane silage has fermentation characterized by high ethanol production and high disappearance of soluble carbohydrates, which may lead to losses of dry matter, reduction in nutritive value and high effluent production (Cavali et al., 2010). The higher ethanol production and effluent losses in cane silage found by Carvalho et al. (2014), allows us to infer that the soluble carbohydrates initially present in the sugar cane were consumed in the silage process, while the inclusion of maniçoba favored the production of organic acids in detriment to the ethanol production of the effluent losses.

The inclusion of maniçoba improved the fiber quality of the silages, which provided the highest total gas production (V), since only the volume of gas from fibrous carbohydrates (Vf2) increased ($p < 0.05$), while the volume of gas of non-fibrous carbohydrates was not influenced. The total gas production (V) increased by 0.29% for each 1% of maniçoba added.

The rate of gas production from non-fiber carbohydrates (m_1) decreased linearly by 0.001% for each percentage point of additional maniçoba. The same behavior was not observed for the rate of gas production from fibrous carbohydrates (m_2), which had its highest value (0.011 mL g^{-1} DM h^{-1}) at the 25% inclusion level. There was a greater total carbohydrate content at that level, and this possibly influenced the result.

Despite its effect on non-fibrous carbohydrates, the addition of maniçoba did not affect the maximum volume of gas production from these components (Vf_1). However, the maximum volume of gas production from the fibrous component (Vf_2) increased linearly, even though the 40% inclusion level showed lower levels of NDFap, a fact that allows us to infer that the inclusion of maniçoba improves degradability of the fibrous components of sugar cane silage. These results were similar to those found by Moreira et al. (2014). NFC exhibits high degradability in the rumen and rapid gas production, while cellulose and hemicellulose are characterized by slow ruminal degradation. NFC is readily available for microbial degradation and exhibits a rapid rate of fermentation, while the fibrous carbohydrate must initially be colonized by microorganisms to be degraded, and even then has a slow fermentation rate (Van Soest, 1994).

With respect to ruminal degradation, there was an increase in the soluble *a* fraction according to the level of maniçoba inclusion (Table 4). The silage with 40% maniçoba had an *a* fraction 40.9% greater than the silage comprising solely of sugar cane; however, the *b* fraction was 39.6% lower in this treatment. The *a* fraction increased 0.36% whereas the *b* fraction decreased 0.41% for each percentage unit of maniçoba. This can be explained by the fermentation profile, which, in general, is characterized by faster fermentation of NFC, and slower fermentation of the fibrous constituents. The *c* fraction (undegradable) did not differ between treatments.

The degradation rate of the *b* fraction (Kd) increased 0.04% h^{-1} with the addition of 40% maniçoba. Besides presenting the smallest *b* fraction, the cane silage with 40% maniçoba showed higher Kd values, which explains, in part, the greater degradation under this treatment. Fortaleza et al. (2012) studied the *in situ* degradability of sugar cane silage treated with chemical additives and bacteria and found approximate DM degradation rates of 0.018, 0.030, 0.050, and 0.026% h^{-1} for silage with added urea inoculant, sodium hydroxide, and calcium hydroxide, respectively.

Table 4. Degradation parameters of sugar cane silage with added maniçoba (*a*, *b*, *c*, PD, and ED in g kg^{-1} DM; Kd in % h^{-1}).

	Maniçoba level (%)				SEM	P Value	
Variable	0	20	30	40		L	Q
a	216.9	251.1	302.8	366.9	1.71	<.0001	0.0812
b	408.0	255.4	288.8	246.2	2.01	<.0001	0,3146
c	375.1	393.5	408.4	386.9	0.90	0.4355	0.4890
Kd	0.01	0.02	0.03	0.05	0.005	<.0001	0.1243
PD	624.9	606.5	591.6	613.1	0.90	0.4980	0.4322
ED	267.4	325.2	389.2	465.6	2.23	<.0001	0.1034
	Regression Equation						R^2
a	$\hat{y} = 20.25 + 0.364x$						0.90
b	$\hat{y} = 41.7 - 0.41x$						0.83
Kd	$\hat{y} = 0.008 + 0.001x$						0.78
ED	$\hat{y} = 25.28 + 0.48x$						0.93

SEM = standard error of the mean; R^2 = coefficient of determination; RE = regression equation; ns = not significant.

Adding maniçoba had no effect ($p > 0.05$) on potential degradability of dry matter (PD), possibly because the silage had the same undegradable *c* fraction (391 g kg^{-1} DM). The effective degradability (ED); however, increased 0.48% with each 1% inclusion. These results can be explained by the increase in DM content, the smaller fibrous constituents, and the higher NFC content observed in silage with maniçoba. The highest effective degradability (465.6 g kg^{-1} DM) was observed in silage containing 40% maniçoba. Rossi Júnior and Schogor (2006) found similar values for degradability (452 g kg^{-1} DM) of sugar cane silage treated with 1% urea. Sugar cane silage with maniçoba positively influences the performance of animals fed with this silage compared to the control. In evaluating the digestibility of sugar cane silage with *Lactobacillus*, urea, and agricultural by-products, a higher rate of degradation of the *b* fraction (0.027% h^{-1}) was found (Maeda et al., 2011), as well as higher consumption (7.54 kg DM d^{-1}) in cattle fed with sugar cane silage with inoculants (Maeda et al., 2012).

The levels of digestible energy (DE), metabolizable energy (ME), and total digestible nutrients (TDN) increased linearly by 0.013%, 0.017%, and 0.378%, respectively, for each percentage unit of maniçoba addition (Table 5).

Ferro, Castro, Zanine, and Souza (2017) found similar behavior of ME (linear increase) although with higher values in sugarcane silage with dehydrated barley residue. According to Campos et al. (2010), total digestible nutrient content (TDN) is a parameter widely used for quantifying the energy available from food. The TDN value of silage without maniçoba addition (511.1 g kg^{-1} DM) was similar to those observed by Pedroso, Rodrigues, Barioni Júnior, and Souza (2011a) and Pedroso et al. (2011b). As maniçoba was added, however, there was an increase in this value, which can be explained by higher levels of CP and higher gas production after 24 h, thus demonstrating the usefulness of maniçoba inclusion in improving sugar cane silage quality.

Table 5. Metabolizable energy (ME, MJ kg^{-1} DM), digestible energy (DE, MJ kg^{-1} DM), and total digestible nutrients (TDN, g kg^{-1} DM) of sugar cane silage with maniçoba.

	Maniçoba level (%)				SEM	P Value	
Variable	0	20	30	40		L	Q
ME	1.85	2.02	2.32	2.35	0.055	<.0001	0.7505
DE	2.25	2.47	2.83	2.87	0.070	0.002	0.7330
TDN	511.1	559.9	641.0	651.6	1.520	<.0001	0.7396

	Regression Equation	R^2
ME	$\hat{y} = 18.3 + 0.136x$	0.79
DE	$\hat{y} = 505.8 + 0.117x$	0.79
TDN	$\hat{y} = 505.8 + 3.8x$	0.79

SEM = standard error of the mean; R^2 = coefficient of determination; RE = regression equation.

Conclusion

The addition of maniçoba improved the nutritional quality and the chemical-bromatological composition of sugar cane silage, and altered the kinetics of gas production. The highest level of maniçoba inclusion (40%) improves gas production as well as the degradation parameters, thereby yielding a higher value for effective degradability of dry matter.

References

Association Official Analytical Chemist [AOAC]. (2005). *Official Methods of Analysis* (18th ed.). Gaitherburg, MD: AOAC International.

American Oil Chemists' Society [AOCS]. (2009). *Official Methods and Recommendations Practices of AOCS*. Denver, CO: AOCS.

Campos, P. R. S. S., Valadares Filho, S. C., Detmann, E., Cecon, P. R., Leão, M. I., Lucchi, B. B., ... Pereira, O. G. (2010). Consumo, digestibilidade e estimativa do valor energético de alguns volumosos por meio da composição química. *Revista Ceres, 57*(1), 79-86.

Carvalho, F. A. L., Queiroz, M. A. A., Silva, J. G., & Voltolini, T. V. (2014). Características fermentativas na ensilagem de cana-de-açúcar com maniçoba. *Ciência Rural, 44*(11), 2078-2083.

Cavali, J., Pereira, O. G., Valadares Filho, S. C., Santos, E. M., Carvalho, G. G. P. d., Santos, M. V., ... Rodrigues, J. F. H. (2010). Bromatological and microbiological characteristics of sugarcane silages treated with calcium oxide. *Revista Brasileira de Zootecnia, 39*(7), 1398-1408.

Ferro, M. M., Castro, W. J. R., Zanine, A. M., & Souza, A. L. (2017). Cinética de fermentação ruminal in vitro de silagem de cana-de-açúcar com resíduo de cervejaria desidratado. *Archivos de Zootecnia, 66*(254), 237-242.

Fortaleza, A. P. S., Silva, L. D. F., Zackm, E., P., B. R., Ribeiro, E. L. A., Pegoraro, M., ... Mizubuti, I. Y. (2012). Composição química e degradabilidade ruminal de silagens da cana-de-açúcar tratada com aditivos químicos e bacteriano. *Semina: Ciências Agrárias, 33*(2), 3341-3352.

Licitra, G., Hernandez, T. M., & Van Soest, P. J. (1996). Standardization of procedures for nitrogen fractionation of ruminant feeds. *Animal Feed Science and Technology, 57*(4), 347-358.

Maeda, E. M., Zeoula, L. M., Jobim, C. C., Bertaglia, F., Jonker, R. C., Geron, L. J. V., & Henrique, D. S. (2011). Chemical composition, fermentation, *in vitro* digestibility and *in situ* degradability of sugar cane silages with Lactobacillus, urea and agricultural byproduct. *Revista Brasileira de Zootecnia, 40*(12), 2866-2877. doi: 10.1590/S1516-35982011001200034

Maeda, E. M., Zeoula, L. M., Jobim, C. C., Cecato, U., Rigolon, L. P., Kazama, R., ... Carvalho, A. F. G. (2012). Intake, digestibility, rumen characteristics and microbial protein synthesis efficiency in bovine and bubaline fed sugar cane silage with additives. *Revista Brasileira de Zootecnia, 41*(3), 707-716. doi: 10.1590/S1516-35982012000300034

Mauricio, R. M., Moulda, F. L., Dhanoab, M. S., Owena, E., Channaa, K. S., & Theodorou, M. K. (1999). A semi-automated *in vitro* gas production technique for ruminant feedstuff evaluation. *Animal Feed Science and Technology, 79*(4), 321-330.

Mehrez, A. Z., Ørskov, E. R., & McDonald, I. (1977). Rates of rumen fermentation in relation to ammonia concentration. *British Journal of Nutrition, 38*(03), 437-443.

Mertens, D. R. (1997). Creating a system for meeting the fiber requirements of dairy cows. *Journal of Dairy Science, 80*(7), 1463-1481.

Moreira, M. N., Silva, A. M. d. A., Carneiro, H., Bezerra, L. R., Morais, R. K. O., & Medeiros, F. F. (2014). *In vitro* degradability and total gas production of biodiesel chain byproducts used as a replacement for cane sugar feed. *Acta Scientiarum. Animal Sciences, 36*(4), 399-403.

Muniz, E. B., Mizubuti, I. Y., Pereira, E. S., Pimentel, P. G., Azambuja, E. L. R., & Pinto, A. P. (2012). Cinética ruminal da fração fibrosa de volumosos para ruminantes. *Revista Ciência Agronômica, 43*(3), 604-610.

National Research Council [NRC]. (2001). *Nutrient Requirements of Dairy Cattle* (7th rev. ed.). Washington, DC: National Academy Press.

Nussio, L. G., Susin, I., Mendes, C. Q., & Amaral, R. C. (2009). Estratégias para garantir eficiência na utilização de cana-de-açúcar para ruminantes. *Tecnologia & Ciência Agropecuária, João Pessoa, 3*(4), 27-33.

Ørskov, E. R., & McDonald, I. (1979). The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. *The Journal of Agricultural Science, 92*(2), 499-503.

Pedroso, A. d. F., Rodrigues, A. d. A., Barioni Júnior, W., & Souza, G. B. (2011a). Fermentation parameters, quality and losses in sugarcane silages treated with chemical additives and a bacterial inoculant. *Revista Brasileira de Zootecnia, 40*(11), 2318-2322. doi: 10.1590/S1516-3598201100060004

Pedroso, A. F., Nussio, L. G., Loures, D. R. S., Paziani, S. F., Igarasi, M. S., Coelho, R. M., ... Rodrigues, A. A. (2007). Efeito do tratamento com aditivos químicos e inoculantes bacterianos nas perdas e na qualidade de silagens de cana-de-açúcar. *Revista Brasileira de Zootecnia, 36*(3), 558-564. doi: 10.1590/S1516-3598200700300006

Pedroso, A. F., Rodrigues, A. A., Barioni Júnior, W., Barbosa, P. F., Santos, F. A. P., & Nussio, L. G. (2011b). Aditivos químicos e inoculante bacteriano na ensilagem de cana-de-açúcar: efeitos sobre a fermentação das silagens e o desempenho de garrotes. *Revista Brasileira de Zootecnia, 40*(6), 1181-1187. doi: 10.1590/S1516-35982011001100006

Rezende, A. V., Rodrigues, R., Barcelos, A. F., Casali, A. O., Valeriano, A. R., & Medeiros, L. T. (2009). Qualidade bromatológica das silagens de cana-de-açúcar (*Saccharum officinarum* L.) aditivadas com raspa de batata. *Ciência e Agrotecnologia, 33*(1), 292-297. doi: 10.1590/S1413-70542009000100040

Robinson, P. H., Givens, D. I., & Getachew, G. (2004). Evaluation of NRC, UC Davis and ADAS approaches to estimate the metabolizable energy values of feeds at maintenance energy intake from equations utilizing chemical assays and in vitro determinations. *Animal Feed Science and Technology, 114*(1-4), 75-90. doi: 10.1016/j.anifeedsci.2003.12.002

Rossi Junior, P., & Schogor, A. L. B. (2006). Degradabilidade in situ de cana-de-açúcar ensilada com uréia e milho em diferentes proporções. *Archives of Veterinary Science, 11*(3), 15-18. doi: 10.5380/avs.v11i3.7432

Statistical Analysis Systems [SAS]. (2003). *SAS/STAT User guide, Version 9.1.* Cary, NC: SAS Institute Inc.

Schmidt, P., Mari, L. J., Nussio, L. G., Pedroso, A. d. F., Paziani, S. d. F., & Wechsler, F. S. (2007). Aditivos químicos e biológicos na ensilagem de cana-de-açúcar: 1. Composição química das silagens, ingestão, digestibilidade e comportamento ingestivo. *Revista Brasileira de Zootecnia, 36*(5), 1666-1675. doi: 10.1590/S1516-35982007000700027

Schofield, P., Pitt, R. E., & Pell, A. N. (1994). Kinetics of fiber digestion from *in vitro* gas production. *Journal of animal science, 72*(11), 2980-2991.

Silva, T. M., Araújo, G. G. L., Oliveira, R. L., Dantas, F. R., Bagaldo, A. R., Menezes, D. R., ... Ferreira, G. D. G. (2011). Degradabilidade ruminal e valor nutritivo da maniçoba ensilada com níveis do resíduo vitivinícola. *Archivos de zootecnia, 60*(229), 93-103. doi: 10.4321/S0004-05922011000100011

Sniffen, C. J., O'Connor, J. D., Van Soest, P. J., Fox, D. G., & Russell, J. B. (1992). A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. *Journal of animal science, 70*(11), 3562-3577.

Souza, E. J. O., Guim, A., Batista, Â. M. V., Albuquerque, D. B., Monteiro, C. C. F., Zumba, E. R. d. F., & Torres, T. R. (2010). Comportamento ingestivo e ingestão de água em caprinos e ovinos alimentados com feno e silagem de Maniçoba. *Revista Brasileira de Saúde e Produção Animal, 11*(4), 1056-1067.

Theodorou, M. K., Williams, B. A., Dhanoa, M. S., McAllan, A. B., & France, J. (1994). A simple gas production method using a pressure transducer to determine the fermentation kinetics of ruminant feeds. *Animal Feed Science and Technology, 48*(3), 185-197.

Van Soest, P. J. (1994). *Nutritional ecology of the ruminant* (Vol. 1). Ithaca, NY: Cornell University Press.

Van Soest, P. J., Robertson, J. B., & Lewis, B. A. (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science, 74*(10), 3583-3597. doi: 10.3168/jds.S0022-0302(91)78551-2

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