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RESEARCH

Influence of increased doses of detoxified castor bean meal on chemical composition and characteristics of sugarcane silage

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ABSTRACT

Sugarcane (*Saccharum officinarum* L.) ensilage presents serious limitations due to the conversion of soluble carbohydrates into ethanol, thus, it is necessary to use additives that reduce losses of DM during the ensilage process. The aim of this study was to evaluate the effect of increasing levels of detoxified castor-bean (*Ricinus communis* L.) meal (DCBM) on the nutritive value, fermentation pattern, stability and losses of sugarcane silages. Twenty mini-silos with sugarcane and five different concentrations of DCBM (0, 50, 100, 150 and 200 g kg^{-1} fresh matter) were prepared in a completely randomized design with five replicates per treatment. After 60 d, silage was sampled to determine chemical-bromatological composition, fractionation of carbohydrates and protein content, ammoniacal N ($N-NH_3$) and losses through gases and effluents. The addition of DCBM increased ($P < 0.05$) DM content, crude protein, fraction A + B1 of the total carbohydrates. However, it reduced ($P < 0.05$) the levels of neutral and acid detergent insoluble fiber, fraction B1 + B2 of total N and $N-NH_3$. The addition of DCBM reduced the losses of total DM but decreased silages aerobic stability. The addition of 150 g kg^{-1} DBCM improved the nutritional value, fermentation pattern and reduced losses of sugarcane silages.

Key words: Biodiesel residue, fractionation of carbohydrates, *Ricinus communis*, *Saccharum officinarum*, silage effluent.

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is cultivated throughout the global tropical zone mainly for the production of sugar and ethanol. Due to the high yield of fresh mass (80 t ha^{-1}) and high soluble carbohydrate content (396 ± 109 g kg^{-1}) (Daniel et al., 2013a), sugarcane is potentially used for animal feeding. The main obstacle to use sugarcane as exclusive roughage is the reduced crude protein levels (55.5 ± 46.8 g kg^{-1}) (Daniel et al., 2013b) and the high labor cost in logistic operations (Siqueira et al., 2012).

Sugarcane ensilage is an operational solution that reduces the daily need for labor. However, the conservation of sugarcane by acidification presents serious limitations due to the losses through effluents (Cavali et al., 2010). In addition, there are inconsistent results of the use of microbial additives in reducing losses and improving nutritive value of sugarcane silage (Novinski et al., 2012; Santos et al., 2015). Thus, it is necessary to use additives that are capable of improving the fermentation pattern of sugarcane silages and reduce losses of DM during the ensilage process (Andrade et al., 2016).

Castor-bean (*Ricinus communis* L.) is a widespread castor oil in the global tropics, which presents many applications such as paints, varnishes and biodiesel production. In this context, after oil extraction via solvent, remains a toxic residue, named castor-bean meal, which could be used in animal feeding after being detoxified. After detoxification, alkalinization promoted by calcium hydroxide causes ricin denaturation (Oliveira et al., 2010), castor-bean meal presents 900 ± 26 g kg^{-1} DM; 340 ± 83 g kg^{-1} crude protein; 30 ± 1.9 g kg^{-1} ether extract; 460 ± 72 g kg^{-1} neutral detergent fiber; 60 ± 4.9 g kg^{-1} non-fibrous carbohydrates, and 180 ± 64 g kg^{-1} lignin (Gionbelli et al., 2014; Menezes et al., 2015; Freire et al., 2017). Therefore, detoxified castor-bean meal is an absorbent and protein additive capable of improving the fermentation process in sugarcane silage, reducing gas and effluent losses and raising protein content of silage (Moreira et al., 2014; 2016).

The aim of this work was to evaluate the nutritional value, fermentation profile and losses in sugarcane silages supplemented with increasing levels of detoxified castor-bean meal.

MATERIALS AND METHODS

The experiment was conducted in the municipality of Arapiraca (09º45'09" S, 36º39'40" W), Alagoas, Brazil. The whole plant sugarcane (*Saccharum officinarum* L.) var. RB07312 was used, and it was harvested at 18-mo without burning. The forage processing for ensilage was in a stationary chopper to obtain particles with an average size of 2 cm. After processing, sugarcane was homogenized and mixed with detoxified castor-bean meal. The castor-bean meal was previously detoxified through the use of calcium hydroxide solution ($Ca(OH)_2$) as recommended by Oliveira et al. (2010). After mixing castor-bean meal with the ($Ca(OH)_2$) solution, the material remained still for 12 h at 25 °C. Then it was dried through sun exposure.

Detoxified castor-bean meal (DCBM) was added at 0, 50, 100, 150, 200 g kg^{-1} fresh matter (w/w) to sugarcane forage and immediately ensiled in 25 plastic buckets (five per treatment), with 32 cm of height and 88 cm of diameter provided with Bunsen valves for the elimination of fermentation gases. Three kilograms of fine sand was added to the bottom of each bucket to drain effluents, and a screen was used to separate the sand from the silage. Compaction was performed to obtain a density of 600 kg m^{-3}. Silos were sealed, weighed and stored in shade for 60 d. Fresh samples of sugarcane and DCBM were collected for analysis of chemical composition (Table 1).

After 60 d, silos were weighed again to estimate total losses of DM (g kg^{-1} DM), losses through gases (LG), losses through effluent (LE) and DM recovery index (DMRI) according to equations proposed by Jobim et al. (2007). The silages of each bucket were also sampled. The collected samples were properly identified, conditioned and stored in a freezer at -10 ºC. Subsequently, part of the samples were thawed at room temperature for pre-drying in a forced-ventilation oven at controlled temperature (55 °C for 72 h). Then they were ground in a Willey-type mill, sieved with 1 mm mesh and subjected to analysis of DM (ID 930.15), ashes (942.05), crude protein (CP) (ID 954.01), and ether

Table 1. Chemical composition of detoxified castor-bean meal (DCBM) and sugarcane forage supplemented or not with DCBM before ensiling.

		Levels of DCBM (g kg^{-1} FM)				
Variable	DCBM	0	50	100	150	200
Dry matter, g kg^{-1} FM	925.2	275.9	279.6	308.1	324.9	347.5
Mineral matter, g kg^{-1} DM	124.2	17.0	37.7	52.2	61.5	78.9
Crude protein, g kg^{-1} DM	448.4	26.6	85.1	123.7	147.0	216.6
Neutral detergent fiber corrected for ashes and protein, g kg^{-1} DM	375.2	455.7	488.9	468.5	473.8	480.6
Hemicellulose, g kg^{-1} DM	46.2	71.9	97.8	87.4	88.3	90.1
Cellulose, g kg^{-1} DM	121.8	363.1	380.3	352.6	348.8	306.0
Ether extract, g kg^{-1} DM	27.0	14.9	14.0	15.9	22.2	23.9
Acid detergent fiber, g kg^{-1} DM	359.0	413.1	435.7	395.2	424.0	401.4
Lignin, g kg^{-1} DM	300.9	78.4	108.5	125.4	159.8	183.3
Neutral detergent insoluble N, g kg^{-1} DM	29.7	6.2	7.9	11.1	13.7	17.5
Acid detergent insoluble N, g kg^{-1} DM	20.0	1.8	5.7	8.2	10.8	14.3
Neutral detergent insoluble N, g kg^{-1} CP	354.8	451.5	577.0	560.3	583.4	504.3
Acid detergent insoluble N, g kg^{-1} CP	238.6	424.6	419.0	412.0	457.4	412.9
Total digestible nutrients, g kg^{-1} DM	671.5	600.8	546.7	553.6	431.3	532.2
Total carbohydrates, g kg^{-1} DM	418.0	950.2	863.3	808.2	843.0	680.6
Non-fibrous carbohydrates, g kg^{-1} DM	73.0	466.9	288.6	271.1	322.5	189.5
Indigestible neutral detergent fiber, g kg^{-1} DM	292.4	173.8	235.2	236.2	223.5	259.5
In vitro DM digestibility, g kg^{-1}	645.1	712.6	630.8	626.0	632.2	661.2

FM: Fresh matter; CP: crude protein.

extract (EE) (ID 920.39) according to the procedures of AOAC (2005). Neutral detergent fiber (NDFap), acid detergent fiber (ADF) and lignin were determined according to methodology proposed by Van Soest et al. (1991). Cellulose and hemicellulose fractions were estimated by the following equations: Hemicellulose = NDF - ADF; Cellulose = ADF – acid detergent lignin (ADL). The percentage of total carbohydrates (TC) was obtained by the equation proposed by Sniffen et al. (1992): TC = 100 - (%CP + %EE + ash). Fibrous carbohydrates were obtained from the NDF corrected for ashes and protein (NDFap); non-fibrous carbohydrate (NFC), i.e., the rapid degradation rate fractions (A + B1) were calculated by the difference between total carbohydrates and NDFap (Hall, 2003) and undegradable rate fraction (C), by indigestible NDF after 244 h of *in situ* incubation as described by Casali et al. (2008). The low degradation rate fraction (B2) was obtained by the difference between NDFap and fraction C. The percentage of total N (TN) was obtained according to AOAC (2005; 954.01). Fractions A (rapid degradation rate), B1 + B2 (rapid degradation rate), B3 (low degradation rate), and C (undegradable rate) of TN were obtained according to Sniffen et al. (1992). Neutral detergent insoluble N (NDIN) and acid detergent insoluble N (ADIN) were obtained according to Sniffen et al. (1992). For the determination of *in vitro* DM digestibility of the diets, the technique described by Tilley and Terry (1963) adapted to the artificial rumen, developed by ANKOM Technology (Macedon, New York, USA), as described by Holden (1999) was adopted.

Fresh silage (50 g) was triturated with 200 mL water in an industrial blender and gauze filtered to extract the aqueous medium and immediately used for pH measurement (Silva and Queiroz, 2002) and ammonia N ($N\text{-}NH_3$) analysis (AOAC, 2005).

To evaluate the aerobic stability, the contents of each silo were homogenized and 4 kg silage were placed in buckets without compaction and exposed in a closed environment – room of 96 m^2, clay tiled roof – 27.61 ± 1.02 °C and 706.8 ± 42.9% air RH. The silages temperatures were verified twice a day during 10 d, using a thermometer inserted in the center of the forage mass, according to Bernardes et al. (2007). The accumulated temperature was calculated by summing the positive differences between the silage and room temperatures. The aerobic stability evaluation was calculated using the parameters proposed by O'Kiely et al. (1999).

Treatments were distributed in a completely randomized design, using the model: $Yijk = \mu + Ti + eijk$. In which *Yijk* is the observed value; μ is general constant; *Ti* is treatment effect i; *eijk* is error associated with each observation. Data were evaluated through ANOVA and regression using the statistical software SAEG version 9.1 (Fundação Arthur Bernardes, Universidade Federal de Viçosa [UFV], Viçosa, Minas Gerais, Brazil). Coefficient of determination (r^2) was the criteria used to choose the model and was calculated as the ratio between the regression sum of squares and the sum of squares of treatments and the observed significance of the regression coefficients.

RESULTS

Chemical-bromatological composition

The addition of increasing doses of DCBM to sugarcane at the ensilage process increased linearly ($P < 0.001$) DM and CP contents of the silages (Table 2). Through the equation, it was estimated that for each 1 g kg^{-1} of DCBM added, there was an increase of 6.7 g kg^{-1} DM and 7.1 g kg^{-1} CP in the silage. The fibrous fractions (NDFap, ADF, cellulose and hemicellulose) of the silage were influenced by DCBM levels. For each unit of additive, there was a reduction of 118 g kg^{-1} NDFap and 51 g kg^{-1} ADF in DM of the silage. Nevertheless, in spite of the negative linear response of ADF, lignin content presented augmented linearly ($P < 0.001$) with increasing amounts of DCBM. *In vitro* DM digestibility (IVDMD) was quadratically affected with a maximum point of 661.5 g kg^{-1} IVDMD at the level of 151.4 g kg^{-1} inclusion of DCBM.

Total carbohydrates (TC) and potentially digestible fibrous carbohydrates (B2) as a percentage of TC decreased linearly with increased amounts of DCBM (Table 3). Quadratic behavior was observed for carbohydrate fractions with high ruminal degradation rate (A + B1). The indigestible fraction (C) also adjusted to the quadratic model ($P < 0.001$) presenting a minimum point of 36.72 g kg^{-1} for the level 86.3 g kg^{-1} DCBM. Regarding N fractionation, total N content augmented linearly with increased amounts of DCBM. However, protein fractions of fast and intermediate degradation (B1 + B2) of TN presented a linear response dropping from 6.3 to 10 g kg^{-1} DCBM (Table 3). Increases of 0.21 and 0.38 g kg^{-1} of the fractions B3 and C (slow degradation protein and non-degradable fraction, respectively) for each 10 g kg^{-1} DCBM added to the silages were also observed.

Table 2. Chemical composition of sugarcane silages supplemented with different levels of detoxified castor-bean meal (DCBM) before ensiling.

Item	Levels of DCBM (g kg^{-1} FM) 0	50	100	150	200	Equation	r^2	CV (%)	P value L	Q
Dry matter, g kg^{-1} FM	193.4	228.7	271.6	301.3	324.5	$\hat{Y}_1$	0.99	2.93	< 0.001	0.009
Mineral matter, g kg^{-1} DM	26.0	47.8	59.1	70.5	80.8	$\hat{Y}_2$	0.97	5.93	< 0.001	< 0.001
Crude protein, g kg^{-1} DM	34.1	103.7	127.3	155.6	185.5	$\hat{Y}_3$	0.95	8.82	< 0.001	0.005
Neutral detergent insoluble protein, g kg^{-1} DM	9.6	27.9	41.1	57.5	71.3	$\hat{Y}_4$	0.99	16.02	< 0.001	0.898
Acid detergent insoluble protein, g kg^{-1} DM	4.9	17.8	24.2	32.0	41.4	$\hat{Y}_5$	0.99	17.53	< 0.001	0.653
Ether extract, g kg^{-1} DM	28.3	14.1	12.1	22.8	27.1	$\hat{Y}_6$	0.82	17.95	0.249	< 0.001
Neutral detergent fiber corrected for ash and protein, g kg^{-1} DM	809.5	693.3	622.7	593.2	563.6	$\hat{Y}_7$	0.91	1.6	< 0.001	< 0.001
Acid detergent fiber, g kg^{-1} DM	628.2	609.9	527.1	526.3	535.9	$\hat{Y}_8$	0.73	3.98	< 0.001	< 0.001
Hemicellulose, g kg^{-1} DM	236.6	177.4	175.3	178.3	171.6	$\hat{Y}_9$	0.56	15.86	0.006	0.039
Cellulose, g kg^{-1} DM	463.7	396.8	328.0	292.5	318.9	$\hat{Y}_{10}$	0.80	10.03	< 0.001	0.001
Lignin, g kg^{-1} DM	124.9	159.5	176.7	197.9	221.7	$\hat{Y}_{11}$	0.99	10.38	< 0.001	0.856
Indigestible neutral detergent fiber, g kg^{-1} DM	363.6	302.1	295.3	293.1	291.7	$\hat{Y}_{12}$	0.62	4.55	< 0.001	<0.001
Indigestible DM, g kg^{-1} DM	412.1	349.7	350.0	349.9	340.2	$\hat{Y}_{13}$	0.60	4.57	< 0.001	0.001

FM: Fresh matter; L: linear effect; Q: quadratic effect; r^2: coefficient of determination; CV: coefficient of variation.
Equations: $\hat{Y}_1 = 196.936 + 6.696DCBM$; $\hat{Y}_2 = 30.380 + 2.646DCBM$; $\hat{Y}_3 = 50.284 + 7.095DCBM$; $\hat{Y}_4 = 10.912 + 3.057DCBM$; $\hat{Y}_5 = 6.628 + 1.743DCBM$; $\hat{Y}_6 = 26.722 - 2.715DCBM + 1.420DCBM^2$; $\hat{Y}_7 = 774.812 - 11.835DCBM$; $\hat{Y}_8 = 613.092 - 5.136DCBM$; $\hat{Y}_9 = 213.668 - 2.583DCBM$; $\hat{Y}_{10} = 438.768 - 7.878DCBM$; $\hat{Y}_{11} = 129.732 + 4.640DCBM$; $\hat{Y}_{12} = 339.700 - 3.053DCBM$; $\hat{Y}_{13} = 389.092 - 2.870DCBM$.

Table 3. Carbohydrates and protein fractions of sugarcane silages containing different levels of detoxified castor-bean meal (DCBM).

Item	Levels of DCBM (g kg^{-1} FM) 0	50	100	150	200	Equations	r^2	CV (%)	P value L	Q
Carbohydrate										
Total carbohydrates, g kg^{-1} DM	911.0	834.0	801.0	751.0	706.0	Y_1	0.98	1.7	< 0.001	< 0.001
Fraction A + B1, g kg^{-1} TC	112.0	169.0	222.0	209.0	202.0	Y_2	0.97	9.3	< 0.001	0.039
Fraction B2, g kg^{-1} TC	489.0	468.0	408.0	399.0	385.0	Y_3	0.92	4.8	< 0.001	0.001
Fraction C, g kg^{-1} TC	398.0	362.0	368.0	390.0	409.0	Y_4	0.87	4.7	< 0.001	< 0.001
Nitrogen										
Total N, g kg^{-1} DM	5.0	16.0	20.0	24.0	29.0	Y_5	0.95	8.8	< 0.001	0.009
Fraction A, g kg^{-1} TN	72.0	61.0	76.0	69.0	77.0	Y = 71.2	-	13.2	0.084	< 0.001
Fraction B1 + B2, g kg^{-1} TN	644.0	667.0	602.0	562.0	538.0	Y_6	0.86	6.6	< 0.001	0.005
Fraction B3, g kg^{-1} TN	139.0	98.0	131.0	164.0	160.0	Y_7	0.42	22.3	0.023	0.023
Fraction C, g kg^{-1} TN	144.0	172.0	189.0	203.0	224.0	Y_8	0.99	14.6	< 0.001	< 0.001

FM: Fresh matter; r^2: coefficient of determination; CV: coefficient of variation; L: linear effect; Q: quadratic effect; TC: total carbohydrates; TN: total N.
Equations: $Y_1 = 899.72 - 9.868DCBM$; $Y_2 = 110.900 + 15.634DCBM - 0.5604DCBM$; $Y_3 = 485.696 - 5.54640DCBM$; $Y_4 = 394.185 - 6.27206DCBM + 0.363143DCBM2$; $Y_5 = 8.03600 + 1.1360DCBM$; $Y_6 = 666.772 - 6.34760DCBM$; $Y_7 = 117.268 + 2.1556DCBM$; $Y_8 = 148.368 + 3.831DCBM$.

Fermentation characteristics and losses in silage

A positive response, linear for pH and quadratic for $N\text{-}NH_3$, as a function of increased DCBM levels (Table 4). The inclusion of increased doses of DCBM reduced linearly ($P < 0.01$) and quadratically ($P < 0.01$) total DM losses, ranging from 35.4% losses in silage without addition of DCBM to 8.0% losses in silage with 200 g kg^{-1} DCBM. As the level of DCBM increased (from 0 to 200 g kg^{-1}), there was a decrease of 64% in gas losses and 87% in losses through effluents (Table 5). For the values of DM recovery index (DMREC), a positive linear response was observed. The addition of 200 g kg^{-1} castor bean meal increased DMREC by 142% when compared to silage without additive.

Aerobic stability

The aerobic stability of the silage presented quadratic behavior ($P < 0.01$). The sugarcane silage without additive was the most stable (144 h), but the silage that received 200 g kg^{-1} DCBM was the most stable among the ones with DCBM addition (Table 5).

Table 4. Temperature variables associated with aerobic stability of sugarcane silages supplemented with different levels of detoxified castor-bean meal (DCBM).

	Levels of DCBM (g kg^{-1} FM)								P value	
Variable	0	50	100	150	200	Equations	r^2	CV (%)	L	Q
Stability, h	144.2	50.2	33.8	38.6	51.6	$\hat{Y}_1$	0.94	20.06	< 0.01	< 0.01
CAT 5 d	-4.4	22.4	32.7	41.5	36.5	$\hat{Y}_2$	0.99	25.61	< 0.01	< 0.01
CAT 10 d	32.2	68.9	95.4	98.7	97.6	$\hat{Y}_4$	0.99	13.48	< 0.01	< 0.01
pH0	3.02	2.98	3.16	3.26	3.4	$\hat{Y}_4$	0.90	1.41	1.41	< 0.001
pH10	3.4	5.6	8.7	8.7	8.7	$\hat{Y}_5$	0.97	12.05	12.05	< 0.001

FM: Natural matter; r^2: coefficient of determination; CV: coefficient of variation; L: linear effect; Q: quadratic effect; CAT: cumulative average temperature by the difference between room temperature and the temperature of the silages in the first 5 d, from the fifth to the tenth day and from zero to 10 d of aerobic exposure.
Equations: $\hat{Y}_1$ = 136.64 - 17.376DCBM + 0.672DCBM^2; $\hat{Y}_2$ = -4.159 + 5.3486DCBM -0.1552DCBM^2; $\hat{Y}_3$ = 35.685 + 3.722DCBM - 0.1266DCBM^2; $\hat{Y}_4$ = 31.526 + 9.0706DCBM -0.2818DCBM^2; $\hat{Y}_5$ = 3.2257 + 0.7065DCBM - 0.02148DCBM^2.

Table 5. Losses and recovery of DM from sugarcane silages supplemented with increasing levels of detoxified castor-bean meal (DCBM).

	Levels of DCBM (g kg^{-1} FM)								P value	
Variable	0	50	100	150	200	Equations	r^2	CV (%)	L	Q
Loss of total DM, g kg^{-1} DM	354.0	226.0	145.0	93.0	80.0	$\hat{Y}^1$	0.92	14.7	< 0.01	< 0.01
Gas losses, g kg^{-1} DM	246.0	179.9	130.3	108.4	89.2	$\hat{Y}^2$	0.93	2.47	< 0.01	< 0.01
Effluent losses, kg t^{-1}	210.0	130.0	32.0	28.0	28.0	$\hat{Y}^3$	0.95	3.5	< 0.01	< 0.01
Dry matter recovery index, g kg^{-1} DM	645.0	773.0	854.0	906.0	919.0	$\hat{Y}^4$	0.98	1.0	< 0.01	< 0.01

FM: Fresh matter; r^2: coefficient of determination; CV: coefficient of variation; L: linear effect; Q: quadratic effect.
Equations: $\hat{Y}_1$= 316.579 - 13.6226DCBM; $\hat{Y}_2$= 227.75 - 7.7DCBM; $\hat{Y}_3$= 215.39 - 23.837DCBM + 0.726DCBM^2; $\hat{Y}_4$= 683.421 + 13.6226DCBM.

DISCUSSION

The addition of DCBM increased DM and CP contents of the silages since the by-product presented a higher DM (925.2 *vs*. 275.9 g kg^{-1}) and CP content (448.4 *vs*. 26.6 g kg^{-1}) than sugarcane. There was an increase of 539% in CP from 3.44% without additive to 18.55% CP in the treatment with 200 g kg^{-1} DCBM. These results are in agreement with Oliveira et al. (2015), who also evaluated the inclusion of castor-bean meal to sugarcane silage and observed an increase of 714% in CP content of the silages.

The reduction in the contents of NDFap and ADF was 303.8 and 147.0 g kg^{-1} respectively, due to the addition of DCBM. The DCBM is a protein concentrate that presents lower hemicellulose (46.2 *vs*. 71.9 g kg^{-1}) and cellulose (121.8 *vs*. 363.1 g kg^{-1}) compared to sugarcane. However, the decrease - 50% lower - in ADF content may be due to the high lignin content (300.9 g kg^{-1}) of DCBM. In fact, the addition of DCBM increased lignin content by 177%. Possibly, the presence of highly lignified husk (Andrade et al., 2013) in castor-bean meal was determinant for the increase of silage lignin.

The decrease in total carbohydrate contents can be attributed to the replacement of sugarcane with TC (950.5 g kg^{-1}) in DM by castor-bean meal with only 418.0 g kg^{-1} CT. These findings are in agreement with Ribeiro et al. (2014), who added castor-bean cake to elephant grass silage and also observed a decrease in the total carbohydrate contents of the silage.

Before ensiling, the fraction A + B1 corresponded to 466.9 g kg^{-1} of the total carbohydrates, while in the silage with 0 g kg^{-1} DCBM the same fraction did not exceed 112.0 g kg^{-1}. However, the addition of DCBM was efficient in conserving residual carbohydrates in sugarcane silage, since the addition of the by-product resulted in contents of 200 g kg^{-1}, on average, in the fraction A + B1. The presence of higher residual carbohydrate content of fraction A + B1 in silages with the inclusion of DCBM can be attributed to the improvement of the fermentation pattern of these silages. The increase in DM reduced water activity, thus reducing the proliferation of undesirable microorganisms that use soluble carbohydrates as substrate (Muck, 2010).

The DCBM presented low levels of hemicellulose (46.2 g kg^{-1}) and cellulose (121.8 g kg^{-1}), which explains the lower percentages of fraction B2 of carbohydrates of the enriched silages. Similarly, Andrade et al. (2010) observed that the addition of cocoa meal caused a decrease in the fraction B2 of the silage enriched with this residue. However, the high lignin content (300.9 g kg^{-1} DM) of the DCBM present in the DCBM justifies the high content of the fraction C observed in the silages.

Castor-bean is a protein concentrate (Cobianchi et al., 2012) and its addition to sugarcane increased TN of the ensiled mixture. The DCBM presented high neutral detergent insoluble N (NDIN) content (354.8 g kg^{-1} CP), and its addition in silage was responsible for raising the level of slow degradation N (B3) and reducing the rapid degradation fraction (B1 + B2). The increase of the fractions B3 and C of the protein with addition of DCBM is due to the high levels of NDIN and acid detergent insoluble N (ADIN) in the meal. The alkalinization promoted by calcium hydroxide causes protein denaturation and reduces protein solubility of the by-product (Oliveira et al., 2010). Consequently, the addition of DCBM increases values of slow degradation and indigestible protein fractions (B3 and C) in the enriched silages.

The *in vitro* DM digestibility (IVDMD) was quadratically affected with a maximum value of 662 g kg^{-1} at the level of 151.4 g kg^{-1} castor-bean meal. Santos et al. (2018) also observed that the addition of up to 150 g kg^{-1} of common bean residue improved the IVDMD of sugarcane silage.

The pH of the silages was between 2.99 (0 g kg^{-1} DCBM) and 3.37 (200 g kg^{-1} DCBM) which are close to the values reported by Santos et al. (2015) for sugarcane silage, and within the optimum range established by McDonald et al. (1991). The increase in pH as a function of the amount of DCBM added is related to the alkalinizing power of calcium hydroxide (Carvalho et al., 2012) added to castor-bean meal for detoxification. Regarding N-NH_3 values (% TN), data demonstrate that from 50 g kg^{-1} DCBM, there is a reduction of ammoniacal N from 6.0 to 4.0 mg dL^{-1}. At the level of 200 g kg^{-1} additive, N-NH_3 did not exceed 2.5 mg dL^{-1}.

The addition of DCBM increased DM contents of the ensiled mass, resulting in an increase in the osmotic capacity of the silage and greater fluid retention and reduction of generated effluents. In addition, the elevation of silage DM also increases the homofermentative bacteria population, which is related to lower gas losses (Muck, 2010).

The aerobic stability of silage was impaired by the addition of DCBM. Probably, the increase in residual carbohydrates, which also occurred with the addition of DCBM, made the silage more susceptible to deterioration (Conaghan et al., 2011). However, the level of 200 g kg^{-1} DCBM presented the greatest stability among the enriched silages. This fact can be explained by the greater presence of calcium hydroxide that increases aerobic stability of sugarcane silages (Custódio et al., 2016).

CONCLUSION

The addition of 150 g kg^{-1} detoxified castor bean meal improved the content of residual carbohydrates and crude protein in silage and reduced losses during sugarcane ensilage.

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