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Fermentation profile and nutritional quality of silages composed of cactus pear and maniçoba for goat feeding

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Abstract

This study aimed to evaluate the fermentation profile and nutritional quality of silages composed of cactus pear and maniçoba. Two experiments were performed: the first evaluated the fermentation characteristics, chemical composition and determined the organic acids in cactus pear silages with the inclusion of five levels of maniçoba (0, 25, 50, 75 and 100%) in six opening times (1, 7, 15, 30, 60 and 90 days). The second experiment determined the nutrient intake, digestibility, water balance and nitrogen balance in Canindé goats fed diets based on cactus pear silage with the inclusion of four levels of maniçoba (25, 50, 75 and 100%), with six animals per treatment. The increase in maniçoba levels in cactus pear silage provided a linear increase in the butyric acid, dry matter (DM), ether extract, crude protein, neutral detergent fibre, acid detergent fibre, lignin, cellulose, hemicellulose, water intake via drinking fountain and metabolic water, and reduced the pH, lactic acid, acetic acid, mineral matter, total carbohydrates, non-fibrous carbohydrates, water intake via food, total water intake, water excreted in the faeces, water excreted in the urine, total water excretion and water balance. Quadratic behaviour was observed for N-NH_3, DM recovery and propionic acid, with an increase in maniçoba levels in cactus pear silages. Regarding the different opening times, there was a significant effect in pH, N-NH_3, acetic acid, lactic acid and butyric acid ($P < 0.050$). The inclusion of maniçoba in cactus pear silage improved the fermentation characteristics and nutritional quality to be used in diets for goats.

Introduction

In the Brazilian semiarid, goat farming is vital to generate food and income on rural properties where vegetation serves as an essential source of forage. However, during the shortage caused by the rainy seasons, the lack of food makes farmers extremely dependent on commercial concentrates (Miranda-Romero *et al*., 2018). Among the alternative sources of food, cactus pear (*Opuntia fícus-indica* Mill) is an exotic plant adapted to arid and semiarid regions. It is a forage species with a high potential for dry matter (DM) production, producing 10–20 t/ha biomass per year under dry conditions and up to 76 t/ha under more intensive and irrigated conditions. It has a high water content (801 g/kg in natural matter; Oliveira *et al*., 2018) and non-fibre carbohydrates (NFC; 523–555 g/kg DM) and low concentration of neutral detergent fibre (NDF; 232–277 g/kg DM). Its use alone is not recommended due to its low fibre and protein content and high moisture that lead to a high rate of passage, which, together with cactus pear mucilage, a substance composed of complex polysaccharides with hydrophilic properties, culminates in a laxative effect in animals, softening the faeces (Macêdo *et al*., 2018).

Cactus pear must be combined with other sources of fibre with high effectiveness, maintaining normal conditions in the rumen, and thus avoiding such undesirable effects. In addition, it must be combined with a viable source of protein that allows an adequate synchronization between the energy and nitrogen supply for the rumen microorganisms, considering the high content of soluble carbohydrates in cactus pear (Silva *et al*., 2019). Thus, maniçoba (*Manihot pseudoglaziovii*) represents a complementary alternative to the nutritional deficit present in cactus pear, due to its high nutritional value, contributing to significant increases in the contents of DM, NDF and crude protein (CP). It is a native species adapted to semiarid conditions and, therefore, easy to obtain, which ensures the feeding of the herd during the most critical time of the year (Gouveia *et al*., 2015; Maciel *et al*., 2019).

The practice of ensiling cactus pear has spread as a viable tool for the rational production of ruminants, bearing in mind that the use of cactus pear in this preservation technique can

Table 1. Chemical composition of maniçoba (*M. pseudoglaziovii*) and cactus pear (*O. ficus indica*)

	Maniçoba	Cactus pear
DM (g/kg NM)	300.1	107.5
MM (g/kg DM)	89.7	164
NDF (g/kg DM)	500.2	304
ADF (g/kg DM)	312.9	159.7
CP (g/kg DM)	145	49.5
EE (g/kg DM)	47.4	14.3
Lignin (g/kg DM)	103.3	21.8

NM, natural matter; DM, dry matter.

Table 2. Chemical composition of the experimental diets

	Maniçoba levels (%)			
Items	25	50	75	100
DM (g/kg NM)	158	191	278	339
MM (g/kg DM)	138	94	78	81
CP (g/kg DM)	153	159	173	198
NDF (g/kg DM)	356	412	451	530
ADF (g/kg DM)	219	229	290	350
EE (g/kg DM)	60	58	70	72
Lignin (g/kg DM)	69	78	83	113

NM, natural matter; DM, dry matter.

mitigate water deficit for goats in arid and semiarid regions, when associated with another food source (Gusha *et al*., 2015), such as maniçoba, highly adapted to the semiarid conditions.

This research aimed to assess the fermentation profile and nutritional quality of silages composed of cactus pear and different levels of maniçoba for feeding Canindé goats in the semiarid region.

Materials and methods

Location

The experiment was conducted at the Animal Metabolism sector of Embrapa Semiárido, Petrolina, State of Pernambuco (latitude: 9°8′8.9″S, longitude: 40°18′33.6″W, 373 m altitude), whose climate according to Köppen's classification is BSwh' semiarid (Köppen and Geiger, 1928). During the experimental period, the average temperature and relative humidity were 26.14°C and 58.10%, respectively, with average evapotranspiration of 4.06 mm (EMBRAPA 2017).

Two experiments were conducted:

Experiment 1: Fermentation profile and chemical composition of cactus pear silages combined with different levels of maniçoba

Five levels of inclusion of maniçoba (0, 25, 50, 75 and 100%) were evaluated in cactus pear silage in six silos opening times (1, 7, 15, 30, 60 and 90 days), in a 5 × 6 factorial arrangement, with three replications, totalling 90 experimental silos.

The cactus pear used to prepare the silage came from a plantation of cactus pear Mexican Elephant Ear variety, harvested 1 year after planting. Maniçoba used came from an experimental area; the upper third of the plants were collected, both crops were established in the Caatinga Experimental Field, Embrapa Semiárido, Petrolina, State of Pernambuco. The harvest was performed manually, and the collected material was processed through a stationary forage (PP-35, Pinheiro máquinas, Itapira, São Paulo, Brazil) chopper to an average particle size of approximately 2.0 cm.

The material was homogenized manually and ensiled in experimental silos made of polyvinyl chloride, 10 cm in diameter and 50 cm in height, equipped with a Bunsen valve to allow gas outflow. At the bottom of the experimental silos, 1 kg dry sand was placed, protected by a cotton cloth, preventing the forage from coming into contact with the sand, thus allowing the effluent to drain. The material was compacted with wooden sockets, inserting ±2 kg fresh forage per silo. The silos were weighed before and after filling. Once sealed, the silos were kept in a covered shed and free from opportunistic animals. Samples of the non-ensiled material (original material) were collected for further laboratory analysis (Table 1).

The total dry weight loss during the ensiling period was determined by the difference between the weight of the initial (FMop – forage mass at opening, in kg) and final mass (FMcl – forage mass at closing, in kg) in the silos. The dry matter recovery (DMR) of the silage was estimated using the equation DMR = (DMop × 100)/DMcl, where DMop = DM content at opening; and DMcl = forage DM content at closing (Pereira *et al*., 2019). Samples were taken at all silos opening times to determine the chemical composition and fermentation profile of the silages.

Experiment 2: Daily intake, apparent digestibility of nutrients, water balance, and nitrogen balance for confined goat fed cactus pear silage combined with different levels of maniçoba

This research was evaluated and approved by the National Council for the Control of Animal Experimentation (CONCEA) and the Ethics Committee on the Use of Animals (CEUA) of Embrapa Semiárid, under protocol number 04/2016.

For the determination of water and nutrient intake from roughage, a digestibility test was carried out. The experimental treatments consisted of the elaboration of diets based on silage of cactus pear combined with one of the four levels of maniçoba (25, 50, 75 and 100%) (Table 2). The silages were made in 200 litre plastic-drum silos (89 × 59 × 59 cm) with a removable lid sealed with a metal ring.

Twenty-four Canindé male, non-castrated goats, with the initial body weight of 25.0 ± 2.6 kg, were distributed in a completely randomized design with four treatments and six replications. The animals were previously identified, weighed, treated against endo- and ectoparasites and housed in individual metabolic cages, provided with a feeder, drinking fountain and salt block, in a roofed area. The experimental period lasted 15 days, with 10 days for adaptation of the animals to diets, cages and faeces collection bags and 5 days for data collection.

Diets were offered twice a day, at 9.00 a.m., and 3.00 p.m. Water was provided at will. The leftovers were collected and weighed to determine intake and adjust the dry matter intake (DMI) to allow 20% leftovers in the trough. Samples of the food supplied, and leftovers were collected weekly for further laboratory analysis.

The daily DMI was obtained by the difference between the total DM of feed consumed and the total DM in the leftovers. Nutrient intake was determined as the difference between the

Table 3. Hydrogen ionic potential (pH), ammonia nitrogen (N-NH_3), DMR and concentration of organic acids of cactus pear silages combined with different levels of maniçoba ($n = 6$)

Items	Maniçoba levels (%)					S.E.M.	P value	
	0	25	50	75	100		L	Q
pH[a]	4.89	4.39	4.33	4.35	4.21	0.021	<0.001	<0.001
N-NH_3 (g/kg total N)[b]	47.5	20.5	17.7	10.9	12.9	0.06	0.216	0.009
DMR (g/kg DM)[c]	941.2	922.5	975.8	978.5	959.3	0.52	0.006	0.004
Lactic acid (g/kg DM)[d]	28.5	23.0	16.2	13.3	7.0	0.15	<0.001	0.342
Acetic acid (g/kg DM)[e]	6.01	14.50	14.00	9.00	5.82	0.050	0.002	<0.001
Propionic acid (g/kg DM)[f]	4.80	6.41	4.55	5.23	1.52	0.043	<0.001	<0.001
Butyric acid (g/kg DM)[g]	9.13	8.70	10.37	17.66	20.29	0.035	<0.001	0.182

S.E.M., standard error of the mean; DM, dry matter; L, significance for a linear effect; Q, significance for a quadratic effect.
Significant at $P \leq 0.05$; Equations: [a]$Y = -0.140x + 4.85$, $R^2 = 70.81$; [b]$Y = 0.3857x^2 - 3.102x + 7.254$, $R^2 = 94.56$; [c]$Y = -0.354x^2 + 3.048x + 90.28$, $R^2 = 46.43$; [d]$Y = -0.021x + 0.71$, $R^2 = 98.92$; [e]$Y = -0.059x + 1.163$, $R^2 = 49.20$; [f]$Y = -0.057x^2 + 0.265x + 0.282$, $R^2 = 80.8$; [g]$Y = 0.311x + 0.385$, $R^2 = 84.97$.

total nutrients in the feed consumed and the total nutrients in the leftovers, on a total DM basis.

Water intake was assessed daily. Water was supplied in buckets, weighed before supply and again 24 h later. The water lost through evaporation was considered when calculating water intake. This variable was estimated using buckets arranged randomly around the experimental shed, with the same amount of water available for each treatment and the difference in weight over 24 h was determined. The water balance was assessed using the following equations: Total water intake (kg/day) = consumed water (supplied water − evaporated water) + water from the diet; Total excretion of water (kg/day) = water excreted in the urine + water excreted in the faeces; Water balance = total water intake − total water excretion (Church, 1976). The production of metabolic water was estimated from the chemical analysis of the diets and calculated by multiplying the intake of carbohydrates, protein and digestible ether extract (EE) by the factors 0.60; 0.42 and 1.10, respectively (Taylor *et al*., 1969; Church, 1976).

The faeces were sampled using collection bags attached to the animals. Bags were weighed and emptied twice a day (8.30 a.m. and 3.30 p.m.). A total of 10% of the total amount of faeces was collected in a composite sample for each treatment and stored at −20°C. Urine was collected and weighed once a day in plastic buckets containing 100 ml 20% sulphuric acid (H_2SO_4) to prevent nitrogen volatilization and sampled (10% of the total excreted) to determine the nitrogen content. The apparent nitrogen balance was calculated according to the method described by Silva and Leão (1979).

Laboratory analysis

Fermentative characteristics of silages and plant

Samples of the material used for the production of the silages (collected at the moment of cutting) and those collected in each period of silo opening were used to determine the pH, ammonia nitrogen (N-NH_3) and organic acids. The pH of the samples was measured immediately after opening the silos and collecting the material, using a portable digital pH meter (Marconi® MA-552, Piracicaba, State of São Paulo, Brazil), previously calibrated. N-NH_3 was determined, according to Bolsen *et al.* (1992).

Organic acids (lactic acid – LA, acetic acid – AA, propionic acid – PA and butyric acid – BA) were determined using high-performance liquid chromatography (HPLC), according to the methodology of Kung and Ranjit (2001).

Chemical analysis

Samples of green material, silages at different silo opening times, food, leftovers and faeces were pre-dried in a forced ventilation oven at 55°C for 72 h and processed in a knife mill (Wiley Mill, Marconi, MA- 580, Piracicaba, Brazil), using 1 mm sieves. Laboratory analyses were performed using the methods described by AOAC (2016) for DM (method 967.03), mineral matter (MM, method 942.05), CP (method 981.10) and EE (method 920.29). The NDF content corrected for ash and protein (using sodium sulphite thermostable alpha-amylase) (NDFap; Licitra *et al.*, 1996; Mertens, 2002), the acid detergent fibre (ADF) was determined as described by Van Soest *et al.* (1991). Lignin was determined by treating the residue of ADF with 72% H_2SO_4 (Silva and Queiroz, 2002). Hemicellulose (HEM) was calculated using the following equation: HEM = NDF − ADF.

Total carbohydrates (TC) were estimated with the equation proposed by Sniffen *et al.* (1992): TC = 100 − (%CP + %EE + %Ashes). The content of NFC was calculated as proposed by Hall (2003): NFC = %TC − %NDF. The apparent digestibility coefficient (ADC) of nutrients was calculated as described by Silva and Leão (1979): ADC = {[Nutrients ingested (kg) − nutrients excreted in the faeces (kg)]/nutrients ingested (kg)} × 100.

Statistical analysis

Data were analysed in Statistic Analysis System 9.1 (SAS Institute, Cary, NC, EUA). All variables analysed were tested by analysis of variance, considering significant values of probability those below 5% ($P < 0.05$) using Tukey's test. For the first experiment, the statistical model was used: $Y_{ij} = \mu + S_i + E_j + S_iE_j + \varepsilon_{ijk}$, where Y_{ij} = value observed in silages submitted to different levels of maniçoba (i) and opening time (j); μ = general constant for all observations; S_i = effect of the i-th maniçoba levels, where $i = 1$–4; E_j = effect of the j-th opening period on silage, where $j = 1$–4; S_iE_j = effect of the interaction between the i-th additive and the j-th opening period and ε_{ijk} = random error associated with each observation. For the second experiment, the statistical model was as follows: $Y = \alpha + \beta + e$, where Y is the measured variable; α is the fixed effect of treatment (maniçoba levels in cactus pear silage); β is the random effect of the block and 'e' is the residual error. The PROC REG was used for regression analysis.

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Table 4. Hydrogen ionic potential (pH), ammonia nitrogen (N-NH_3), DMR and concentration of organic acids of cactus pear silages combined with different levels of maniçoba at different opening times (n = 6)

	Opening times (days)							*P* value	
Items	1	7	15	30	60	90	S.E.M.	L	Q
pH[a]	4.21	4.36	4.44	4.46	4.51	4.66	0.027	<0.001	0.773
N-NH_3 (g/kg total N)[b]	14.14	16.21	20.30	23.84	28.63	28.40	0.054	0.011	0.267
DMR (g/kg DM)	953.4	950.4	950.2	963.1	959.8	956.6	0.52	0.946	0.609
Lactic acid (g/kg DM)[c]			18.14	19.76	17.24	15.40	0.045	<0.001	0.063
Acetic acid (g/kg DM)[d]			8.00	8.99	11.60	10.91	0.039	<0.001	0.011
Propionic acid (g/kg DM)			4.60	4.68	5.12	3.71	0.023	0.201	0.061
Butyric acid (g/kg DM)[e]			13.4	9.6	19.3	10.4	0.15	0.923	0.050

S.E.M., standard error of the mean; DM, dry matter; L, significance for a linear effect; Q, significance for a quadratic effect.
Significant at $P \leq 0.05$; Equations: [a]$Y = 0.078x + 4.168$, $R^2 = 93.53$; [b]$Y = 0.321x + 1.068$, $R^2 = 96.36$; [c]$Y = -0.106x + 2.025$, $R^2 = 58.16$; [d]$Y = 0.114x + 0.7$, $R^2 = 76.54$; [e]$Y = -0.127x^2 + 0.644x + 0.662$, $R^2 = 11.24$.

Results

The different levels of inclusion of maniçoba in cactus pear silage resulted in a significant effect on pH, N-NH_3, DMR, LA, AA, PA and BA ($P < 0.050$) (Table 3). Regarding the different opening times, there was an increasing linear effect for pH ($P < 0.001$), N-NH_3 ($P = 0.011$) and AA ($P < 0.001$). LA showed a linear decreasing effect ($P < 0.001$) according to the increase in the opening times of the silos. A quadratic behaviour was found for BA ($P = 0.050$) (Table 4).

The chemical composition of silages did not show a significant effect ($P > 0.050$) in the different opening times (Table 5). Regarding the different levels of inclusion of maniçoba in cactus pear silages, an increasing linear effect was verified for DM, EE, CP, NDF, ADF, lignin, cellulose and HEM ($P < 0.050$) and a decreasing linear behaviour for MM, TC and NFC ($P > 0.050$) (Table 6).

Intakes of CP ($P = 0.004$), EE ($P = 0.020$), NDF ($P = 0.003$), ADF ($P = 0.003$) and NFC ($P = 0.002$) showed increasing linear behaviour with increasing levels of inclusion of maniçoba in cactus pear silages (Table 7). The digestibility coefficients of DM ($P = 0.002$) and NDF ($P = 0.003$) decreased linearly and the CP digestibility coefficient increased ($P = 0.031$) according to the increase in the levels of maniçoba in the cactus pear silages (Table 7).

There was an increasing linear effect for water intake via drinking fountain ($P = 0.013$) and metabolic water ($P = 0.040$). On the other hand, water intake via food ($P < 0.001$); total water intake ($P < 0.001$); water excreted via faeces ($P = 0.002$); water excreted via faeces urine ($P < 0.001$); total water excretion ($P < 0.001$); water balance ($P < 0.001$) and decreased according to the increase in the levels of maniçoba in the cactus pear silages (Table 8). The nitrogen ingested ($P = 0.003$); nitrogen in the urine ($P = 0.041$) and the nitrogen balance ($P = 0.007$) increased according to the levels of inclusion of maniçoba in cactus pear silages (Table 8).

Discussion

The inclusion of maniçoba increases pH, probably due to the reduction of soluble carbohydrates. This result is in agreement with the results found by Çürek and Özen (2004), which evaluated the fermentation characteristics of silage of cactus pear plus a legume and observed a variation of 3.54 to 4.5. Values of pH from 3.8 to 5.0 in silages indicate the dominance of lactic acid bacteria and, consequently, the accumulation of lactic acid, which inhibits undesirable microorganisms and favours the preservation process (Miranda-Romero *et al.*, 2018).

According to McDonald *et al.* (1991), the high moisture content and low levels of soluble carbohydrates influence the fermentation process avoiding the rapid decline of pH and consequently favouring the appearance of unwanted secondary fermentation, which dilute the organic acids, main products of the fermentation by heterofermentative bacteria, negatively influencing the drop of pH of the medium (Borreani *et al.*, 2018). Moreover, this high water activity provides the development of bacteria of the genus *Clostridium*, responsible for reducing the nutritional value, which causes the production of poor quality silage, even resulting in losses of nutrients, due to the effluent produced in large amount (Silva *et al.*, 2017; Wang *et al.*, 2019).

The increase in the concentration of N-NH_3 in silages containing higher proportions of cactus pear is linked to the higher pH value observed for this silage. The protein content may undergo deamination when the cactus pear is added to silage due to a reduction in the NDF content. Presumably, microorganisms can improve protein degradation when fibre fractions are reduced by increasing the attachment of microorganisms to the substrate (Arreola *et al.*, 2019). Although the silage consisting only of cactus pear showed higher concentrations of N-NH_3, the values found agree with Gois *et al.* (2019), who considered values of less than 10% of N-NH_3/TN as indicative of adequate fermentation.

Maniçoba has adequate levels of DM and soluble carbohydrates and low buffering power (Carvalho *et al.*, 2018). These characteristics contribute to the establishment of a better silage fermentation pattern. It also has adequate levels of moisture, which prevents the development of undesirable microorganisms and consequently reduces losses from the fermentation process, thus leading to an increase in the DMR rate.

In silages containing cactus pear, there were higher concentrations of lactic acid. The lactic acid is directly related to the concentrations of soluble carbohydrates present in the mucilage of the cactus pear, favouring an increase in the contents of lactic acid to the other acids, causing a drop in the pH of the ensiled mass. The levels of lactic acid in silage indicate an adequate fermentation pattern, in which they must vary from 4 to 6%; acetic

Table 5. Chemical composition of cactus pear silages combined with different levels of maniçoba at different opening times ($n = 6$)

Items	Opening times (days)						S.E.M.	P value	
	1	7	15	30	60	90		L	Q
DM (g/kg NM)	208.6	205.1	207.4	208.5	205.9	205.1	0.13	0.888	0.989
MM (g/kg DM)	107.2	110.3	109.5	109.8	112.8	109.2	0.07	0.661	0.819
EE (g/kg DM)	31.77	31.80	31.72	31.44	31.90	31.09	0.031	0.941	0.989
CP (g/kg DM)	92.40	93.88	93.10	90.10	91.69	92.11	0.062	0.816	0.971
NDF (g/kg DM)	399.4	405.4	392.6	404.3	403.0	400.7	0.38	0.919	0.994
ADF (g/kg DM)	231.0	228.9	230.7	235.8	235.5	233.8	0.26	0.638	0.893
TC (g/kg DM)	768.7	764.0	765.7	768.8	764.6	766.7	0.11	0.884	0.954
NFC (g/kg DM)	369.2	358.7	373.1	364.5	361.5	366.0	0.39	0.909	0.993
Lignin (g/kg DM)	79.8	60.2	62.7	62.3	61.7	62.6	0.66	0.170	0.148
Cellulose (g/kg DM)	168.4	176.5	168.6	168.5	167.5	166.9	0.29	0.086	0.104
HEM (g/kg DM)	16.6	16.9	16.8	17.3	17.4	17.1	0.26	0.507	0.781

S.E.M., standard error of the mean; NM, natural matter; DM, dry matter; MM, mineral matter; NDF, neutral detergent fibre; ADF, acid detergent fibre; TC, total carbohydrates; NFC, non-fibrous carbohydrates; L, significance for a linear effect; Q, significance for a quadratic effect.
Significant at $P \leq 0.05$.

acid must be less than 2% and propionic acid must be less than 0.5% (Araújo *et al.*, 2018).

The concentration of lactic acid found in the current study corroborates the results reported by Mokoboki *et al.* (2016), who, when evaluating the effects of including molasses levels in proportions 0, 8, 16 and 24% on the fermentation characteristics and nutritional value of cactus pear silage, obtained lactic acid concentrations ranging from 4.9 to 10.05%.

Regarding the different opening times, it was observed that at 30 days after making the silages, the concentration of lactic acid reached a maximum point, indicating that the microorganisms responsible for its production (lactic acid bacteria), continued their development until that period. Differently from the observed for lactic acid, the production of acetic acid reached its maximum at 60 days after making the silages. This result may be related to the development of undesirable microorganisms by reducing the growth of lactic acid bacteria.

Ramos *et al.* (2016) and Borreani *et al.* (2018) claim that the compaction of the material to be ensiled directly influences the production of acetic acid. In the presence of oxygen, there are favourable conditions for the development of microorganisms responsible for the production of this acid, related to the growth of heterofermentative lactic acid bacteria, which are responsible for both the production of lactic and acetic acids. The latter acid is also responsible for promoting the preservation of silage. However, at concentrations higher than 0.8%, it causes the appearance of undesirable changes that occurred during ensiling (Bernardes *et al.*, 2018).

Although all the acids formed in the fermentation process act by reducing the pH of the ensiled mass, lactic acid is the main responsible for acidification of the medium because it is a strong acid (K_a of 3.86), and because it has a higher constant of dissociation than the others, with the more significant release of hydrogen ions in the medium (Silva *et al.*, 2017). The higher conversion of soluble sugars into lactic acid, consequently, the increased concentration of this acid, is due to the buffering of the acids produced by fermentation, which prevents the production of ethanol, promoting quantitative gains due to the lower loss by gases and the more significant recovery of DM (Ren *et al.*, 2018).

The increase in DM content in silages is directly related to the nutritional characteristics of maniçoba, whose chemical composition indicates a higher content of DM, NDF and protein compared to cactus pear (Table 1). The combination of cactus pear with fibre foods is a determining factor for normal functioning of activities such as rumination, ruminal movement, homogenization of ruminal content and salivary secretion. The DM values found for silages with 100% maniçoba silage are similar to those recommended by McDonald *et al.* (1991), which justifies the variation in the DM content between 30 and 35%, ideal for making good quality silages.

Cactus pear, in general, has low concentrations of DM, NDF and CP and has high concentrations of NFC, pectin and minerals, mainly calcium (Oliveira *et al.*, 2018). Although it is a forage plant adapted to arid and semiarid conditions, with potential as a source of water and nutrients for feeding ruminants, its use in large proportions or exclusive supply can cause nutritional disturbances in ruminant animals, causing diarrhoea, as usually, its concentration of fibre is not sufficient to maintain the proper conditions of ruminal functions. Animals fed with cactus pears should integrate their feed with a fibre source and a protein source (Rodrigues *et al.*, 2016).

Silage of cactus pear combined with a legume, in addition to providing a water reserve, improves the levels of effective fibre and CP, providing a water reserve of high potential (Gusha *et al.*, 2015). In the current study, silages provided values of CP intake higher than those recommended by the NRC (2007) (49.8 g/day) to meet the nutritional requirements of goats under maintenance conditions, which demonstrates the acceptability and potential of complementarity between the two fodder, there since the silages showed CP content above 7% reported by Van Soest (1994) for the microbial fermentation occurs appropriately.

The increase in EE intake observed with the increase of maniçoba levels in cactus pear silages is due to the higher

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Table 6. Chemical composition of cactus pear silages combined with different levels of maniçoba ($n = 6$)

	Maniçoba levels (%)						P value	
Items	0	25	50	75	100	s.e.m.	L	Q
DM (g/kg NM)[a]	106.1	182.6	211.2	245.0	288.9	0.14	<0.001	<0.001
MM (g/kg DM)[b]	146.9	96.4	101.1	118.0	85.3	0.07	<0.001	<0.001
EE (g/kg DM)[c]	13.59	22.03	35.69	42.31	45.20	0.060	<0.001	<0.001
CP (g/kg DM)[d]	49.89	70.53	92.15	112.21	136.40	0.059	<0.001	<0.001
NDF (g/kg DM)[e]	305.3	347.4	409.2	452.7	491.9	0.40	<0.001	<0.001
ADF (g/kg DM)[f]	151.8	207.4	229.9	276.6	299.5	0.27	<0.001	<0.001
TC (g/kg DM)[g]	789.6	789.1	771.2	749.1	733.3	0.11	<0.001	<0.001
NFC (g/kg DM)[h]	484.3	441.6	361.9	297.4	242.3	0.37	<0.001	<0.001
Lignin (g/kg DM)[i]	27.0	57.5	66.7	84.4	88.6	0.77	<0.001	<0.001
Cellulose (g/kg DM)[j]	154.5	145.7	179.2	176.0	191.2	0.30	<0.001	<0.001
HEM (g/kg DM)[k]	123.7	162.0	163.1	191.2	210.8	0.28	<0.001	<0.001

s.e.m., standard error of the mean; NM, natural matter; DM, dry matter; NDF, neutral detergent fibre; ADF, acid detergent fibre; TC, total carbohydrates; NFC, non-fibrous carbohydrates; L, significance for a linear effect; Q, significance for a quadratic effect.
Significant at $P \le 0.05$; Equations: [a]$Y = 0.172x + 12.03$, $R^2 = 96.59$; [b]$Y = -0.58x + 13.89$, $R^2 = 89.84$; [c]$Y = 0.036x + 1.30$, $R^2 = 90.92$; [d]$Y = 0.085x + 4.90$, $R^2 = 99.79$; [e]$Y = 0.190x + 30.58$, $R^2 = 99.38$; [f]$Y = 0.146x + 15.95$, $R^2 = 97.85$; [g]$Y = -0.061x + 79.70$, $R^2 = 94.27$; [h]$Y = -0.251x + 49.11$, $R^2 = 99.32$; [i]$Y = 0.057x + 3.66$, $R^2 = 93.06$; [j]$Y = 0.086x + 12.47$, $R^2 = 99.17$; [k]$Y = 0.044x + 14.63$, $R^2 = 70.79$.

Table 7. Daily intake, apparent digestibility of nutrients in goat fed of cactus pear silage combined with different levels of maniçoba ($n = 6$)

	Maniçoba levels (%)					P value	
Items	25	50	75	100	s.e.m.	L	Q
	Intake (g/day)						
DM	957	1113	1127	1220	55.7	0.057	0.807
MM	129	116	111	84	5.1	0.528	0.465
CP[a]	149	183	187	245	10.1	0.004	0.553
EE[b]	59	70	76	89	3.9	0.02	0.906
NDF[c]	332	742	751	801	35.7	0.003	0.795
ADF[d]	208	473	505	656	25.8	0.003	0.362
TC	619	264	316	433	20.6	0.060	0.518
NFC[e]	287	269	245	145	10.9	0.002	0.010
	Digestibility (g/kg)						
DM[f]	736	684	674	610	1.3	0.002	0.817
CP[g]	619	697	70.3	745	1.2	0.031	0.184
EE	681.0	581.7	494.9	395.6	0.90	0.079	0.394
NDF[h]	597.4	454.4	372.3	337.6	0.91	0.003	0.212
ADF	650	719	690	721	3.3	0.173	0.200

s.e.m., standard error of the mean; L, significance for a linear effect; Q, significance for a quadratic effect.
Significant at $P \le 0.05$; Equations: [a]$Y = 29.107x + 118.3$, $R^2 = 89.78$; [b]$Y = 9.687x + 50.075$, $R^2 = 98.25$; [c]$Y = 141.62x + 302.86$, $R^2 = 70.32$; [d]$Y = 137.52x + 117.09$, $R^2 = 90.98$; [e]$Y = -45.145x + 349.92$, $R^2 = 83.9$; [f]$Y = -3.869x + 77.32$, $R^2 = 93.66$; [g]$Y = 3.861x + 59.505$, $R^2 = 89.05$; [h]$Y = -8.615x + 65.58$, $R^2 = 92.66$.

concentration of this nutrient in maniçoba (Table 1). The average values observed are higher than those reported by the NRC (2007) (30 g/kg DM). Thus, all diets made it possible to maximize intake by animals, which were not affected by physical limitations due to excess fibre or high energy concentration.

Lower levels of maniçoba in the diets promoted lower CNF intake by the animals. This result is directly related to the chemical composition of the cactus pear, which has a high NFC content when compared to maniçoba. The increase in NDF and FDA intakes is due to the increased inclusion of maniçoba in silages. According to the NRC (2001) and NRC (2007), it is necessary to include a minimum of 20% physically effective NDF (peNDF) in the diet of beef cattle and small ruminants, although there are few studies with this sheep and goat species. Cardoso

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Table 8. Water balance and nitrogen balance in goat fed of cactus pear silage combined with different levels of maniçoba ($n = 6$)

Items	Maniçoba levels (%)				S.E.M.	*P* value	
	25	50	75	100		L	Q
	Water balance						
Water intake via drinking fountain (g/day)[a]	253	381	444	768	41.0	0.013	0.009
Water intake via food (kg/day)[b]	5	5	3	2	164.0	<0.001	0.544
Metabolic water (g/day)[c]	423	519	533	583	26.2	0.04	0.654
Total water intake (kg/day)[d]	6	6	4	3	183.4	<0.001	0.206
Water excreted via faeces (g/day)[e]	554	481	355	242	28.4	0.002	0.709
Water excreted via urine (kg/day)[f]	2	2	874	745	71.3	<0.001	0.255
Total water excretion (kg/day)[g]	3	2	1	987	98.9	<0.001	0.396
Water balance (kg/day)[h]	3	3	3	2	142.4	<0.001	0.097
	Nitrogen balance						
Nitrogen intake (g/day)[i]	24	29	30	39	1.6	0.003	0.553
Nitrogen faeces (g/day)	6.0	10.7	8.7	7.7	0.67	0.090	0.061
Nitrogen urine (g/day)[j]	5.3	6.4	7.6	7.8	0.46	0.041	0.620
Nitrogen balance (g/day)[k]	13	12	14	24	1.3	0.007	0.060

S.E.M., standard error of the mean; L, significance for a linear effect; Q, significance for a quadratic effect.
Significant at $P \le 0.05$. Equations: [a]$Y = 161.02x + 59.415$, $R^2 = 89.71$; [b]$Y = -957.61x + 6198.4$, $R^2 = 89.62$; [c]$Y = 49.402x + 391.66$, $R^2 = 91.0$; [d]$Y = -811.99x + 6811.5$, $R^2 = 87.81$; [e]$Y = -106.24x + 674.13$, $R^2 = 98.89$; [f]$Y = -568.13x + 2861.7$, $R^2 = 93.36$; [g]$Y = -674.37x + 3535.8$, $R^2 = 95.14$; [h]$Y = -137.62x + 3275.7$, $R^2 = 18.62$; [i]$Y = 4.656x + 18.93$, $R^2 = 89.79$; [j]$Y = 0.869x + 4.59$, $R^2 = 94.12$; [k]$Y = 3.46x + 6.9$, $R^2 = 67.74$.

et al. (2006) concluded that the ideal content of NDF in the diet of growing lambs is approximately 30% or the equivalent of 22% peNDF. Thus, as pointed out in the paper mentioned above, with up to 75% of cactus pear, the amount of NDF is approximately 35.6%, demonstrating a balance between NDF and NFC, avoiding changes in the rumen fermentation pattern, with a decrease in DMI.

Although there was no difference between the treatments for the intake of DM, it is possible to notice an increase in the intake of this nutrient, which would justify the increase in the intake of the variables mentioned above. DMI is directly related to the nutritional value of the diet, influenced by the shorter time of ingestion and rumination so that in this relationship, the NDF acts as the main factor in the activity of the rumen (Beauchemin, 2018).

Analysing the factors that interfere with digestibility, it is observed that, with the use of cactus pear caused a change in the composition of the diet, mainly regarding the proportions of NFC, NDF and CP. The increase in CP content due to the increase of maniçoba in the diets improved the development of ruminal flora and the fermentation process, which can be attributed to the increase in the rate of passage of nitrogenous material to the small intestine (Moyo and Nsahlai, 2017).

The increase in the proportion of NFC possibly provided better conditions in the rumen, given that NFC are readily degraded, increasing the energy supply and improving the energy: protein synchrony, which favours microbial growth and therefore, digestion (Zadeh and Kor, 2013; Ma *et al.*, 2015). Thus, the reduced digestibility of DM and NDF is related to the high content of NFC present in cactus pear, which after being rapidly fermented in the rumen, promote a marked drop in rumen pH, an increase in the rate of passage, and consequently a reduction in cellulolytic activity. All these elements influence the digestibility of the fibre directly (Pinho *et al.*, 2018).

The ability of the diet to meet animals' water requirement is related to the DM content of the forage. Diets containing cactus pear silage in its composition leads to a reduction in water intake (Miranda-Romero *et al.*, 2018). This behaviour is due to the amount of water the cactus pear contains since it has a low DM content (9.2%), and, consequently, a high moisture content (Mayer and Cushman, 2019). In this way, it provided a reduction in direct water intake by the animals. Neto *et al.* (2016) observed that small ruminants fed diets containing fresh cactus pear showed lower intake of drinking water and that, under these conditions, they excrete large volumes of urine, as a compensatory mechanism in the regulation of the total volume circulating in the body.

The National Research Council (NRC 2007) recommends a daily water intake of 0.732 kg for goats. Thus, the current study highlights that, for all levels evaluated, considering only the intake of water via food, there was a water consumption higher than that required for the functioning of the animals' physiological functions.

For adequate animal production, it is necessary a stable or positive water balance, with a water balance between its body fluids (Al-Dawood, 2017). Thus, the animals that consumed more water also excreted higher concentrations of water, maintaining a positive water balance.

The increase in nitrogen consumption is in line with the DMI presented by the animals fed increasing levels of maniçoba in the diets. The increase in faecal nitrogen may be related to the attempt to synchronize the availability of energy and protein for the rumen microorganisms, which may have increased the digestibility of the eliminated CP – mainly through faeces (Hartinger *et al.*, 2018). According to Getahun *et al.* (2019), the N found in the faeces derives from the microbial cells formed in the large intestine, enzyme excretion and from food that has not been degraded in the gastrointestinal tract.

The positive nitrogen balance indicates that the animals did not need to dislocate body protein reserves to meet their nutritional requirements and that the diet was sufficient to increase nitrogen intake (Alves *et al.*, 2014). The observed results indicate that there were no losses of protein or nitrogen compounds during the experimental period, demonstrating that the protein fraction of the diets were used efficiently by the animals.

Conclusion

The inclusion of maniçoba in cactus pear silage resulted in better fermentation characteristics and nutritional quality to be used in diets for ruminants. The inclusion levels of maniçoba in cactus pear silage increased the levels of CP, EE, NDF and ADF in the diets, which promoting a higher intake of these nutrients.

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Conflict of interest. The authors declare that they have no competing interests.

Ethical standards. This research was evaluated and approved by the National Council for the Control of Animal Experimentation (CONCEA) and the Ethics Committee on the Use of Animals (CEUA) of Embrapa Semiárido, under protocol number 04/2016.

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