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Chemical and Mineral Composition, Kinetics of Degradation and *in vitro* Gas Production of Native Cactus*

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Abstract

This study aimed to evaluate the chemical and minerals composition, fractions of carbohydrate and nitrogen compounds, kinetics of degradation and *in vitro* gas production of native cactus species of the brazilian Semiarid. The experiment was conducted in a completely randomized design, with five native cactus species and 4 replications per species were randomly selected. The native cactus species evaluated were: *Cereus jamacaru* DC., *Melocactus bahiensis* Br. Et Rose Werderm, *Opuntia inamoene* K. Schum, *Pilosocereus gounellei* (A. Weber ex K. Schum) Bly ex Rowl and *Pilosocereus pachycladus* Ritter, all *in natura*. The native cactus species showed differences for chemical and mineral compositions (P <0.05). The nitrogenous components, *C. jamacaru* cactaceae presented higher contents of fractions A (228.1 g/kg CP) and B3 (241.7 g/kg CP) and smaller fraction C (174.0 g/kg CP). For carbohydrate fraction *C.*

jamacaru presented lower fractions A + B1 (412.2 g/kg TC) and C (38.2 g/kg TC) and high fraction B2 (549.7 g/kg TC) and low fraction C. The cactus *C. jamacaru* and *M. bahiensis* presented a high PD (856.6 and 837.9 g/kg DM, respectively). The parameters a and b and the effective degradability present diferences (P<0.05) in function of 2% and 5% passage rate. The *in vitro* true digestibility of dry matter was above 700 g/kg of DM for all species. Cactus have high levels of potentially digestible fractions of total carbohydrates, indicating their importance as food for ruminants in created in the semiarid, where Caatinga vegetation is a basal resource.

Keywords: *Cactaceae*, *In vitro* fermentation, semiarid

1. Introduction

The semiarid region of Brazil is characterized by a temporal and spatial variation of rainwater pulses concentrated in only a few months of the year in most cases. Considering the local edaphoclimatic conditions, it can be stated that forage production in the semiarid is challenging (Pinheiro *et al.*, 2017; Chaves *et al.*, 2019). In this context, the search for food alternatives that enable animal production in the Brazilian semiarid is essential, making use of adapted or native forage plants can be considered as the main forage support for the food shortage period. In addition, the cactus pear, as well as the other native semiarid cacti, such as *Opuntia inamoene* K. Schum (common name: Quipá), *Cereus jamacaru* DC. (common name: Mandacaru), *Pilosocereus pachycladus* Ritter (common name: Facheiro) and *Pilosocereus gounellei* (A. Weber ex K. Schum). Bly ex Rowl (common name: Xique-xique), have great forage potential because they are adapted to the region's edaphoclimatic conditions, enabling satisfactory dry matter yields per unit area, source of energy and fiber (Lucena *et al.*, 2013; Monteiro *et al.*, 2015; Carvalho *et al.*, 2018).

Several studies have been conducted on the use of native and exotic plants adapted the Semiarid, using them as a forage resource and supplying the scarcity of information about the nutritional values and the feeding attributes of ruminants. Silva *et al.*, (2010), studying the use of native cactus (*Cereus jamacaru* and *Pilosocereus gounellei*) associated with different sources of fiber (sabiá hay, silk flower and mesquite pods), observed that all diets evaluated met the nutritional requirements of animals and also promoted a gain of 89 g/day per animal. Such combinations are considered by the authors as satisfactory for the Semiarid region. Furtado *et al.*, (2016), studying *Pilosocereus gounellei* comprising up to 36% of the diet of lactating cows, observed that animals that ate a great proportion of this cactus increased the intake of water from food and reduced the intake of drinking water. In addition, the animals kept the milk production efficiency. The authors then stated that this cactus can be used in the diet of lactating cows without losses on the herd productivity.

The determination of the minerals, fractions of carbohydrates and proteins and the kinetic parameters of ruminal degradation is of utmost importance for nutritionists (Kalegowda *et al.*, 2015; Alves *et al.*, 2017). This information can be used in modern feed formulations for ruminants to maximize the synchronization of degradation of carbohydrates and nitrogen compounds, minimizing energy and nitrogen losses due to ruminal fermentation and promoting a greater efficiency of microbial synthesis (Boufennara *et al.*, 2016; Santos *et al.*, 2019).

Therefore, it is necessary to further study the fractions of chemical components of such foods and the kinetics of degradation of the compounds present in such plants to optimize their use for the diet of ruminants.

Thus, the objective of this study is to evaluate the chemical and mineral composition, fractions of carbohydrate and nitrogen compounds, kinetics of degradation and *in vitro* gas production of native cactus species of the brazilian semiarid.

2. Materials and Methods

2.1 Site Description

The study was carried out in the Federal Rural University of Pernambuco (UFRPE), academic Unit of Garanhuns, located in Garanhuns, Pernambuco - Brazil. Their study follows the principles of the Declaration of Helsinki.

2.2 Samples and Experimental Design

The samples were collected at four distinct points in the Caatinga área, in the Rural Technology Development and Diffusion Station of Sertão Alagoano, located in the city of Piranhas, Alagoas – Brazil. The experiment was conducted in a completely randomized design, with 5 native cactus species (treatments) and 4 replications per species were randomly selected. The native cactus species evaluated were: *Cereus jamacaru* DC. (Mandacaru), *Melocactus bahiensis* Br. Et Rose Werderm. (Coroa de Frade), *Opuntia inamoene* K. Schum (Quipá), *Pilosocereus gounellei* (A. Weber ex K. Schum) Bly ex Rowl (Xiquexique) and *Pilosocereus pachycladus* Ritter (Facheiro), all *in natura*.

2.3 Preparation of the Samples for Analysis

The spines of *M. bahiensis*, *P. gounellei* and *P. pachycladus* were removed. For the species *C. jamacaru*, the central portion or core of the plant was discarded, because it was a rigid structure. Only the outer part of the plant was used, in which the spines were previously removed.

Samples were pre-dried in a forced ventilation oven at 55 ℃ for 72 h and ground to 1-mm and 2 mm-sized particles (Wiley mill, Marconi, MA - 580, Piracicaba, Brazil) to determine the chemical composition, mineral composition, gas production, degradability and in vitro digestibility assays.

2.4 Chemical Analysis

All chemical analyses were carried out using the procedures described by the AOAC (2016) for dry matter (DM, method 967.03), organic matter (OM), mineral matter (MM, method 942.05), ether extract (EE, method 920.29) and crude protein (CP, method 981.10). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to the methodology proposed by Van Soest *et al.*, (1991). Neutral detergent fiber corrected for ash (a) and protein (p) (using thermo-stable alpha-amylase, without sodium sulfite) (NDFap; Mertens 2002; Licitra *et al.*, 1996) and lignin was determined by treating the acid detergent fiber residue with 72% sulfuric acid (Silva and Queiroz, 2002). The pectin was quantified according to Canteri-Shemin *et al.*, (2005) with changes of Zanella & Taranto (2015). The fractions of cellulose (CEL) and hemicellulose (HEM) were estimated by the equations: CEL = ADF – LIG and HEM = NDF - ADF. The total digestible nutrients (TDN) and digestible energy (DE) were estimated using the NRC (2001).

2.5 Mineral Composition

The concentrations of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), (B) copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) were determined according to the methodologies described by Nogueira & Souza (2005). Sodium and potassium levels were determined by flame photometry, whereas the concentrations of Ca and Mg were analyzed by titration, by determining the Ca contents, and subsequently the Ca + Mg contents, and the Mg concentration was defined as the difference. Sulfur levels were determined indirectly, first by obtaining the concentrations of sulfates and subsequently, by considering the atomic molecular weight, the concentration of S were determined. Phosphorus was determined using a molecular spectrophotometer while the determination of B, Cu, Fe, Mn and Zn, was performed on an atomic absorption spectrophotometer (model Analyst 100, Perkin Elmer®).

2.6 Fractionation of Carbohydrate and Protein

Total carbohydrates (TC) were calculated according to Sniffen *et al.*, (1992), where: TC (% DM) = 100 – (CP + EE + MM). Non-fibrous carbohydrate (NFC), corresponding to the fractions A+B1, was measured by the equation NFC = 100 - (CP + NDFap + EE + MM). The fraction C was obtained by the indigestible NDF after 288 hours *in situ* incubation, as described by Valente *et al.*, (2011). The fraction B2 (digestible fiber) was obtained by the difference between NDFap total carbohydrate and C fraction (indigestible fiber).

Non-protein nitrogen (fraction A), neutral detergent insoluble nitrogen (NDIN) and acid detergent insoluble nitrogen (ADIN) were estimated according to the methodology described by Licitra *et al.*, (1996). The protein fractionation was calculated by the CNCPS system (Sniffen *et al.*, 1992). The protein was analyzed and calculated for the five fractions, A, B1, B2, B3 and C. The fraction A, made up by NPN compounds, was determined by the difference between total N and trichloroacetic acid (TCA) insoluble nitrogen with the formula: A (%Nt) = Nt - N1/Nt x 100, where Nt = total nitrogen of the sample, and N1 = content of trichloroacetic acid insoluble nitrogen.

The fraction B1 refers to soluble protein, rapidly degraded in the rumen, obtained by the difference between the borate phosphate buffer (TBF) insoluble nitrogen minus the NPN, by the formula: B1 (%Nt) = N1 - N2/Nt x 100, where: N2 = borate phosphate buffer insoluble nitrogen. The fractions B2 and B3 consist of insoluble protein with intermediate-slow degradation rate in rumen, determined by the difference between the borate phosphate buffer insoluble nitrogen and NDIN, the NDIN minus the ADIN, respectively. The value of B2 is achieved with B2 (%Nt) = N2 - NIDN/Nt x 100 and the fraction B3, with B3 (% Nt) = NDIN - ADIN/Nt x 100. The fraction C is formed by insoluble protein indigestible in the rumen and intestine, and was determined by the content of residual nitrogen of the sample after treated with acid detergent and expressed in percentage of Nt of the sample.

2.7 "in vitro" Ruminal Degradation Kinetics by Gas Production

The *in vitro* dry matter degradability was performed according to the first stage of the Tilley e Terry (1963) method, using a nutrient medium of Marten & Barnes (1979) through in vitro incubations of 600 mg of dry air sample with 60 mL of buffer solution (combination of solutions A + B with pH 6.8) and 15 mL of inoculum collected from ruminal inoculum collected from two rumen fistulated sheeps, filtered in four layers of gauze, constantly injecting carbon dioxide to maintain the anaerobic environment. Samples were incubated at 0, 3, 6, 9, 12, 18, 24, 36 and 48 hours, whereas at time zero the samples underwent only a washing under distilled water at 39 ℃. In the other times, the samples were incubated in an oven with a constant temperature of 39 ℃.

In vitro degradation parameters (*a*, *b* and *c*) and potential dry matter degradability were estimated using the model proposed by Orskov & McDonald (1979): $PD = a + b (1 - e^{-ct})$ using the PROC NLIN procedure of the SAS software, where *PD* is the actual percentage of nutrient degraded after t hours of incubation, *a* is readily soluble fraction, b is the fraction that can be degraded if there is time, *c* is *b* fraction degradation rate or speed, and *t* is incubation time. To estimate the effective degradability (ED), the following equation was used: ED = $a + (b*c)/(c + k)$, where k is food passage rate. Rumen particle passage rates are estimated at 0.02, 0.05 and 0.08 h^{-1} as suggested by AFRC (1993).

The analysis of *in vitro* dry matter digestibility (IVDMD) was conducted according to Tilley & Terry (1963), with the modifications proposed by Holden (1999), through in vitro incubations of 1 g of dry sample in air, with 80 mL of buffer solution and 20 mL of ruminal fluid, filtered in four layers of gauze, constantly injecting carbon dioxide to maintain the anaerobic environment. After 48 hours of incubation, 6 mL of 20% hydrochloric acid (HCl) and 2 mL of pepsin (1: 1000) were added into each vial and, after the 24 hours incubation period, the filtration procedures were performed vacuum, drying and weighing of the waste, in order to calculate the IVDMD.

For in vitro gas production, 1.0 g of sample was added to glass bottles (160 mL), to which 90 mL of nutrient medium were added, according to Theodorou *et al.*, (1994). Subsequently, 10 mL of rumen fluid (from the rumen of three goats) were added to each vial, which was kept under CO_2 aspersion. Then, they were sealed with rubber corks and aluminum seals. The pressure caused by fermentation was measured using a pressure transducer (Datalogger Universal Logger AG100 - Agricer). The readings were made with a higher rate during the initial period and with a lower rate towards the end of the study period (2, 4, 6, 8, 10, 12, 15, 18, 21, 24, 30, 36, 42 and 48 hours of incubation). The pressure in PSI (pressure per square inch) were converted into volume of gas (V) by the equation V = 5.1612*psi - 0.3017, R^2 = 0.9873, generated in the Production Laboratory (LPG) of the Academic Unit of Garanhuns, UFRPE, based on 937 observations (-8 °90'77" S, -36 °49'49" W, altitude 844 meters). 1 psi = 4.859 mL of gas. From each pressure reading, the total produced by the bottles without substrate (white), for each sample, was subtracted.

2.8 Statistical Analysis

The data obtained from chemical analyses, fractionation of carbohydrates, nitrogenous compounds and IVDMD were submitted to analysis of variance using the PROC GLM procedure. Cumulative gas production data were adjusted by the two-compartment model suggested by Schofield *et al*.,, (1994) using the procedure NLMIXED of SAS (2011).

$$V(t) = (Vf1 / 1 + e^{[2-4kd1(T-L)]}) + (Vf2 / 1 + e^{[2-4kd2(T-L)]})$$

where, V(t) is the maximum total volume of produced gas; Vf1 (mL) is the maximum volume of gas for the rapidly digested carbohydrate fraction (NFC); VF2 (mL) is the maximum volume of gas for the slowly digestion fraction (FC); *kd1* (h^{-1}) is the rate of degradation of the rapidly digested fraction (NFC); *kd2*(h^{-1}) is the rate of degradation of the slowly digested fraction; *L* is the duration of initial digestion events (lag phase) common to the two phases; and T (h) is fermentation time.

The means were compared by Tukey test at 5% significance level using the statistical software *Statistical Analysis System* (SAS®).

3. Results

The native cactus species evaluated showed differences for mineral matter (P<0.0001), organic matter (P<0.0001), ether extract (P<0.0001), crude protein (P<0.0001), neutral detergent insoluble protein (P = 0.008), acid detergent insoluble protein (P<0.0001), neutral detergent fiber (P<0.0001), acid detergent fiber (P<0.0001), hemicellulose (P<0.0001), acid detergent lignin (P<0.0001), cellulose (P<0.0001), non-fiber carbohydrates (P<0.0001), pectin (P = 0.014), total digestible nutrients (P<0.0001) and digestible energy (P<0.0001) (Table 1).

Table 1. Chemical composition of native cactus of the Brazilian Semiarid

Variables	Native cactus species					SEM	*P* value
	Cereus jamacaru	*Melocactus bahiensis*	*Opuntia inamoene*	*Pilosocereus gounellei*	*Pilosocereus pachycladus*		
DM [1]	154.1a	116.2a	135.5a	113.5a	148.4a	5.65	0.052
MM [2]	141.3cd	183.1bc	116.4d	267.4a	233.6ab	14.21	<0.0001
OM [2]	858.5ab	816.8bc	883.6a	732.5d	766.4cd	14.2	<0.0001
EE [2]	15.4b	17.4ab	25.6a	5.7c	19.9ab	1.67	<0.0001
CP [2]	65.9a	59.7a	29.8b	26.0b	52.3a	4.08	<0.0001
NDIP [3]	415.7b	457.4ab	569.9ab	599.5a	404.9b	24.17	0.008
ADIP [3]	174.0c	269.7bc	498.8ab	476.3a	361.4b	29.6	<0.0001
NDF [2]	457.1a	292.0d	402.2b	355.1bc	347.7c	13.6	<0.0001
ADF [2]	258.5ab	260.0a	170.7c	236.1b	167.6c	9.69	<0.0001
HEM	198.7a	32.0c	231.6a	119.0b	180.0a	16.93	<0.0001
ADL [2]	5.6c	18.5b	10.9bc	36.0a	34.7a	2.99	<0.0001
CEL [2]	252.8a	241.5a	161.3c	200.1b	132.8d	10.65	<0.0001
NFC [2]	320.3b	447.8a	425.9a	345.7b	346.4b	12.7	<0.0001
Pectin[2]	45.7b	75.4ab	99.9a	76.5ab	38.8b	6.95	0.014
TDN[2]	658.9a	637.3a	698.7a	498.8b	542.3b	18.3	<0.0001
DE[4]	2.8a	2.7a	3.0a	2.1b	2.3b	0.08	<0.0001

Means followed by the same letter in columns do not differ (P>0.05) by Tukey test, DM = dry matter, MM = mineral matter, OM = organic matter, EE = ether extract, CP = crude protein, NDIP = neutral detergent insoluble protein, ADIP = acid detergent insoluble protein, NDF =

neutral detergent fiber, ADF = acid detergent fiber, HEM = hemicellulose, ADL = acid detergent lignin, CEL = cellulose NFC = non-fiber carbohydrates, TDN = total digestible nutrients, DE = digestible energy, SEM = standard error mean. [1]g/kg of natural material; [2]g/kg of DM; [3]g/kg of CP; [4] Mcal/kg of DM

Regarding mineral composition, differences were observed between the studied species for the minerals Phosphorus (P <0.0001), Calcium (P = 0.0004), Magnesium (P <0.0001), Boron (P <0.0001), Iron (P = 0.01), Manganese (P <0.0001) and Zinc (P = 0.002) (Table 2).

Table 2. Mineral composition of native cactus from the Brazilian Semiarid

Variables	Native cactus species					SEM	*P* value
	Cereus jamacaru	*Melocactus bahiensis*	*Opuntia inamoene*	*Pilosocereus gounellei*	*Pilosocereus pachycladus*		
P[1]	1.4b	2.7a	0.9c	0.7c	0.5c	0.2	<0.0001
K[1]	9.4a	11.0a	12.3a	8.6a	10.9a	0.5	0.15
Ca[1]	38.2c	41.3bc	35.3c	56.1ab	58.5a	2.6	0.0004
Mg[1]	8.7b	9.1b	8.4b	16.2a	15.3a	0.9	<0.0001
S[1]	0.3a	0.3a	0.7a	0.6a	0.3a	0.1	0.23
B[2]	79.8a	80.5a	63.1b	88.7a	84.5a	2.3	<0.0001
Cu[2]	2.3a	3.4a	2.0a	3.5a	2.7a	0.2	0.14
Fe[2]	28.9b	122.5ab	134.8a	47.5ab	129.9ab	13.9	0.01
Mn[2]	261.9c	359.8bc	89.5c	1880.6a	1189.8ab	173.6	<0.0001
Zn[2]	39.4ab	24.0bc	17.6c	49.0a	45.0ab	3.4	0.002

Means followed by the same letter in columns do not differ (P>0.05) by Tukey test, SEM = standard error mean. P – Phosphorus; K – Potassium; Ca – Calcium; Mg – Magnesium; S – Sulfur; B – Boron; Cu – Copper; Fe – Iron; Mn – Manganese and Zn – Zinc. [1]g/kg of Dry Matter; [2]mg/kg of Dry Matter.

In relation to the fractions of nitrogen compounds, there were differences (P<0.05). The high content of the fraction A corresponds to the non-protein nitrogen (NPN) in the species *C. jamacaru* (228.1 g/kg CP), followed by *M. bahiensis* (146.2 g/kg CP), *O. inamoene* (102.3 g/kg CP) and *P. pachycladus* (83.2 g/kg CP). There was a low content of fraction A in *P. gounellei* (54.2 g/kg CP). For the fractions B1+B2, there were no differences (P>0.05) (Table 3).

Table 3. Fractions of nitrogen compounds of native cactus from the Brazilian Semiarid

Variables	Native cactus species					SEM	*P* value
	Cereus jamacaru	*Melocactus bahiensis*	*Opuntia inamoene*	*Pilosocereus gounellei*	*Pilosocereus pachycladus*		
CP [1]	65.9a	59.7a	29.8b	26.0b	52.3a	4.1	<0.0001
A [2]	228.1a	146.2ab	102.3ab	54.2b	83.2ab	19.8	0.0292
B1+B2 [2]	356.1a	396.3a	327.7a	346.2a	511.9a	26.5	0.177
B3 [2]	241.7a	187.7ab	71.2c	123.3bc	43.5c	19.3	<0.0002
C [2]	174.0c	269.7bc	498.8a	476.3a	361.4b	29.6	<0.0001

Means followed by the same letter in columns do not differ (P>0.05) by Tukey test, SEM = standard error mean, CP = Crude protein, A = non-protein nitrogen, B1+B2 = high and average rumen nitrogen degradation fraction, B3 = slow nitrogen degradation fraction, C = unavailable nitrogen fraction. [1]g/kg of DM; [2]g/kg of CP.

For the fraction B3, highest values were observed for *C. jamacaru* (241.7 g/kg CP) and the lowest values were observed for *P. pachycladus* (45.3 g/kg CP) (Table 3).The highest values were observed for *O. inamoene* (498.8 g/kg CP) and *P. gounelli* (476.3 g/kg CP), which differed (P<0.05) from the other cactus. The lowest presence of unavailable protein was observed for *C. jamacaru* (174.0 g/kg CP) (Table 3).

There were differences (P<0.05) among the species in the total carbohydrate ratios and their fractions. The highest total carbohydrate compositions were observed for *O. inamoene* (828.2 g/kg DM) and *C. jamacaru* (777.4 g/kg DM). The lowest total carbohydrate compositions were observed for *P. pachycladus* (694.1 g/kg DM) (Table 4).

Table 4. Fractions of carbohydrate compounds of native cactus of the Brazilian Semiarid

Variables	Native cactus species					SEM	*P* value
	Cereus jamacaru	*Melocactus bahiensis*	*Opuntia inamoene*	*Pilosocereus gounellei*	*Pilosocereus pachycladus*		
TC [1]	777.4ab	739.8bc	828.2a	700.8c	694.1c	13.0	<0.0001
A+B1 [2]	412.2c	605.4a	514.3b	492.0b	498.9b	15.1	<0.0001
B2 [2]	549.7a	339.4bc	288.0c	369.2b	372.5b	21.4	<0.0001
C [2]	38.2b	55.2b	197.7a	138.8a	128.6a	14.9	<0.0001

Means followed by the same letter in columns do not differ (P>0.05) by Tukey test, SEM = standard error mean, TC = Total carbohydrate, A+B1 = soluble fraction, B2 = potentially degradable fiber, C = indigestible fiber. [1]g/kg of DM; [2]g/kg of TC.

The highest values of the fraction A+B1, which corresponds to carbohydrates with a high degradation rate, were observed for *M. bahiensis* (605.4 g/kg TC). The highest proportion of the fraction B2 (potentially digestible fiber) was observed for *C. jamacaru* (549.7 g/kg TC). For the fraction C (unavailable fiber), values of 197.7 g/kg TC for *O. inamoene* and 38.2 g/kg TC for *C. jamacaru* were observed. These values represent the highest and lowest means observed for the fraction C (Table 4).

Potential degradation was above 60% for all species and there were differences (P<0.05) among species (Table 5). The cactus *C. jamacaru* and *M. bahiensis* presented a high PD: 856.6 and 837.9 g/kg DM, respectively (Tables 1 and 4).

There were differences (P<0.05) in the parameters *a* and *b* and the effective degradability (ED) in function of a 2% (slow) and a 5% (average) passage rate. However, when an ED for a passage rate of 8% (fast) was estimated, it was observed that there were no differences (P>0.05) among species.

The *in vitro* true digestibility of dry matter was above 700 g/kg of DM for all species. The highest IVDMD was observed for *M. bahiensis* (865.8 g/kg of DM). The lowest value was found for *P. pachycladus* (721.1 g/kg DM) (Table 5). Such low IVDMD is due to a high proportion of fiber compounds with a low digestibility in the part C of the carbohydrates.

Table 5. Kinetics of degradation and *in vitro* true dry matter digestibility of native cactus of the Brazilian Semiarid

Variables	Native cactus species					SEM	*P* value
	Cereus jamacaru	*Melocactus bahiensis*	*Opuntia inamoene*	*Pilosocereus gounellei*	*Pilosocereus pachycladus*		
a[1]	170.8c	255.6ab	233.4b	237.7ab	283.2a	9.5	<0.0001
b[1]	685.9a	582.3b	454.5c	537.8bc	334.7d	28.5	<0.0001
c(h^{-1})	0.04a	0.04a	0.06a	0.04a	0.05a	0.02	0.22
ED[1](0.02 h^{-1})	644.9a	624.1ab	566.3cd	592.0bc	525.3d	10.6	<0.0001
ED[1](0.05 h^{-1})	495.4ab	498.9a	471.4ab	473.1ab	454.4b	5.5	0.04
ED[1](0.08 h^{-1})	417.6a	438.9a	419.4a	414.1a	415.6a	4.1	0.35
Pd[1]	856.6a	837.9a	687.8bc	775.4ab	618.0c	23.2	<0.0001
IVDMD[1]	796.6b	865.8a	733.4c	792.1b	721.1c	12.03	<0.0001

Means followed by the same letter in columns do not differ (P>0.05) by Tukey test, SEM = standard error mean; *a*, *b* and *c* refer to parameters of Orskov & McDonald (1979); ED = effective degradability for a passage rate of 0.02, 0.05 and 0.08 h^{-1}; Pd = potential degradability represented by the sum of *a* and *b*; IVDMD = *in vitro* true dry matter digestibility. [1]g/kg of DM.

The production of total gases *in vitro* (Vt1) and the production adjusted by the bicompartmental model (Vt2) presented differences between species (P<0.05). TC fermentation resulted in a higher Vt1 for *C. jamacaru* (267.2 mL/g incubated DM) and for *O. inamoene* (266.2 mL/g DM). They did not differ from *M. bahiensis* (258.0 mL/g DM) (Table 6). The lowest Vt1 produced by TC fermentation of *P. pachycladus* (192.4 mL/g DM) was due to the low proportion of total carbohydrates present in its composition, and also due to a low Pd.

There was a difference (P<0.05) in the gas production from the fermentation of non-fiber carbohydrates (Vf1). The *C. jamacaru* produces most gases, which differed from all other species. On the other hand, the production of gases by the degradation of fiber carbohydrates (Vf2) was low for *C. jamacaru*, not differing from *O. inamoene* and *P. pachycladus* (Table 6).

Table 6. Kinetics of *in vitro* gas production of native cactus of the Brazilian Semiarid

Variables	Native cactus species					SEM	*P* value
	Cereus jamacaru	*Melocactus bahiensis*	*Opuntia inamoene*	*Pilosocereus gounellei*	*Pilosocereus pachycladus*		
V_{t1}	277.4a	258.0ab	266.2a	222.2bc	192.4c	8.2	<0. 0001
V_{t2}	300.4a	265.4ab	265.3ab	227.4bc	196.5c	9.2	<0.0001
V_{f1}	239.9a	162.1bc	174.2b	126.3cd	119.0d	10.5	<0.0001
k_1	0.21a	0.09a	0.11a	0.10a	0.10a	0.02	0.52
V_{f2}	60.6b	103.2a	91.1ab	101.1a	77.5ab	4.7	0.005
k_2	0.03ab	0.03ab	0.04a	0.03ab	0.03b	0.001	0.03
λ	8.1a	3.4b	2.0b	2.8b	2.1b	0.5	<0.0001

Means followed by the same letter in columns do not differ (P>0.05) by Tukey test, SEM = standard error mean; V_{t1} = total volume observed (mL/g DM); V_{t2} = total volume (mL/g DM) estimated from the model; V_{f1} = volume (mL) of gas produced by the degradation of the fraction A+B_1 of the Cornell System (NFC); k_1 = specific rate (h^{-1}) of gas production by the degradation of the fraction A+B_1 (NFC); V_{f2} = volume (mL) of gas produced by the degradation of the fraction B_2 of fiber carbohydrates; k_2 = specific rate (h^{-1}) of production of gases by the degradation of the fraction B_2 (FC); λ = latency (h).

4. Discussion

The species of the family *Cactaceae* present a high water storage capacity (Griffiths & Males 2017). For this reason, they are known as being highly resistant to Semiarid regions. This particularity is confirmed by the high volume of water in the collected material (above 85%) and, consequently, by the low dry matter (DM) content in the species evaluated. A high water content is fundamental for the survival of such species, and it makes them excellent sources of water to animals that extract water from food (Taddesse *et al.*, 2014; Paiva *et al.*, 2016). This fact emphasizes the importance of the inclusion of such forage plants in diets and contributes to meeting the requirements of this nutrient by animals, especially in the Semiarid region, where water is scarce.

The species *P. gounellei* had a low and *O. inamoene* had a high proportion of OM and EE. The OM present in such plants is related to the presence of other nutrients that can be digested, such as total carbohydrates, proteins and lipids. The EE is mainly the result of the waxes that protect the surface of such plants, part of an adaptation strategy of these forages to Semiarid regions. However, all species belonging to the family *Cactaceae* are poor in proteins, as they are part of a group of foods classified as energetic due to the presence of high amounts of carbohydrates (above 70% in most plants). This indicates that such cacti should not be offered to ruminants as a sole source of food. They should be offered to them in conjunction with other ingredients that can meet the nutrient requirements of the species and the categories of animals (Prieto-Garcia *et al.*, 2016; Gouws *et al.*, 2019).

Cavalcanti & Resende (2007), evaluating the effects of the use of *C. jamacaru* and *P. gounellei* on the weight gain of goats during drought periods, concluded that the supply of diets composed exclusively of cacti did not meet the nutritional requirements of animals kept in confinement. However, when associated with protein and fiber ingredients, it was possible to meet such nutritional requirements. Silva *et al.*, (2010) evaluated the use of *P. gounellei* and *C. jamacaru* associated with legume hay and the use of concentrates for lambs. There were no differences in DM intake among the animals that received *P. gounellei* or *C. jamacaru*, indicating that these two cactus can be used for animal feed without interfering in the intake of DM, provided they are associated to other sources of nutrients.

The high presence of NDF (above 40%) in *C. jamacaru* does not that it will be less digestible since the presence of non-digestible fiber is low in plants of the Cactaceae family. In addition, the NDF of these species is composed mostly of HEM and CEL, which are susceptible to ruminal degradation although they are slow-digestion carbohydrates. The presence of less lignin in *C. jamacaru* plants can be explained by the initial treatment of the samples: we used only the external part of the plant for this species. Such part is offered to small ruminants in Caatinga regions.

The greater presence of pectin in O. *inamoene* is related to the higher proportion of non-fibrous carbohydrates, since the pectin is contained in non-fibrous carbohydrates which is solubilized by the neutral detergent solution.

The species *C. jamacaru*, *M. bahiensis* and *O. inamoene* had the highest values of TDN. This can be explained by the high proportion of carbohydrates and the low ADL content, indicating that most compounds in these forages can be digestible. Just as the forages, *P. gounellei* and *P. pachycladus* presented low proportions of TDN and DE due to a high presence of ADL.

There is little information available in the literature on mineral content in native semiarid cacti and its effects on yield. Essential minerals play a vital role in the functioning of the animal organism. They participate in various metabolic processes and act in biochemical reactions and appear as activators or components of some specific enzymes. Among the native cactus studied, the genus *Pilosocereus* (*Pilosocereus gounellei* and *Pilosocereus pachycladus*) presented the highest levels of Calcium (56.1 and 58.5 g/kg), Magnesium (16.2 and 15.3 g/kg), Manganese (1880.6 and 1189.8 mg/kg) and Zinc (49.0 and 45.0 mg/kg) (Table 2). The higher concentrations observed are probably due to interactions between soil and plant nutrients. Correia *et al.*, (2012) studying macronutrients and micronutrients contents of shoots (*Pilosocereus gounellei* subsp. Gounellei) shoots found values of 24.40 g/kg Ca, 58.47 g/kg Mg, 178.40 mg/kg Mn and, 156.70 mg/kg Zn.

The amount of calcium present in the evaluated native cactus species is within the limit recommended by the NRC (2001) for dairy cattle, whose range varies from 1: 1 to 7: 1, in a Ca:P ratio. Calcium bioavailability in foods rich in phytic and oxalic acids has lower absorption, while carbohydrate and vitamin C rich foods have higher absorption (Hailu & Addis 2015).

The total amount of nutrients in the plant increases with age, but the concentration in a given tissue may increase, decrease, or remain unchanged, depending on the nutrient and tissue. Seasonal changes in tissue nutrient concentrations occur, but they may result from changes in plant growth at a greater rate than changes in nutrient availability to the plant (Ai *et al.*, 2017; du Toit *et al.*, 2018). The plants need continuous supply of B for growth, this situation is justified by the high concentration of the element in the cell wall in structural form. Its deficiency directly impacts on cell structure, growth and division, and the death of meristematic tissue is one of the most common signs of B scarcity. Other factors indirectly affected by B deficiency are water absorption and root growth, as in the state deficiency occurs a reduction in the water absorption surface, and consequently, the nutrient reduction is also impaired (Wimmer & Eichert, 2013; Chatterjee & Bandyopadhyay 2017; Shireen *et al.*, 2018).

Regarding the fractionation of nitrogen compounds, a higher content of fraction A was found, which corresponds to non-protein nitrogen in *C. jamacaru*. This means that this plant provides adequate supply of non-protein nitrogen compounds to the microbial population that ferment structural carbohydrates, and consequently also provides a protein fraction throughout the gastrointestinal tract. The B1 + B2 fraction is degraded at an intermediate rate in the rumen, which may be a source of amino acids and peptides for the same and small intestine. In foods where this fraction is significant, its evaluation is fundamental, since the amount effectively degraded in the rumen is a direct function of the passage rate, that is, it will depend on the degradation rate/passage rate ratio. However, it is extensively ruminally degraded, contributing to microbial nitrogen requirements in this compartment (Chrenková *et al.*, 2014; Ferreira *et al.*, 2018; Brandstetter *et al.*, 2019). Although the amount of nitrogen in cacti is low, over 50% of the N present in the species evaluated are available for use by ruminal microorganisms, especially *C. jamacaru* and *M. bahiensis*, which presented an availability of N above 70%, as they are components of the fractions A, B1+B2 and B3 (Table 3).

For fraction C, all species are above the limit of 5 to 10%, which is considered for fodder the concentration of total lignin-bound nitrogen, making it unavailable (Van Soest 1994). Fraction C consists of lignin-associated proteins, tannic-protein complexes and Maillard reaction products, highly resistant to microbial and enzymatic degradation, and is therefore considered unusable in both the rumen and intestine (Chrenková *et al.*, 2014) (Table 3).

Carbohydrates are the main source of energy for the ruminal microbiota, which in turn converts them into short-chain fatty acids (Loor *et al.*, 2016). The highest proportion of the fraction B2 (potentially digestible fiber) and the lowest fraction C of carbohydrates of the species *C. jamacaru* is explained by the lowest presence of ADL in the material analyzed.

The fractions A+B1 and B2 are composed of carbohydrates that can be degraded by ruminal microorganisms. More than 80% of the total carbohydrates of the cacti native from the Brazilian semiarid region can be digestible. These data confirm the forage potential of such species and the availability of carbohydrates, which are the main source of energy for ruminants in this region especially during periods of severe drought. According to Lima-Nascimento *et al.*, (2019), in the northeast region of Brazil, which is mostly characterized by vegetation typical of the Caatinga, cacti are a symbol of resistance to limiting climatic conditions, with a rich diversity and abundance of species, represented by about 90 native species. Native cacti can be seen as a food strategy for periods of food shortage (Pérez-Marin *et al.*, 2017).

Variation in carbohydrate fraction C content was not considered high, and according to Neumann *et al.*, (2017) and Brandstetter *et al.*, (2019) are significant differences in this fraction among forage species, since this fraction interferes with ruminal repletion, causing a lower energy availability due to its indigestible characteristic, as it results in lower food consumption in unit time. Plants with high levels of this fraction interfere with the animal food intake, so this forage should be supplemented with energy sources of rapid rumen availability (Mendoza *et al.*, 2014), when it does not have protein limitation in quantity and quality.

Potential degradation was above 60% for all species. The cactus *C. jamacaru* and *M. bahiensis* presented a high PD. The difference between these two species in relation to the others is due to the great availability of carbohydrates to ruminal micro-organisms present in these cactus, since 96.1 and 94.4%, respectively for each species above, of these carbohydrates can be digested, although all species have a high percentage of carbohydrates, which may result in different degradation rates. Another factor that may have interfered with degradation is the proportion of the fraction C of carbohydrates and the amount of lignin in some species (Tables 1 and 4).

There were differences in the parameters a and b and the effective degradability in function of a slow and average passage rate. However, when an ED for a fast passage rate was estimated, it was observed that there were no differences among species. In addition to the fact that there were no differences in fast passage rates between the species, it was observed that degradation decreased. This happens due to the short time of exposure to which this food is subjected in the ruminal environment.

The lowest Vt1 produced by TC fermentation of *P. pachycladus* (192.4 mL/g DM) was due to the low proportion of total carbohydrates present in its composition, and also due to a low Pd. As for the adjustment of the two-compartment model, there was less precision in the adjustment only for *C. jamacaru* plants probably due to the fermentation characteristics of the carbohydrates present in the composition of this species.

There was a high gas production by *P. gounellei* and *M. bahiensis*. The difference in gas production from fiber and non-fiber carbohydrates is related to the chemical composition of these species and the rate of degradation of the compounds present in each species. In general, for cactaceae that are rich in non-fiber carbohydrates, there is a tendency of a higher gas production from such carbohydrates, confirming their greater degradation.

The species *C. jamacaru* presented the highest gas production, but it depended on a longer time to establish the fermentation completely, reflecting in a longer lag time, or latency phase. In addition, a fermentation different from that of *C. jamacaru*, in relation to the other species, was probably due to its chemical composition, which may hinder the adhesion of the microorganisms to the substrate. Although the highest final volume was obtained by C. jamacaru, the degradation curve indicated high yields up to 42 hours and a better adjustment for *O. inamoene*.

5. Conclusion

The evaluated cacti have a satisfactory chemical composition capable of supplying part of the daily energy needs of animals in Caatinga areas as it presents high levels of potentially digestible fractions of total carbohydrates. This confirms the importance of their use for feeding ruminants, especially during periods of severe drought. During such periods, Caatinga's cacti are a basal forage resource.

6. Conflict of interest

The authors declare that they have no competing interests.

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