Journal of Arid Environments 181 (2020) 104243

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Forage nutritional differences within the genus *Opuntia*

Diana Valadares Pessoa[a], Albericio Pereira de Andrade[a], André Luiz Rodrigues Magalhães[a], Ana Lúcia Teodoro[b], Djalma Cordeiro dos Santos[c], Gherman Garcia Leal de Araújo[d], Ariosvaldo Nunes de Medeiros[e], Daniel Bezerra do Nascimento[a], Roberta de Lima Valença[a,*], Daniel Barros Cardoso[a]

[a] *Department of Animal Science, Federal University of Agreste of Pernambuco, Garanhuns, Brazil*
[b] *Instituto Federal de Educação, Ciência e Tecnologia Do Piauí, Corrente, Brazil*
[c] *Instituto Agronômico de Pernambuco, Arcoverde, Brazil*
[d] *Embrapa Semiárido, Petrolina, Brazil*
[e] *Department of Animal Science, Federal University of Paraíba, Areia, Brazil*

ARTICLE INFO

Keywords:
Erect prickly pear
Digestibility
Pectin
Phenophase
Prickly pear African

ABSTRACT

The objective of this study is to evaluate the bromatological composition, carbohydrate fractionation, *in vitro* digestibility and gas production of varieties of forage cactus of the genus *Opuntia*, associated with different phenological phases. The experiment was conducted in a completely randomized design in a 5 × 3 factorial arrangement consisting of five forage cactus varieties of the genus Opuntia ((IPA-20 (*Opuntia ficus-indica* Mill), Gigante (*Opuntia ficus-indica* Mill), Erect Prickly Pear (EPP) (*Opuntia stricta* Haw), African Prickly Pear (APP) (*Opuntia undulata*) and F-08 (*Opuntia atropes* Rose)). and three phenological phases (young, intermediate and mature). The concentrations of neutral detergent fiber and the C ratio of carbohydrates were lower in the Erect Prickly Pear (EPP) variety, in this same variety, a higher proportion of pectin was observed along with the giant variety and higher *in vitro* digestibility, with similar digestibility for the African Prickly Pear (APP) and F-08. The concentration of total carbohydrates was higher in the IPA-20 variety since the gas production adjusted by the bicompartmental model was higher for APP. Was observed in all varieties greater concentration of neutral detergent fiber and the C fraction of the carbohydrates in the mature cladodes. *In vitro* digestibility of mature phase was also superior in all varieties except APP. The Erect Prickly Pear and African Prickly Pear varieties present best nutritional value for feeding ruminants and mature phase is the least relevant.

1. Introduction

In arid and Semiarid regions, where there are long periods of drought with high temperatures resulting in low forage production and availability to animals (Rodrigues et al., 2016), forage cactus stands out due to the photosynthetic process called CAM (Crassulacean acid mechanism). It provides cactus with the ability to adapt to water stresses, heat and solar radiation, which are common features in these places (Abidi et al., 2009; Donato et al., 2014).

These plants belong to the family *Cactaceae*, composed of about 130 genera, with approximately 1.500 species, being 300 of the genus *Opuntia* Mill (Mohamed-Yasseen et al., 1996). In Brazil, this forage resource stands out as animal feed, especially during periods of drought.

Forage cactus is considered an energetic food due to the high concentration of non-fiber carbohydrates: approximately 585.5 g/kg expressed as dry matter (DM) and total digestible nutrients (TDN) reaching 800.0 g/kg DM (Silva and Sampaio, 2015). It also presents high concentrations of minerals, especially calcium (52.6–70.2 g/kg DM), potassium (4.4–19.0 g/kg DM) and phosphorus (1.8–2.1 g/kg DM) (Abidi et al., 2009; Cordova-Torres et al., 2015). On the other hand, it has low dry matter contents (120.0–144.0 g/kg, expressed as natural matter (NM), acid detergent fiber (160.0–189.0 g/kg DM), neutral detergent fiber (257.0–284.0 g/kg DM) (Batista et al., 2003; Silva et al., 2017; Barros et al., 2018) and crude protein (33.0–63.0 g/kg DM) (Batista et al., 2009; Cordova-Torres et al., 2015; Moraes et al., 2019).

In view of the limitations of Brazilian Semiarid regions, with climatic adversities such as irregular and unstable rainfalls for most of the year and deficiency in forage production, there is a need for more detailed studies of forage resources adapted to such conditions, such as

* Corresponding author. Av. Bom Pastor, s/n – Boa Vista, Garanhuns, PE, Brazil.
E-mail address: robertalimav@hotmail.com (R. de Lima Valença).

https://doi.org/10.1016/j.jaridenv.2020.104243
Received 14 January 2020; Received in revised form 7 June 2020; Accepted 8 June 2020
Available online 20 June 2020
0140-1963/

forage cactus, with the purpose of optimizing and using nutrients from plants by animals.

The objective of this study is to evaluate the chemical-bromatological composition, the fractions of carbohydrates and the kinetics of *in vitro* fermentation of forage palm varieties of the genus *Opuntia* in the function of different phenological phases.

2. Materials and methods

The samples were collected in August 2016 at the Experimental Station of the Instituto Agronômico de Pernambuco (IPA), located in the city of Arcoverde, PE, at - 8.433333° and −37.05°, altitude 680.7 m, average temperature 24.9 ± 10.53 °C, RU 79.6 ± 11.95%, wind speed of 3.1 ± 0.8 m/s, mean annual rainfall of 1058.8 mm, Moxotó Sertão micro-region (INMET, 2017).

The varieties of forage cactus used were: IPA-20 (*Opuntia* ficus-indica Mill), Gigante (*Opuntia* ficus-indica Mill), Erect Prickly Pear (EPP) (*Opuntia* stricta Haw), African Prickly Pear (APP) (*Opuntia* undulata) and F-08 (*Opuntia* atropes Rose). Four plants of similar size were selected from each variety of forage cactus mentioned above. Cladodes were selected from each plant at different phenological phases: young phase (cladodes located at the distal or lateral extremities of the plant, bright green and expanding), intermediate phase (cladodes located in the median part of the plant, dark green) and mature phase (cladodes located just above the cladode base, light whitish color, fully expanded). After collection, the samples were processed and pre-dried in a forced-air ventilation oven to maintain a constant weight, then weighed and ground in a knife mill with 2 mm and 1 mm sieves. They were identified and packed in plastic pots.

The analyses of dry matter (DM) (930.15), organic matter (OM) (942.05), mineral matter (942.05), crude protein (CP) (954.01) and ether extract (EE) (Soxhlet) (920.39) were performed according to the methodology described by the Association of Official Analytical Chemists (AOAC, 1990).

Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to the methodology of Van Soest et al. (1991), adapted by Senger et al. (2008). Acid-digested lignin (ADL) was determined according to the methodology of Van Soest et al. (1991). We estimated hemicellulose (HEM) by the equation HEM = NDF - ADF, and cellulose by the equation CEL = ADF - ADL. Total carbohydrates (TC) were estimated according to Sniffen et al. (1992). Non-fiber carbohydrates (NFC), which correspond to the fractions A + B1, were obtained by the difference between TC and NDF.

The C fraction corresponding to indigestible NDF was determined according to the methodology of Valente et al. (2011). The B2 fraction, which corresponds to the available fraction of fiber, was estimated by the difference between NDF and the C fraction. The extraction of pectin was performed according to the methodology of Zanella and Taranto (2015). The determination of *in vitro* digestibility of DM (IVDDM) was performed according to the technique of Tilley and Terry (1963), adapted from Holden (1999), where the incubation procedure was performed for 48 h; then, 6 M hydrochloric acid and pepsin 1:10,000 were added.

The determination of *in vitro* gas production was conducted according to Theodorou et al. (1994). The readings were measured at 2, 4, 6, 8, 10, 12, 15, 18,21, 24,30, 36,42 and 48 h after incubation. Pressure data (psi = pressure per square inch) were converted in to the volume of gas (V) by the equation V = 5.1612P-0.3017, R2 = 0.9873, generated in the Production Laboratory (LPG) of the Federal University of Agreste of Pernambuco, UFAPE, from 937 observations.

Cumulative gas production data were adjusted by the bicompartmental model suggested by Schofield et al. (1994) using PROC NLMIXED in SAS®.

$$V_t = \frac{V_{f1}}{1 + e^{[2-4kd1(t-\lambda)]}} + \frac{V_{f2}}{1 + e^{[2-4kd2(t-\lambda)]}}$$

where V_t is the maximum total volume of produced gas, V_{f1} (mL/g of DM incubated) is the maximum volume of gas for the fast digestion fraction (NFC), V_{f2} (mL/g) is the maximum volume of gas for the slow digestion fraction (FC), k_{d1} (h) is the rate of degradation of fast digestion fraction (NFC), k_{d2} (h) is the rate of degradation of the slow digestion fraction, λ *(Lag time)* is the duration of initial digestion events common to both phases, and t (h) is the fermentation time.

The experiment was conducted in a 5 × 3 factorial arrangement (five varieties of forage cactus and three phenological phases) with four replications. We analyzed *in vitro* fermentation kinetics data using the mixed non-linear procedure, where fermentation parameters were generated from data observed at different incubation times *in vitro*. All data were submitted to analysis of variance using the general procedures of linear models, and the averages were compared by Tukey test considering α = 0.05 using the software Statistical Analysis System (SAS®).

3. Results

There was no difference (*P > 0.05*) in the concentrations of the dry matter (DM), ether extract (EE), crude protein (CP) and humidity between varieties and phenological phases (Table 1).

There was a significant difference (*P < 0.05*) in MM between the varieties in cladodes at the mature phase. The lowest proportion 82.8 g/kg DM was presented by IPA-20, which differed from APP (117.5 g/kg DM) and Gigante (111.5 g/kg DM). In F-08, there was an the effect of phenological phase (*P < 0.05*), which had 133.5 g/kg DM for young phase cladodes and 130.5 g/kg DM for intermediate phase cladodes (Table 1).

There was a difference (P < 0.05) between the varieties as for mineral matter (MM) only in cladode sat the mature phase. The lowest proportion, 82.8 g/kg DM, was presented by the IPA-20 variety, which differed from APP and Gigante varieties, presenting MM of 117.5 and 111.5 g/kg DM, respectively. When evaluating the effects of phenological phases, there was a difference (P < 0.05) only for the F-08 variety, which presented 133.5 g/kg DM for young phase cladodes and 130.5 g/kg DM for intermediate phase cladodes (Table 1).

There was a difference (*P* < 0.05) in the pectin concentration per g/kg of DM (Table 2), with lower values of 98.0 and 133.7 g/kg DM for the cladodes of Gigante forage cactus at the intermediate and mature phases, respectively. These values differed from those of the Erect Prickly Pear (EPP), which presented 180.1 and 210.1 g/kg DM for the cladodes at the same phases, respectively.

There was a difference (*P* < 0.05) between the varieties as for neutral detergent fiber (NDF). The EPP presented lower concentrations in cladodes at the young and intermediate phases, whereas the mature phase presented concentrations similar to the African Prickly Pear (APP), IPA-20 and F-08varieties.

As for NDF, by variety, there was a difference (*P* < 0.05) for mature phase cladodes to the intermediate and young phenological regarding the varieties EPP, IPA-20, and F-08. For the APP, the lowest value was for cladodes at the young phase, which differed (*P* < 0.05) from the other phases. For Gigante variety, there was a difference between all phenological phases (Table 2).

For concentration of hemicellulose, there was a difference (*P* < 0.05) between the varieties (Table 2), so that the highest concentration for young phase cladodes was 114.1 g/kg DM for the forage cactus F-08. However, there was no difference (*P* > 0.05) for the varieties IPA-20, Gigante and APP at the same phases. At the intermediate phase the EPP presented a lower value (*P* < 0.05) in relation to the other varieties.

Concerning acid detergent fiber (ADF) between varieties, there was a difference (P < 0.05) between the cladodes of EPP pear and Gigante varieties at the young and intermediate phases. At the mature phase, the forage cactus IPA-20 presented higher concentrations than the EPP and APP varieties. For the values of ADF by variety, there was a

Table 1
Chemical composition of forage cacti varieties of the genus *Opuntia* in function of different phenological phases.

Phenological phases	Varieties					SEM	P-value
	EPP	APP	Gigante	IPA-20	F-08		
Dry Matter (g/kg Natural Matter)							
Young	90.9	113.5	95.2	99.8	109.1	4.9	0.60
Intermediate	92.8	97.7	93.1	98.4	98.0	3.5	0.90
Mature	106.9	113.7	105.2	114.7	111.8	2.9	0.80
SEM	4.4	8.6	3.2	3.8	4.2		
P-value	0.30	0.70	0.30	0.10	0.40		
Organic Matter (g/kg Dry Matter)							
Young	889.2	882.6	888.8	904.5	866.5B	4.7	0.10
Intermediate	880.0	892.3	897.7	906.1	869.5AB	4.7	0.08
Mature	892.4 ab	882.5b	888.5 ab	917.2a	898.0abA	3.8	0.04
SEM	5.3	5.8	5.4	2.5	5.8		
P-value	0.70	0.70	0.80	0.07	0.03		
Crude protein (g/kg dry matter)							
Young	56.5	59.3	47.5	42.6	44.3	2.5	0.10
Intermediate	55.7	56.7	51.4	48.0	48.5	2.0	0.60
Mature	47.3	52.2	50.1	45.5	47.0	1.4	0.60
SEM	4.0	2.1	1.0	2.6	1.2		
P-value	0.6	0.4	0.3	0.7	0.4		
Ether Extract (g/kg Dry Matter)							
Young	16.7	15.5	17.4	18.4	14.9	0.6	0.40
Intermediate	15.5	15.9	15.0	17.4	17.2	0.6	0.60
Mature	14.1	13.8	15.2	15.2	14.7	0.6	0.90
SEM	0.6	1.0	0.8	0.6	0.8		
P-value	0.30	0.70	0.50	0.08	0.40		
Mineral Matter (g/kg Dry Matter)							
Young	110.8	117.4	111.2	95.5	133.5A	4.7	0.10
Intermediate	120.0	107.7	102.3	93.9	130.5AB	4.7	0.08
Mature	107.6 ab	117.5a	111.5a	82.8b	102.0abB	4.0	0.04
MSE	5.3	5.8	5.4	2.5	5.8		
P-value	0.70	0.70	0.80	0.07	0.03		

EPP = erect prickly pear; APP = African prickly pear; SEM: standard error of mean; Means followed by lowercase letters differ in the rows and capital letters in columns (P < 0.05).

difference ($P < 0.05$) for the forage cactus F-08, IPA-20 and EPP in cladodes at the mature phase in relation to the intermediate and young phases (Table 2).

For acid digested lignin (ADL), there were differences between the varieties ($P < 0.05$). In cladodes at young and intermediate phases, the EPP and APP varieties showed lower concentrations when compared to others. At the mature phase, greater concentrations were observed for the cladodes of the IPA-20 forage cactus compared to the EPP pear and APP. When analyzing the ADL by variety, the EPP presented a difference ($P < 0.05$), so that the young and intermediate phases of cladodes had lower concentrations than at the mature phase. For the IPA-20 variety, the highest concentration ($P < 0.05$) was observed for cladodes at the mature phase, and the lowest concentration occurred at the intermediate phenophase (Table 2).

In relation to carbohydrate fractions (Table 3), there was a difference ($P < 0.05$) in the total carbohydrate concentration (TC). For the IPA-20 variety, it presented the highest concentration (840.7 g/kg DM); the F-08 presented the lowest concentration (803.8 g/kg DM) for intermediate phase cladodes, however, they did not differ from others. In cladodes at the mature phase, the IPA-20 variety had a concentration of 856.6 g/kg DM, which was higher ($P < 0.05$) than the 816.5 g/kg DM identified for the APP. For the TC concentration, by variety, there was a difference ($P < 0.05$) for EPP. A lower value (812.4 g/kg DM) was identified for cladodes at the young phase, which differs from the other phases, with 336.0 g/kg DM at the intermediate phase and 831.6 g/kg DM at the mature phase. It did not differentiate between themselves ($P > 0.05$).

The NFC (g/kg DM) differed among cladodes of all varieties ($P < 0.05$) at the young and intermediate phases. The EPP had 665.7 g/kg DM and 663.4 g/kg DM, respectively. It differed from the other varieties at the same phases. However, the mature phase showed similar concentrations to those of APP, IPA-20, and F-08 (Table 3).

For the NFC concentration, the EPP and the F-08 presented a difference ($P < 0.05$) for cladodes at the mature phase in comparison to the others. For the APP and IPA-20 varieties, there was a difference ($P < 0.05$) at the mature and young phases, the latter being higher for both varieties. By analyzing Gigante forage cactus, there is a difference ($P < 0.05$) for cladodes at all phenological phases, with a concentration of 507.0, 496.1 and 425 g/kg DM for young, intermediate and mature phases, respectively (Table 3).

For the fractions A + B1 (g/kg TC) corresponding to fast-decaying carbohydrates, a difference ($P < 0.05$) was obtained for cladodes of the EPP, with 819.5 g/kg TC at the young phase and 793.6 g/kg TC at the intermediate phase, concentrations higher than those of all other varieties at the same phases. For the concentrations of these fractions by variety, there was a difference ($P < 0.05$) for cladodes of EPP, APP, IPA-20, and F-08 at the mature phase in relation to the others, which presented a lower concentration. However, for the Gigante variety, all phases differed from each other ($P < 0.05$), with 681.6 g/kg TC for young phase cladodes, 599.4 g/kg TC for intermediate phase cladodes and 504.7 g/kg TC for mature phase cladodes (Table 3).

For the fraction B2 (g/kg TC), there was a statistical difference for young phase cladodes of the F-08 variety it presented the highest value 279.3 g/kg TC, IPA-20 with an intermediate value (208.0 g/kg TC), and EPP with the lowest value (125.9 g/kg TC). Att the intermediate phase, the was a difference in the variety of EPP in relation to the others. In contrast, at the mature phase, cladodes of the EPP and Gigante pear varieties did not differ from each other ($P > 0.05$), but differed from the others ($P < 0.05$). As for the fraction B2 (g/kg TC), a difference ($P < 0.05$) was observed between cladodes at the mature and young phases of African and Gigante prickly pear. For EPP, the difference ($P < 0.05$) was for the mature phase in relation to the others (Table 3).

For the concentration of C fraction (g/kg TC), there was a difference ($P < 0.05$) for the IPA-20 forage cactus cladodes at the young and

Table 2
Fiber compounds of forage cacti varieties of the genus *Opuntia* in function of different phenological phases.

Phenological phases	Varieties					SEM	P- value
	EPP	APP	Gigante	IPA-20	F-08		
Pectin (g/kg dry matter)							
Young	212.8	203.9	128.0	136.0	139.3	13.6	0.10
Intermediate	180.1a	185.4a	98.0b	144.3 ab	132.5 ab	10.2	0.02
Mature	210.1a	153.5 ab	133.7b	169.9 ab	174.5 ab	8.6	0.05
SEM	15.7	9.2	8.4	13.4	11.8		
P-value	0.70	0.06	0.20	0.60	0.30		
Neutral detergent fiber (g/kg Dry Matter)							
Young	146.7bB	220.0 aB	266.2 aC	245.0 aB	255.7 aB	11.4	< 0.01
Intermediate	172.6bB	289.4aAB	331.4 aB	301.8 aB	300.9 aB	14.3	< 0.01
Mature	310.7bA	360.3abA	417.5 aA	374.7abA	389.6abA	11.4	0.02
SEM	24.4	19.9	20.4	18.2	18.1		
P-value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01		
Hemicellulose (g/kg Dry Matter)							
Young	17.7bB	116.2 aB	107.5 aB	99.6 aB	114.a	9.1	< 0.01
Intermediate	45.29bB	157.9aAB	159.4 aB	142.2aAB	142.4a	12.5	< 0.01
Mature	143.7A	185.9A	216.6A	175.5A	162.9	9.4	0.10
SEM	19.6	12.0	15.4	12.8	8.8		
P-value	< 0.01	0.04	< 0.01	0.03	0.06		
Acid detergent fiber (g/kg Dry Matter)							
Young	129.0bB	123.8b	158.aB	145.4bB	141.5abB	3.9	0.02
Intermediate	127.4bB	131.4 ab	172.0aAB	159.6abB	158.5abB	5.6	0.03
Mature	167.0bA	174.4b	200.9abA	199.1 aA	226.7abA	6.7	0.02
SEM	6.6	10.4	6.9	8.2	11.7		
P-value	< 0.01	0.09	0.02	< 0.01	< 0.01		
Cellulose (g/kg Dry Matter)							
Young	122.4B	114.0	131.4B	121.3	121.7B	2.7	0.40
Intermediate	119.4B	120.5	141.4B	137.3	138.1B	4.4	0.40
Mature	151.7bA	158.1 ab	172.0abA	163.1 ab	203.9 aA	6.2	0.04
SEM	5.5	9.3	6.4	7.7	11.2		
P-value	0.01	0.10	< 0.01	0.07	< 0.01		
Acid digested lignin (g/kg dry matter)							
Young	6.6 cB	9.7c	27.2a	24.1abAB	19.9b	1.9	< 0.01
Intermediate	8.0 cB	10.9c	30.3a	22.3bB	20.5b	2.0	< 0.01
Mature	15.4bA	16.3b	28.9 ab	36.0 aA	22.8 ab	2.2	< 0.01
SEM	1.3	1.4	1.4	2.5	1.0		
P-value	< 0.01	0.10	0.70	0.03	0.50		

EPP = erect prickly pear; APP = African prickly pear; SEM: standard error of mean; Means followed by lowercase letters differ in the rows and capital letters in columns ($P < 0.05$).

intermediate phases in relation to the EPP, APP, and F-08; however, it did not differ ($P > 0.05$) from the Gigante variety. There was a difference ($P < 0.05$) for the C fraction by variety, with higher concentrations for mature phase cladodes, which differed from the young and intermediate phases, but did not differ from each other, however in the young and intermediate phases the APP and F-08 varieties had the lowest concentration of the C fraction (Table 3).

In relation to the parameters of *in vitro* gas production (Table 4), a difference ($P < 0.05$) was observed between the varieties as for the total volume of gas produced (Vt1) for cladodes of APP, which presented higher volumes than the EPP and IPA-20. As for the volume of gas per variety, there was a difference ($P < 0.05$) for cladodes of the Gigante forage cactus, where the highest volume was 323.6 mL/gDM for the young phase.

For total production, adjusted by the bicompartmental model (Vt2), the IPA-20 and EPP varieties presented lower volumes ($P < 0.05$) compared to the APP for cladodes at intermediate and mature phases (Table 4). For the volume of gas produced by the degradation of the fraction A + B1 of the Cornell System (NFC) of fast fermentation (Vf1), there was a difference ($P < 0.05$) between the varieties. The F-08 forage cactus cladodes, attheyoungphase,presentedavolumeof223.1mL/gDMthanAPPvariety, which presented 189.1 mL/gDM (Table 4).

For the rate of degradation of the fast digestion fraction (Kd1), there was a difference ($P < 0.05$) among varieties. The APP presented lower gas volumes in relation to the IPA-20 and F-08 cladodes at the young and intermediate phases. When analyzing the rate of degradation by variety, there was a difference ($P < 0.05$) for the giant variety, with the highest volume for young cladodes; however, the intermediate and mature phases did not differ from each other ($P > 0.05$). We observed difference ($P < 0.05$) for the IPA-20 variety, with a lower volume at the mature phase, but no difference was observed between the young and intermediate phases (Table 4).

For the volume of gas produced by the degradation of the fraction B2 of the Cornell System (FC), with a slow degradation, the APP presented a higher volume ($P < 0.05$) in relation to the other varieties for cladodes at the intermediate phase. By analyzing the volume of gas produced by variety, the forage cactus IPA-20 and F-08 presented volume of gas produced at the mature phase and did not differ from the intermediate phase in both varieties (Table 4).

For *in vitro* true digestibility parameters (Table 4), there was no difference ($P > 0.05$) between cladodes of EPP, APP and F-08 at the young and intermediary phases. However, they presented difference ($P < 0.05$) for the Gigante and the IPA-20 at the same phases. Regarding *in vitro* true digestibility by variety, there was a difference ($P < 0.05$) for mature phase cladodes with a lower digestibility in relation to the other phases for the EPP, IPA-20, and F-08.

4. Discussion

In general, forage cactus has a low dry matter (DM) concentration, and the values found for cladodes of the varieties in this research (Table 1) corroborate those identified for *Opuntia* genus, which were 105.5–127.3 g/kg of natural matter (Pessoa et al., 2009; Silva et al., 2017). Due to the low concentrations of DM in forage cactus, when

Table 3
Concentrations of total carbohydrates (TC) and neutral detergent fiber (NFC) and carbohydrates fractions of forage cactus varieties of the genus *Opuntia* in function of different phenological phases.

Phenological phases	Varieties					SEM	P- value
	EPP	APP	Gigante	IPA-20	F-08		
TC (g/kg Dry Matter)							
Young	812.4B	807.7	836.1	843.6	807.4	5.7	0.10
Intermediate	836.0abA	819.7 ab	827.5 ab	840.7a	803.8b	4.3	0.04
Mature	831.6abAB	816.5b	843.3 ab	856.6a	836.38 ab	4.2	0.02
SEM	4.3	7.7	3.6	4.0	6.6		
P-value	0.04	0.80	0.20	0.20	0.07		
NFC (g/kg Dry Matter)							
Young	665.7 aA	567.7bA	570.0bA	598.6bA	551.7bA	11.0	<0.01
Intermediate	663.4 aA	530.3bAB	496.1bB	538.9bAB	502.9bA	15.7	<0.01
Mature	520.9 aB	456.1abB	425.8bC	481.9abB	446.8abB	11.4	0.04
SEM	23.6	17.7	19.9	17.1	14.6		
P-value	<0.01	0.01	<0.01	<0.01	<0.01		
Fractions of total carbohydrates							
A + B1 (g/kg TC)							
Young	819.5 aA	702.2bA	681.6bA	709.4bA	683.3 ± 16.2bA	12.7	<0.01
Intermediate	793.6 aA	646.8bA	599.4bB	641.0bA	625.5bA	17.7	<0.01
Mature	626.1B	558.1B	504.7C	562.5B	534.5B	13.4	0.06
MSE	29.2	20.1	24.0	20.8	20.0		
P-value	<0.01	<0.01	<0.01	<0.01	<0.01		
B2 (g/kg TC)							
Young	125.9 cB	247.5abB	242.1abB	208.0b	279.3a	12.8	<0.01
Intermediate	142.3bB	293.7aAB	313.7aAB	260.0a	322.4a	17.1	<0.01
Mature	257.4bA	327.8abA	364.4bA	275.5 ab	328.9 ab	13.1	0.04
MSE	21.4	13.3	18.1	14.2	10.5		
P-value	<0.01	0.02	<0.01	0.10	0.10		
C (g/kg TC)							
Young	54.6bcB	50.2 cB	76.3abB	82.5 aB	37.4 cB	4.4	<0.01
Intermediate	64.1bcB	59.5 cB	86.8abB	99.0 aB	52.1 cB	4.7	<0.01
Mature	116.5A	114.1A	130.8A	161.9A	136.6A	7.7	0.30
MSE	8.9	11.5	8.6	11.6	14.3		
P-value	<0.01	0.03	<0.01	<0.01	<0.01		

EPP = erect prickly pear; APP = African prickly pear; SEM: standard error of mean; Means followed by lowercase letters differ in the rows and capital letters in columns ($P < 0.05$).

there is a large supply of this food to animals, meeting the DM requirements can be compromised. On the other hand, this characteristic represents a great contribution of water to the animals via cactus (Vieira et al., 2008; Costa et al., 2012; Cardoso et al., 2019), a limiting factor in Semiarid regions (Dubeux Júnior et al., 2010).

The crude protein (CP) concentrations found in cladodes of all varieties (Table 1) are considered low. For the growth and development of ruminal microorganisms, which are responsible for the degradation of slow-digesting nutrients, the diet should contain concentrations of around 60.0–70.0 g/kg DM (Reis et al., 2004; Silva et al., 2011). As an alternative to low CP concentrations urea can be used, since microorganisms use urea when the presence of readily fermentable energy in the rumen occurs for the formation of microbial protein (Wanderley et al., 2012).

For mineral matter (MM), a decrease in concentrations as the plant developed, for the F- 08 variety. However, despite the difference, the forage cactus presented high concentrations of MM in its cladodes, which, according to Melo et al. (2003), is related to the high concentration of mineral macroelements in its composition.

There were differences in pectin concentrations (g/kg DM) among the varieties in (Table 2). It is important to note that pectin is a structural compound of the cell wall of plants, together with other compounds such as cellulose and hemicellulose, but it has a high solubility and, consequently, contributes to increase the digestibility of dry matter and neutral detergent fiber (Hall and Akinyode, 2000; Ramos et al., 2013). Foods with a high pectin content have great potential to be used in ruminant diets because they have a high energy density, they have a desirable type of fermentation without the production of lactic acid, helping to maintain a favorable ruminal environment (Muller and Prado, 2005).

The highest neutral detergent fiber (NDF) concentrations (Table 2) for the mature phase of the varieties may be related to the high maturity of cladodes at this phase compared to the others. This is because the maturation of the plant implies an increase of the cellular wall, cellulose and hemicellulose, which constitute the NDF. This occurs at the expense of organic molecules, which participate in metabolic processes by depositing non-nitrogenous organic molecules (cellulose, hemicellulose, lignin), causing a reduction in the concentration of nitrogen compounds (Van Soest, 1994; Velásquez et al., 2010).

In work conducted by Batista et al. (2003) and Batista et al. (2009), values obtained for NDF of varieties of the genus *Opuntia* ranged from 241.0 to 284.0 g/kg DM, while Cordova-Torres et al. (2015) identified a variation of 420–489 g/kg DM for varieties of the same genus. Therefore, the concentrations of NDF in cladodes at the young and intermediate phases in this research resemble those of the authors mentioned. Concentrations at the mature phase are higher, which is possibly related to the complete development of the cladode and consequently a high concentration of fiber.

In a study developed by Mokoboki and Sebola (2017) in South Africa, varieties of the genus *Opuntia* had lower concentrations of HEM for almost all the varieties studied in this work (Table 2) regardless of phenological phase: *Opuntia* algerian (6.03 g/kg DM), *Opuntia* morado (10.45 g/kg DM), *Opuntia* american giant (7.40 g/kg DM), *Opuntia* roetan (10.76 g/kg DM) and *Opuntia* crossx (7.40 g/kg DM). Such differences are possibly related to the varieties themselves, milder temperatures and the soil of the region.

The acid detergent fiber (ADF) concentrations in cladodes of the Gigante variety (Table 2), independent of the phenological phase, are relatively similar to those obtained by Torres et al. (2009), who identified 16.87% of ADF for the same variety. However, the highest

Table 4
Kinetics of *in vitro* gas production and *in vitro* true dry matter digestibility of forage cactus of the genus *Opuntia* in function of different phenological phases.

Phenological phases	Varieties					SEM	P- value
	EPP	APP	Gigante	IPA-20	F-08		
Total volume of gas produced (mL/gDM)							
Young	302.8	320.9	323.6A	286.1	307.5	4.9	0.09
Intermediate	286.7b	326.5a	301.6abB	285.9b	300.4 ab	4.6	0.02
Mature	282.5b	327.9a	301.8abB	274.5b	276.4b	5.5	<0.01
MSE	4.7	6.8	3.4	3.8	6.3		
P-value	0.20	0.90	<0.01	0.40	0.09		
Total production adjusted by the bi-compartment model (mL/gDM)							
Young	300.5 ab	313.2 ab	320.2 aA	280.0b	300.9 ab	4.6	0.04
Intermediate	285.4b	325.3a	298.9abB	280.6b	294.2 ab	4.7	0.01
Mature	279.8b	326.0a	299.5abB	270.1b	271.3b	5.8	<0.01
MSE	4.6	6.5	3.2	3.6	6.1		
P-value	0.20	0.70	<0.01	0.40	0.10		
Volume of gas produced by the degradation of NFC (mL/gDM)							
Young	200.2abA	189.1b	214.9abA	199.0abA	223.1 aA	4.0	0.04
Intermediate	186.8AB	196.2	193.4B	193.0A	205.6A	3.2	0.50
Mature	181.4B	180.7	186.2B	171.3B	165.5B	3.0	0.20
MSE	3.4	5.5	4.3	4.5	8.6		
P-value	0.04	0.6	<0.01	0.01	<0.01		
Rate of degradation of the fast digestion fraction (/h)							
Young	0.15bc	0.12c	0.14 cA	0.18 aA	0.18 ab	0.007	<0.01
Intermediate	0.14 ab	0.12c	0.13bcB	0.16abAB	0.17a	0.006	<0.01
Mature	0.13 ab	0.11b	0.12abB	0.14abB	0.14a	0.004	0.02
MSE	0.03	0.003	0.003	0.008	0.008		
P-value	0.20	0.70	0.02	0.03	0.10		
Lag time (h)							
Young	3.8bc	3.7bc	3.2c	5.1a	4.6 ab	0.2	<0.01
Intermediate	3.9bc	3.8bc	3.4c	4.9a	4.5 ab	0.1	<0.01
Mature	3.8	3.7	3.4	5.2	3.5	0.2	0.08
MSE	0.08	0.2	0.08	0.08	0.3		
P-value	0.90	0.90	0.50	0.60	0.30		
Volume of gas produced by the degradation of FC (mL/gDM)							
Young	100.3bc	124.1a	105.2 ab	81.0 cB	77.8 cB	4.4	<0.01
Intermediate	98.6b	129.0a	105.5b	87.6bAB	88.6bAB	3.8	<0.01
Mature	98.5b	145.4a	113.3 ab	98.9bA	105.7bA	5.0	<0.01
MSE	2.8	5.9	1.8	3.1	4.3		
P-value	0.90	0.30	0.10	0.04	0.01		
Rate of degradation of the slow digestion fraction (/h)							
Young	0.04b	0.04b	0.04b	0.04b	0.05a	0.001	0.03
Intermediate	0.04	0.04	0.04	0.04	0.04	0.001	0.10
Mature	0.04	0.04	0.04	0.04	0.04	0.0007	0.05
MSE	0.001	0.001	0.001	0.001	0.001		
P-value	0.10	0.70	0.70	0.70	0.30		
In vitro true digestibility (g/kg DM)							
Young	912.4 aA	904.3a	871.3bA	874.2bA	911.0 aA	4.9	<0.01
Intermediate	903.9 aA	908.9a	862.1bA	856.1bA	906.2 aA	6.1	<0.01
Mature	852.4B	858.7	820.3B	798.0B	826.1B	7.8	0.07
MSE	8.7	11.0	8.1	10.7	12.5		
P-value	<0.01	0.10	<0.01	<0.01	<0.01		

EPP = erect prickly pear; APP = African prickly pear; NFC = non-fiber carbohydrates; FC = fiber carbohydrates; SEM: standard error of mean; Means followed by lowercase letters differ in the rows and capital letters in columns ($P < 0.05$).

concentrations of ADF, at the mature phase of EPP, Gigante and F-08 should be related to the greater maturity of the cladodes at this phase.

In research developed by Vilela et al. (2010) on the Gigante variety, the concentrations obtained from acid digested lignin (ADL) were 30.2 g/kg DM, values close to those identified in this research (Table 2) for cladodes of the same variety. Batista et al. (2003) found an ADL of 14.0 g/kg DM for the Gigante forage cactus and 17.0 g/kg DM for the IPA-20 variety. These results only contribute to the affirmation that plants have a chemical composition that may vary according to species, age, soil conditions, among other factors. According to Melo et al. (2006), as the plant develops, there is a great reduction in protein concentrations and an increase of fibers associated with the increase of lignin. The latter forms a barrier, which makes it impossible for the adhesion of microorganisms and the enzymatic hydrolysis of cellulose and hemicellulose, causing a limitation in the digestibility of food.

A high concentration of total carbohydrates (TC) was observed for all varieties at all phenological phases (Table 3). In a study conducted by Urbiola et al. (2011) on *Opuntia* sp. at different ages at 40, 50, 60, 70, 80, 90, 100, 115 and 135 days, the authors observed a significant increase in carbohydrate concentrations: from 40.92 g/kg at 40 days to 60.77 g/kg at 135 days. These results corroborate with those of this study, evidencing that, in addition to the difference between the phenological phases and between varieties, the age of plants in other researches influenced the concentration of TC.

For NFC concentrations, the EPP presented higher proportions in cladodes at the young and intermediate phases compared to all other varieties of the study. This is related to the low concentrations of NDF, ADF, and LIG (Table 2). As for the lower NFC values at the mature phase, the high concentrations of fiber fractions at this phase were also closely related due to the higher maturity of cladodes (Table 2).

In this study, the NFC contents of cladodes decreased during the course of vegetative development. According to Balsalobre et al. (2003), the maturity of plants changes the cell wall and in counterpart decreases the concentration of NFC, which interferes with the availability of fast degradation energy for the microorganisms of the rumen in forage plants.

The high concentrations of the A + B1 fraction in the cladodes of the EPP and APP varieties (Table 3) may be associated with the high pectin ratios in the dry matter (Table 2). According to Santos et al. (2019), foods with high concentrations of the A + B1 fraction are excellent energy sources for ruminal microorganisms, resulting in greater microbial growth.

The varieties with higher concentrations of the fraction B2 in the cladodes at all phases (Table 3) can maximize microbial growth, with greater activity of microorganisms that use fibrous carbohydrates. The higher values of the C fraction at the mature phase may result in a decrease in the digestibility of these cladodes. According to Van Soest (1994), the C fraction promotes less energy availability of food due to its indigestible characteristic, promoting less potential intake per unit of time.

The highest volumes of *in vitro* gas observed for cladodes of APP (Table 4) may be associated with a low concentration of the indigestible fraction (C fraction), and with greater availability of fast and slow digestion carbohydrates. On the other hand, gas volumes for the Gigante forage cactus, higher concentrations were, cladodes at the young phase, are related to the higher concentration of NFC at this phase in comparison with theothers. The lowest gas volumes adjusted by the bicompartmental model (Vt2) in cladodes of IPA-20 (Table 4) may be related to the high concentration of C fraction (Table 3), which decreases the concentrations of digestible carbohydrates.

The volume of gas produced by NFC degradation (Table 4) in the F-08 forage cactus was probably due to the low concentration of the C fraction. Of all varieties studied and for the cladodes at the mentioned phase, this variety presented the lowest C fraction value (Table 3). Besides, most of the fractions TC and NFC are concentrated in this phase.

The highest *in vitro* true dry matter digestibility (Table 4) in cladodes of the EPP and APP varieties may be related to the lowest values of ADF. According to Van Soest (1994) the lower the concentrations of ADF in food, the higher the digestibility of the food. This is also related to the lower lignification of the cell wall.

In general, there was a high digestibility of dry matter in cladodes of the varieties at all phases, which is related in large part to the high concentrations of soluble carbohydrates in their tissues. These results are similar to those reported by Batista et al. (2003), who obtained an average digestibility of 814.0 g/kg DM and 806 g/kg DM for Gigante and IPA-20, respectively.

5. Conclusion

Due to the higher values of pectin, non-fibrous carbohydrates, gas production adjusted by the bicompartmental model and digestibility, the erect prickly pear varieties and the Prickly Pear African best nutritional value for feeding ruminants in relation to the Gigante, IPA-20 and F-08 varieties. Mature phase is the least relevant.

CRediT authorship contribution statement

Diana Valadares Pessoa: Conceptualization, Investigation, Methodology, Writing - original draft. **Albericio Pereira de Andrade:** Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing - original draft. **André Luiz Rodrigues Magalhães:** Conceptualization, Data curation, Methodology, Writing - original draft. **Ana Lúcia Teodoro:** Conceptualization, Data curation, Methodology, Writing - original draft. **Djalma Cordeiro dos Santos:** Conceptualization, Data curation, Methodology, Writing - original draft. **Gherman Garcia Leal de Araújo:** Conceptualization, Data curation, Methodology, Writing - original draft. **Ariosvaldo Nunes de Medeiros:** Conceptualization, Data curation, Methodology, Writing - original draft. **Daniel Bezerra do Nascimento:** Conceptualization, Investigation, Methodology, Writing - original draft. **Roberta de Lima Valença:** Data curation, Visualization, Writing - original draft, Writing - review & editing. **Daniel Barros Cardoso:** Data curation, Visualization, Writing - original draft, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no competing interests.

Acknowledgements

The authors thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the granting of a postgraduate scholarship (Master degree) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for funding this research.

References

Abidi, S., Salem, H.B., Vastab, V., Priolob, A., 2009. Supplementation with barley or spineless cactus (*Opuntia* ficus indica f. inermis) cladodes on digestion, growth and intramuscular fatty acid composition in sheep and goats receiving oaten hay. Small Rumin. Res. 87, 9–16.
AOAC, 1990. International official methods of analysis. In: Association of Official Analytical Chemists, fifteenth ed. AOAC, Arglington, USA, pp. 745.
Balsalobre, M.A.A., Corsi, M., Santos, P.M., Vieira, I., Cárdenas, M.R., 2003. Composição química e fracionamento do nitrogênio e dos carboidratos do capim- tanzânia irrigado sob três níveis de resíduo pós-pastejo. Rev. Bras. Zootec. 32, 519.
Barros, L.J.A., Ferreira, M.A., Oliveira, J.C.V., Santos, D.C., Chagas, J.C.C., Alves, A.M.S.V., Silva, A.E.M., Freitas, W.R., 2018. Replacement of Tifton hay by spineless cactus in Girolando post-weaned heifers diets. Trop. Anim. Health Prod. 50 (1), 149–154.
Batista, A.M., Mustafa, A.F., Wang, Y., Soita, H., McKinnon, J.J., 2003. Effects of variety on chemical composition, in situ nutrient disappearance and in vitro gas production of spineless cacti. J. Sci. Food Agric. 83, 140–145.
Batista, A.M.V., Ribeiro Neto, A.C., Lucena, R.B., Santos, D.C., Dubeux Júnior, J.B., Mustafa, A., 2009. Chemical composition and ruminal degradability of spineless cactus grown in northeastern Brazil. Rangel. Ecol. Manag. 62, 297–301.
Cardoso, D.B., Carvalho, F.F.R., Medeiros, G.R., Guim, A., Cabral, A.M.D., Véras, R.M.L., Santos, K.C., Dantas, L.C.N., Nascimento, A.G.O., 2019. Levels of inclusion of spineless cactus (*Nopalea cochenillifera* Salm Dyck) in the diet of lambs. Anim. Feed Sci. Technol. 247, 23–31.
Cordova-Torres, A.V., Mendoza-Mendoza, J.C., Bernal-Santos, G., García-Gasca, T., Kawas, J.R., Costa, R.G., Mondragon Jacobo, C., Andrade-Montemayor, H.M., 2015. Nutritional composition, in vitro degradability and gas production of *Opuntia* ficus indica and four other wild cacti species. Life Sci. J. 12 (2).
Costa, R.G., Trevino, I.H., Medeiros, G.R., Medeiros, A.N., Pinto, T.F., Oliveira, R.L., 2012. Effects of replacing corn with cactus pear (*Opuntia* ficus indica, Mill) on the performance of Santa Inês lambs. Small Rumin. Res. 102, 13–17.
Donato, P.E.R., Pires, A.J.V., Donato, S.L.R., Silva, J.A., Aquino, A.A., 2014. Valor nutritivo da palma forrageira 'gigante' cultivada sob diferentes espaçamentos e doses de esterco bovino. R. C. 17, 163–172.
Dubeux Júnior, J.C.B., Araújo Filho, J.T., Santos, M.V.F., Lira, M.A., Santos, D.C., Pessoa, R.A.S., 2010. Adubação mineral no crescimento e composição mineral da palma forrageira-Clone IPA-201. R. Bras. Cie. Agrar. 5, 129–135.
Hall, M.B., Akinyode, A., 2000. Cottonseed hulls working with a novel fiber source. In: Annual Florida Ruminant Nutrition Symposium, pp. 179–186 11. 2000, Gainesville. Proceedings… Gainesville.
Holden, L.A., 1999. Comparison of methods of in vitro dry matter digestibility for ten feeds. J. Dairy Sci. 82, 1791–1794.
INMET, 2017. Instituto nacional de Meteorologia, parâmetros meteorológicos de Recife, Pernambuco. Available in: http://www.inmet.gov.br/.
Melo, A.A.S., Ferreira, M.A., Verás, A.S.C., Lira, M.A., Lima, L.E., Viela, M.S., Melo, E.O.S., Araújo, P.R.B., 2003. Substituição parcial do farelo de soja por uréia e palma forrageira (*Opuntia* ficus indica Mill) em dietas para vacas em lactação. Rev. Bras. Zootec. 32, 727–736.
Melo, A.S., Ferreira, M.A., Véras, A.S.C., Lira, M.A., Lima, L.E., Bispo, S.V., Cabral, A.M.D., Azevedo, M., 2006. Desempenho leiteiro de vacas alimentadas com caroço de algodão em dieta à base de palma forrageira. Pesq. Agropec. Bras. 41, 1165–1171.
Mohamed-Yasseen, Y., Barringer, S.A., Splittstoesser, W.E., 1996. A note on the uses of *Opuntia* spp. in Central/North America. J. Arid Environ. 32, 347–353.
Mokoboki, K., Sebola, N., 2017. Chemical composition and feed intake of *Opuntia* cladodes varieties offered to goats. J. Anim. Plant Sci. 32, 5096–5103.
Moraes, G.S.O., Guim, A., Tabosa, J.N., Chagas, J.C.C., Almeida, M.P., Ferreira, M.A., 2019. Cactus [Opuntia stricta (Haw.) Haw] cladodes and corn silage: how do we maximize the performance of lactating dairy cows reared in semiarid regions? Livest. Sci. 221, 133–138.
Muller, M.E., Prado, I.N., 2005. Metabolismo da pectina em animais ruminantes, uma revisão. Varia Sci. 45–56 04, 08.
Pessoa, R.A.S., Leão, M.I., Ferreira, M., Valadares Filho, S.C., Valadares, R.F.D., Queiroz, A.C., 2009. Balanço de compostos nitrogenados e produção de proteína microbiana

em novilhas leiteiras alimentadas com palma forrageira, bagaço de cana-de açúcar e uréia associados a diferentes suplementos. Rev. Bras. Zootec. 38, 941–947.
Ramos, A.O., Ferreira, M.A., Véras, A.S.C., Costa, S.B.M., Conceição, M.G., Silva, E.C., Salla, L.E., Souza, A.R.D.L., 2013. Diferentes fontes de fibra em dietas a base de palma forrageira na alimentação de ovinos. Rev. Bras. Saúde Prod. Anim. 14, 648–659.
Reis, R.A., Bertipaglia, L.M.A., Freitas, D., Melo, G.M.P., Balsalobre, M.A.A., 2004. Suplementação protéica energética e mineral em sistemas de produção de gado de corte nas águas e nas secas. In: 1ª ed. Pecuária de corte intensiva nos trópicos, vol. 1. FEALQ, Piracicaba, pp. 171–226.
Rodrigues, A.M., Pitacas, F.I., Reis, C.M.G., Blasco, M., 2016. Nutritional value of *Opuntia* ficus-indica cladodes from Portuguese ecotypes. Bulg. J. Agric. Sci. 22, 40–45.
Santos, C.B., Costa, K.A.D.P., Souza, W.F.D., Epifanio, P.S., Santos, H.S., 2019. Protein and carbohydrates fractionation in Paiaguas palisadegrass intercropped with grain sorghum in pasture recovery. Acta Sci. Anim. Sci. 41.
Senger, C.C.D., Kozloski, G.V., Bonnecarrere Sanchez, L.M., Mesquita, F.R., Alves, T.P., Castagnino, D.S., 2008. Evaluation of autoclave procedures for fiber analysis in forage and concentrate feedstuffs. Anim. Feed Sci. Technol. 146, 169–174.
Silva, V.L., Costa, L.S., Bastos, M.P.V., Facuri, L.M.A.M., Rego Júnior, N.O., Silva, M.V., 2011. Caracterização físico-química e bioquímica do farelo de palma forrageira redonda (*Opuntia* ficus) utilizado na alimentação de ruminantes. Pubvet 5, 1–13.
Silva, R.R., Sampaio, E.V.S.S., 2015. Palmas forrageiras *Opuntia* ficus-indica e *Nopalea cochenillifera* : sistemas de produção e usos. Revisão Científica 2, 131–141.
Silva, E.T.S., Melo, A.A.S., Ferreira, M.A.F., Oliveira, J.C.V., Santos, D.C., Silva, R.C., Inácio, J.G., 2017. Acceptability by Girolando heifers and nutritional value of erect prickly pear stored for different periods. Pesq. Agropec. Bras. 52 (9), 761–767.
Schofield, P., Pitt, R.E., Pell, A.N., 1994. Kinetics of fiber digestion from in vitro gas production. J. Anim. Sci. 72, 2980–2991.
Sniffen, C.J., O'connor, J.D., Van Soest, P.J., Fox, D.G., Russel, J.B., 1992. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. J. Anim. Sci 70, 3562–3577.
Theodorou, M.K., Williams, B.A., Dhanoa, M.S., Mcallan, A.B., France, J., 1994. A simple gas production method using a pressure transducer to determine the fermentation kinetics of ruminant feed. Anim. Feed Sci. Technol. 48, 185–197.
Tilley, J.M.A., Terry, R.A., 1963. A two-stage technique for the in vitro digestion of forage crops. J. Br. Grassl. Soc. 18, 104–111.
Torres, L.C.L., Ferreira, M.A., Guim, A., Vilela, M.S., Guimarães, A.V., Silva, E.C., 2009. Substituição da palma-gigante por palma-miúda em dietas para bovinos em crescimento e avaliação de indicadores internos. Rev. Bras. Zootec. 38 (11), 2264–2269.
Urbiola, M.H., Terrero, E.P., García, M.E.R., 2011. Chemical analysis of nutritional content of Prickly Pads (*Opuntia* ficus indica) at Varied ages in an organic harvest. J. Environ. Res. Publ. Health. 8, 1287–1295.
Van Soest, P.J., 1994. Nutritional Ecology of the Ruminant. Cornell, Ithaca, pp. 476p.
Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and non starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74, 3583–3597.
Velásquez, P.A.T., Berchielli, T.T., Reis, R.A., Rivera, A.R., Dian, P.H.M., Texeira, I.A.M., 2010. Composição química, fracionamento de carboidratos e proteínas e digestibilidade in vitro de forrageiras tropicais em diferentes idades de corte. Rev. Bras. Zootec. 39, 1206–1213.
Valente, T.N.P., Detman, E., Queiroz, A.C., Valadares Filho, S.C., Gomes, D.I., Figueiras, J.F., 2011. Evaluation of ruminal degradation profiles of forages using bags made from different textiles. Rev. Bras. Zootec. 40, 2565–2573.
Vieira, E.L., Batista, A.M.V., Guim, A., Carvalho, F.F.R., Nascimento, A.C., Araújo, R.F.S., Mustafá, A.F., 2008. Effects of hay inclusion on intake, in vivo nutrient utilization and ruminal fermentation of goats fed spineless cactus (*Opuntia* fícus- indica Mill) based diets. Anim. Feed Sci. Technol. 141, 199–208.
Vilela, M.S., Ferreira, M.A., Azevedo, M., Modesto, E.C., Farias, I., Guimares, A.V., Bispo, S.V., 2010. Effect of processing and feeding strategy of the spineless cactus (*Opuntia* fícus-indica Mill.) for lactating cows: ingestive behavior. Appl. Anim. Behav. Sci. 125, 1–8.
Wanderley, W.L., Ferreira, M.A., Batista, A.M.V., Véras, A.S.C., Bispo, S.V., Silva, F.M., Santos, V.L.F., 2012. Consumo, digestibilidade e parâmetros ruminais em ovinos recebendo silagens e fenos em associação à palma forrageira. Rev. Bras. Saúde Prod.Anim. 13, 444–456.
Zanella, K., Taranto, O.P., 2015. Influence of the drying operating conditions on the chemical characteristics of citric acid extracted pectins from pera sweet orange (*Citrus Sinensis* L. Osbeck) albedo and flavedo. J. Food Eng. 166, 111–118.