An Acad Bras Cienc (2024) 96(3): e20221001 DOI 10.1590/0001-3765202420221001
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

ANIMAL SCIENCE

Nutritional value and kinetics of *in vitro* fermentation of spineless cactus of the genus *Nopalea* in different phenological phases

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Abstract: The objective was to evaluate the chemical composition and *in vitro* fermentation of spineless cactus of the genus Nopalea, F-21 (Nopalea cochenillifera Dyck), IPA-Sertânia (Nopalea cochenillifera Dyck) and Miúda (Nopalea cochenillifera Salm Dyck), in different phenophases. There was no effect ($P < 0.05$) of the phenological phases of spineless cactus on DM, ash, OM, EE, and CP. Varieties F-21 and Miúda presented higher values of DM and OM, whereas the CP was higher for IPA-Sertânia. The contents of NDF, ADF, and ADL, as well as the fractions of carbohydrates B2 and C were higher in the mature stage, irrespective of the variety. The Miúda variety showed higher levels of NFC and fractions A + B1 and the lower levels of pectin compared to the F-21 and IPA-Sertânia varieties, but not differ of TC to F-21. The volume of gas produced via the degradation of NFC was higher for young phenological phases. The young and intermediate stages showed a higher *in vitro* digestibility of DM. Based on the results, varieties IPA-Sertânia and Miúda have a high potential for use in animal feed because of their high nutritional quality. Mature cladodes showed a higher fibrous fraction and lower digestibility in all varieties.

Key words: Animal feed, Cactaceae, forage, semi-arid.

INTRODUCTION

In livestock raising, feed costs represent some of the largest costs, mainly due to the high prices of traditional feed components such as soybean meal and corn (Valença et al. 2020). Thus, there is a search for alternative sources, especially in semi-arid regions, where low precipitation, associated with high temperatures, hampers food production (Campos et al. 2017).

In this context, spineless cactus appears as an important feed source. In an extensive literature review, Dubeux Jr et al. (2021) reported the following composition of spineless cactus varieties used in Northeast Brazil: dry matter, 110.3 g kg^{-1} DM, crude protein, 58.1 g kg^{-1} DM, neutral detergent fiber, 300.8 g kg^{-1} DM, non-fiber carbohydrates, 565.9 g kg^{-1} DM, and *in vitro* dry matter digestibility, g kg^{-1} DM. Pessoa et al. (2020) reported a total carbohydrate amount of 827.9 g kg^{-1} DM, whereas Sá et al. (2021) reported an ash content of 124.7 g kg^{-1} DM. Spineless cactus is also adapted to the edaphoclimatic conditions of semi-arid regions (Costa et al. 2012, Silva et al. 2016), making it a potentially valuable crop for forage and fruit production, in addition to the sale of the cladodes (Abidi et al. 2009).

The main species of spineless cactus cultivated in northeastern Brazil are *Opuntia fícus indica* Mill and *Nopalea cochenillifera* Salm Dyck, with a predominance of *O. fícus indica*,

mainly the varieties Redonda and Gigante (Galvão Júnior et al. 2014). However, in recent years, the pest carmine cochineal has caused great economic losses in these varieties in the northeast of Brazil (Torres et al. 2009). Given the above, the search for spineless cactus varieties resistant to pests and with a good nutritional value has intensified, highlighting varieties of the genus *Nopalea*, such as Miúda and IPA-Sertânia (Vasconcelos et al. 2009, Lopes et al. 2010).

However, the nutritional composition as well as aspects related to the digestibility of these new varieties in their different phenological stages still need to be investigated. Thus, the objective of this study was to evaluate the chemical composition, fractionation of carbohydrates, and *in vitro* fermentation of different varieties of spineless cactus from the genus *Nopalea* in the different phenophases.

MATERIALS AND METHODS

Place and collection of plant material

The samples were collected in August 2016, at the Experimental Station of the Agricultural Institute from Pernambuco (*Instituto Agronômico de Pernambuco – IPA)*, located in the municipality of Arcoverde-PE, latitude -8.43 °, longitude -37.05 °, altitude 680.7 meters, average temperature 24.9 ± 10.53 ° C, RH 79.6 ± 11.95%, wind speed 3.1 ± 0.8 m/s, average annual precipitation 1,058.8 mm, microregion of the Moxotó hinterland (INMET 2017).

The studied varieties were: *Nopalea cochenillifera* Dyck var. F-21, *Nopalea cochenillifera* Dyck (IPA-Sertânia) and *Nopalea cochenillifera* Salm Dyck (Miúda). From each variety of spineless cactus, four plants of about the same size were selected, where from each plant cladodes were selected in different phenological phases, these being: young stage (with the cladodes located at the distal or lateral ends of the plant, light green in color and expanding). Intermediate stage (located in the middle part of the plant and dark green in color). Mature stage (located just above the base cladode, light whitish in color, fully expanded). This procedure was carried out with the objective of standardizing the samples in relation to the age of the plants.

Laboratory analysis

Samples were pre-dried in a forced ventilation oven at 55 °C for 72 hours and ground in a Wiley mill (Marconi, MA-580, Piracicaba, Brazil) with 2-mm (digestibility and gas production) and 1-mm (chemical-bromatological analyzes) sieves. Analysis of dry matter (DM) (method, 930.15), organic matter (OM) (method, 942.05), ash (method, 942.05), crude protein (PB) (method, 954.01) and the ether extract (EE) (Sohxlet) (method, 920.39) were performed according to the methodology described by the Association of Official Analytical Chemists (AOAC 1990).

Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid-digested lignin (ADL) were determined according to Van Soest et al. (1991). Total carbohydrates (TC) were measured using the equation: TC = 100 – (CP + EE + MM), and non-fibrous carbohydrates (NFC), corresponding to the fractions A+B1, measured by the equation: NFC = TC - NDF; and B2 fraction was estimated by the difference between the NDF and the C fraction according to Sniffen et al. (1992). While the fraction C was obtained by the indigestible NDF after 288 hours *in situ* incubation, as described by Valente et al. (2011).

The extraction of pectin was determined according to the methodology of Zanella & Taranto (2015). *In vitro* dry matter digestibility (IVDMD) was performed according to the technique of Tilley & Terry (1963), with adaptation by Holden (1999), where the incubation

procedure was carried out for 48 hours, then 6 mL of 20 % hydrochloric acid (HCl) and 2 mL of pepsin (1:1000) were added into each vial and, after the period of 24 hours of incubation, the filtration procedures were performed (vacuum process, drying, and weighing of the waste) in order to calculate the IVDMD.

Gas production *in vitro* was performed according to Theodorou et al. (1994). The readings were measured at the times 2, 4, 6, 8, 10, 12, 15, 18, 21, 24, 30, 36, 42 and 48 h after incubation. The pressure data (psi = pressure per inch) were converted into volume of gases (V), adopting the equation, V = 5.1612P - 0.3017, R2 = 0.9873, generated at the Gas Production Laboratory (LPG) of the Federal University of the Agreste of Pernambuco (*Universidade Federal do Agreste de Pernambuco - UFAPE*), based on 937 observations.

The cumulative gas production data were adjusted using the bicompartmental model suggested by Schofield et al. (1994), using the SAS® PROC NLMIXED:

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

where, *Vt* represents the maximum total volume of gases produced; *Vf1* (mL/g of incubated DM) represents the maximum gas volume for the fast digesting fraction (NFC); *Vf2* (mL/g) represents the maximum gas volume for the fraction of slow digestion (FC); *kd1* (h) is equivalent to the rate of degradation of the fast digesting fraction (NFC); *kd2* (h) is equivalent to the rate of degradation of the fraction of slow digestion; *λ* (Lag time) represents the duration of the initial digestion events (latency phase), common to both phases; and t (h) represents the fermentation time.

Statistical analysis

The experiment was carried out in a 3x3 factorial arrangement (three varieties of spineless cactus and three phenological stages), with four replications. The model used for the chemical composition and fractionation of carbohydrates was:

$$Yijk = \mu + Vi + Pj + \varepsilon ijk$$

where: Yijk = observed value of the dependent variable; μ = general mean; *Vi* = varieties effect; *Pj* = phenological stages effect; and εijk = residual error.

Data of *in vitro* fermentation kinetics were analyzed using the mixed nonlinear procedure, where the fermentation parameters were generated from the data observed in the different *in vitro* incubation times, according to the model below:

$$Yijk = \mu + Vi + Pj + Tij + \varepsilon ijk$$

where: *Yijk* = observed value of the dependent; μ = general mean; *Vi* = varieties effect; *Pj* = phenological stages; *Tij* = incubation times effect; and εijk = residual error.

The data were submitted to analysis of variance in factorial arrangement 3 x 3 (three varieties of spineless cactus and three phenological stages of the cladode) and the means were compared with Tukey test, at 5% probability, using the Statistical Analysis Software - SAS (2003).

RESULTS

There was no interaction (P = 0.291) between varieties x phenological phases of spineless cactus for DM, ash, OM, EE and CP variables. Furthermore, the different stages also did not influence the chemical-bromatological composition (P>0.05) (Table I). However, there was effect (P<0.05) for the average content of DM, ash, OM, EE, and CP among the different varieties (Table I).

For DM (g/kg natural matter) and OM (g/kg DM) the lowest values were for the IPA-Sertânia

Table I. Chemical-bromatological composition of spineless cactus varieties of the genus *Nopalea* in function of different phenological phases.

Phenophases	Varieties				SEM	*P - value*		
	F-21	IPA-Sertânia	Miúda	Average		P	V	P*V
Dry matter (g/kg Natural matter)								
Young	104.9±9.6	80.8±7.2	103.8±12.1	96.48	4.5	0.163	<0.001	0.291
Intermediate	101.3±13.6	85.2±3.0	107.6±8.4	98.06	4.0			
Mature	99.2±9.3	96.8±7.7	117.4±6.7	104.46	3.7			
Average	101.80a	87.60b	109.60a					
Ash (g/kg Dry matter)								
Young	108.2±11.7	138.4±21.1	107.6±7.5	118.08	6.2	0.131	<0.001	>0.050
Intermediate	97.9±16.3	139.6±22.4	103.3±5.0	113.64	7.4			
Mature	83.0±13.6	135.9±22.9	90.5±6.3	103.13	8.5			
Average	96.38b	137.98a	100.49b					
Organic matter (g/kg Dry matter)								
Young	891.8±11.7	861.6±21.1	892.4±7.5	881.92	6.2	0.131	<0.001	>0.050
Intermediate	902.1±16.3	860.4±22.4	896.7±5.0	886.36	7.4			
Mature	917.0±13.6	864.1±22.9	909.5±6.3	896.87	8.5			
Average	903.61a	862.02b	899.51a					
Ether extract (g/kg Dry matter)								
Young	18.4±1.5	14.5±3.3	15.0±0.8	15.97	0.8	>0.050	0.002	0.205
Intermediate	17.8±1.7	17.8±0.6	13.5±2.1	16.37	0.8			
Mature	18.4±1.4	16.4±0.4	15.9±2.6	16.92	0.6			
Average	18.22a	16.26ab	14.79b					
Crude protein (g/kg Dry matter)								
Young	49.2±2.8AB	60.8±14.7A	37.4±3.3B	49.13	3.9	>0.050	<0.001	<0.010
Intermediate	50.8±4.0AB	60.6±15.6A	40.9±1.4B	50.74	3.7			
Mature	53.9±10.0B	64.5±11.7A	43.0±3.6B	53.80	3.8			
Average	51.29	61.93	40.43					

SEM: standard error of mean; Different letters, lowercase in columns and uppercase in rows differ by Tukey's test (*P*<0.05). P = phenological phases; V = varieties; V*P = interactions effect.

variety (Table I). The same variety had the highest average ash content. While for the average EE content (g/kg DM) the highest value was for the F-21 variety (18.22) and the lowest value for the fine variety (14.79). For CP contents, spineless cactus variety IPA-Sertânia showed the highest values in all phenological phases compared to the Miúda variety (*P*<0.05), however, did not differ from the F-21 variety (P>0.05; Table I).

There was interaction effect (*P*<0.05) between spineless cactus variety and phenological phases to the fibrous compounds in g/kg DM (Figure 1). There was difference (*P*<0.05) in the content of pectin by the varieties studied (Figure 1a), with higher values for varieties F-21 and IPA-Sertânia. But it did not differ between the phenological phases (Figure 1b). There was difference (*P*<0.05) between varieties for NDF and ADL contents, with higher values for IPA-Sertânia and F-21, respectively (Figure 1c and 1e). Regarding the phenological phases, the NDF and ADL values where higher (*P*<0.05) for mature phenological phases for all varieties (Figure 1d and 1f). While the ADF was lower (*P*<0.05; Figure 1g) in the IPA-Sertânia variety in the mature stage. When

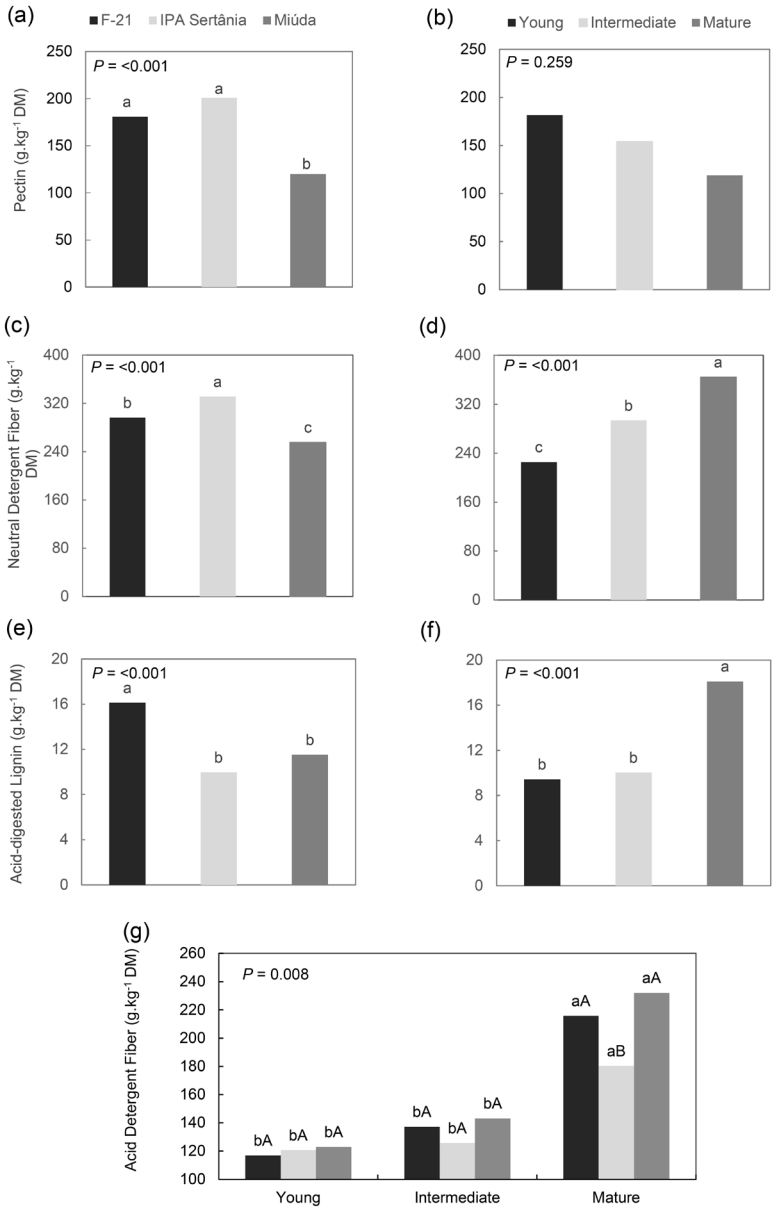

Figure 1. **Chemical-bromatological composition (g/kg Dry matter) of spineless cactus varieties of the genus *Nopalea* in function of different phenological phases. Pectin (a) spineless cactus variety and (b) phenological phases; Neutral Detergent Fiber = (c) spineless cactus variety and (d) phenological phases; Acid-digested Lignin = (g) spineless cactus variety and phenological phases. Lowercase letters compare mean values for spineless cactus variety within each phenological phase, and uppercase letters compare mean values for phenological phases within each spineless cactus variety by Tukey test (*P*<0.05).**

comparing the phenological phases, this was higher for the mature stage (Figure 1g).

There was a significant effect (*P*<0.05) for the average TC content, when comparing spineless cactus varieties (Table II). With higher levels for the F-21 (834.10 g/kg DM) and Miúda (844.30 g/kg DM) varieties. While the lowest level was for the IPA-Sertânia variety (781.87 g/kg DM).

While the NFC and the A+B1 fraction differed (*P*<0.05) for average content between varieties, as well as between the average content of stages. The NFC and A+B1 fraction showed similar behavior, in which the highest levels were, respectively, for the Miúda variety, F-21 and IPA-Sertânia. However, in relation to the phenological phases, the highest average contents of both variables were in the young stage (Table II).

In fractions B2 and C (g/kg TC) there was interaction between variety x phenological

Table II. Contents of total carbohydrates (TC) and non-fibrous carbohydrates (NFC), and fractions of carbohydrates from spineless cactus varieties of the genus *Nopalea* in function of different phenological phases.

Phenophases	Varieties			Average	SEM	*P - value*		
	F-21	IPA-Sertânia	Miúda			P	V	P*V
	TC (g/kg Dry matter)							
Young	824.1±12.7	782.4±32.3	840.0±9.5	815.50	9.6	>0.050	<0.001	>0.050
Intermediate	833.5±20.7	782.0±38.0	842.3±7.2	819.27	11.1			
Mature	844.7±22.1	781.2±30.8	850.6±4.5	825.50	11.6			
Average	834.10a	781.87b	844.30a					
	NFC (g/kg Dry matter)							
Young	579.3±11.9	536.7±13.9	654.3±20.6	590.11a	15.4	<0.001	<0.001	0.257
Intermediate	530.6±49.4	444.5±73.1	602.0±19.4	525.69b	25.0			
Mature	502.8±49.4	370.3±24.0	510.5±18.4	461.22c	21.9			
Average	537.59b	450.50c	588.92a					
Fractions of total carbohydrates								
	A+B1 (g/kg TC)							
Young	702.9±4.0	686.5±14.9	778.8±19.0	722.73a	12.8	<0.001	<0.001	0.140
Intermediate	635.9±49.2	566.6±78.6	714.6±21.0	639.05b	24.6			
Mature	594.2±44.2	473.9±20.1	600.1±18.6	639.05c	19.7			
Average	644.37b	575.64c	697.85a					
	B2 (g/kg TC)							
Young	260.2±8.4aAB	274.7±15.9bA	191.4±15.9bB	242.10c	11.7	<0.001	<0.001	0.001
Intermediate	306.6±48.7aAB	385.4±81.8aA	236.5±16.6bB	309.47b	24.9			
Mature	260.3±54.7aB	443.7±25.5aA	364.8±18.5aA	356.24a	25.2			
Average	275.69b	367.92a	264.20b					
	C (g/kg TC)							
Young	36.8±8.7b	38.8±8.9b	29.8±4.7	35.16c	2.6	<0.001	<0.001	<0.001
Intermediate	57.5±5.6b	48.0±6.8b	48.9±12.9	51.47b	3.0			
Mature	145.5±23.4aA	82.4±6.9aB	35.1±0.2C	87.69a	14.3			
Average	79.94a	56.44b	37.94c					

SEM: standard error of mean; Different letters, lowercase in columns and uppercase in rows differ by Tukey's test (*P*<0.05). P = phenological phases; V = varieties; V*P = interactions effect.

phases (*P*=0.001; Table II). Which the B2 fraction was higher (*P*<0.05) for the IPA-Sertânia varieties in all phenological phases, followed by the F-21 variety in the young and intermediate phases. While in the mature phenological phases the IPA-Sertânia did not differ from the Miúda (Table II). When evaluating the values of the B2 fraction by phenological phases of each variety, the highest values were for the intermediate and mature stages, in IPA-Sertânia, and mature in the Miúda variety (*P*<0.05). While did not differ for the F-21 variety (Table II). The fraction C differed between the phenological phases (*P*<0.05), for F-21 and Sertânia IPA varieties, with higher values for the mature phenophase. However, regarding the averages, the F-21 variety and the mature phenological phases obtained higher values (Table II).

There was no interaction between variety x phenological phases, nor an independent effect (P>0.05) between the average values of the total volumes of gas production adjusted by the bicompartmental model (mL g^{-1} DM) (Table III and Figure 2c and 2d), as well as for

the volume of gas produced by degradation of NFC and FC (mL g^{-1} DM), rate of degradation of the rapidly digestion fraction (/h) and volume of gas produced by degradation of FC (mL g^{-1} DM) (Table III). There was a difference in the average values of the gas volumes produced by NFC degradation between the phenological phases, in which the young stage presented greater volume compared to the mature stage.

There was interaction (P<0.05) in the volume of gas production and the rate of degradation of the slow digestion fraction (/h) between variety x phenological phases. The IPA-Sertânia variety had a lower volume, while in the intermediate stage the highest volume was for the F-21 variety (Table III). For Lag time (λ), there was a difference between the varieties (P<0.05), with higher values for the Miúda variety (Figure 2e). However, did not differ (P>0.05) between phenological phases (Figure 2f).

The IVDMD did not differ between the varieties of spineless cactus (Figure 2a), although, there was a difference (P<0.05) between the phenological phases in all varieties, where the mature stage cladodes showed less digestibility compared to the others (Figure 2b).

Table III. *In vitro* gas production kinetics and *in vitro* digestibility of dry matter of spineless cactus of the genus *Nopalea* in function of different phenological phases.

Phenophases	Varieties			Average	SEM	*P - value*		
	F-21	IPA-Sertânia	Miúda			P	V	P*V
Total production adjusted by the bicompartmental model (mL/gDM)								
Young	323.5±27.9	289.5±17.6	300.5±9.3	304.50	7.3	0.170	>0.050	0.138
Intermediate	309.4±7.8	291.6±36.3	300.6±7.5	300.53	6.9			
Mature	272.7±16.1	296.2±21.5	293.6±7.7	287.51	5.8			
Average	301.87	292.43	298.24					
Volume of gas produced by NFC degradation (mL/gDM)								
Young	228.6±3.0	188.4±31.9	207.1±16.4	208.05a	8.0	0.046	0.114	0.336
Intermediate	212.4±2.6	186.0±40.4	203.3±13.1	200.56ab	8.1			
Mature	174.5±11.8	181.2±22.4	193.5±10.7	183.05b	5.3			
Average	205.19	185.19	201.29					
Degradation rate of the rapidly digesting fraction (/h)								
Young	0.05±0.0	0.04±0.0	0.05±0.01	0.04	0.001	0.217	>0.050	>0.050
Intermediate	0.05±0.0	0.05±0.02	0.04±0.0	0.05	0.004			
Mature	0.04±0.0	0.04±0.0	0.04±0.0	0.04	0.001			
Average	0.05	0.05	0.04					
Volume of gas produced by the degradation of FC (mL/gDM)								
Young	94.8±28.1	101.1±17.3	93.4±12.3	96.45	6.2	>0.050	0.300	0.340
Intermediate	97.0±6.1	105.6±15.6	97.3±7.2	99.96	3.4			
Mature	98.2±17.7	115.0±13.2	100.1±16.7	104.45	5.3			
Average	96.67	107.24	96.94					
Degradation rate of the slow digesting fraction (/h)								
Young	0.16±0.03	0.11±0.01	0.15±0.01	0.14	0.01	0.010	<0.001	0.017
Intermediate	0.16±0.01A	0.11±0.04B	0.15±0.01AB	0.14	0.01			
Mature	0.16±0.04	0.11±0.01	0.15±0.02	0.14	0.01			
Average	0.16a	0.11b	0.15a					

SEM: standard error of mean; Different letters, lowercase in columns and uppercase in rows differ by Tukey's test (P<0.05). P = phenological phases; V = varieties; V*P = interactions effect.

DISCUSSION

Spineless cactus is characterized by its low proportion of DM, which is related to its high moisture content. In the present study, the DM content did not differ among the phenological phases (Table I). However, it differed between the varieties, with the highest value for Miúda. Magalhães et al. (2021) and Rocha Filho et al. (2021) also observed lower DM values in the variety IPA-Sertânia compared to Miúda. The higher DM value of the variety Miúda may be related to the lower water storage capacity of its cladodes compared to the other studied variety. However, this difference is more pronounced when species of *Nopalea* are compared to those of *Opuntia* (Magalhães et al. 2021). Paulo Neto et al. (2016) mention that diets formulated with large proportions of spineless cactus generally have a high moisture content, a favorable characteristic in regions where water becomes a limiting factor at certain times of the year.

The higher ash content in the IPA-Sertânia variety can be attributed to its genotypic characteristics. The levels of ash found in this work are within the range observed by Alves et al. (2016), who studied the bromatological composition of seven varieties of *Nopalea* and observed levels of 76.20 to 130.50 g kg^{-1} DM. The high ash content found for this variety might be due to the presence of Ca and calcium oxalate (Silva et al. 2021). According to Santos et al. (2018), factors such as soil mineral and moisture contents can significantly affect the ash content

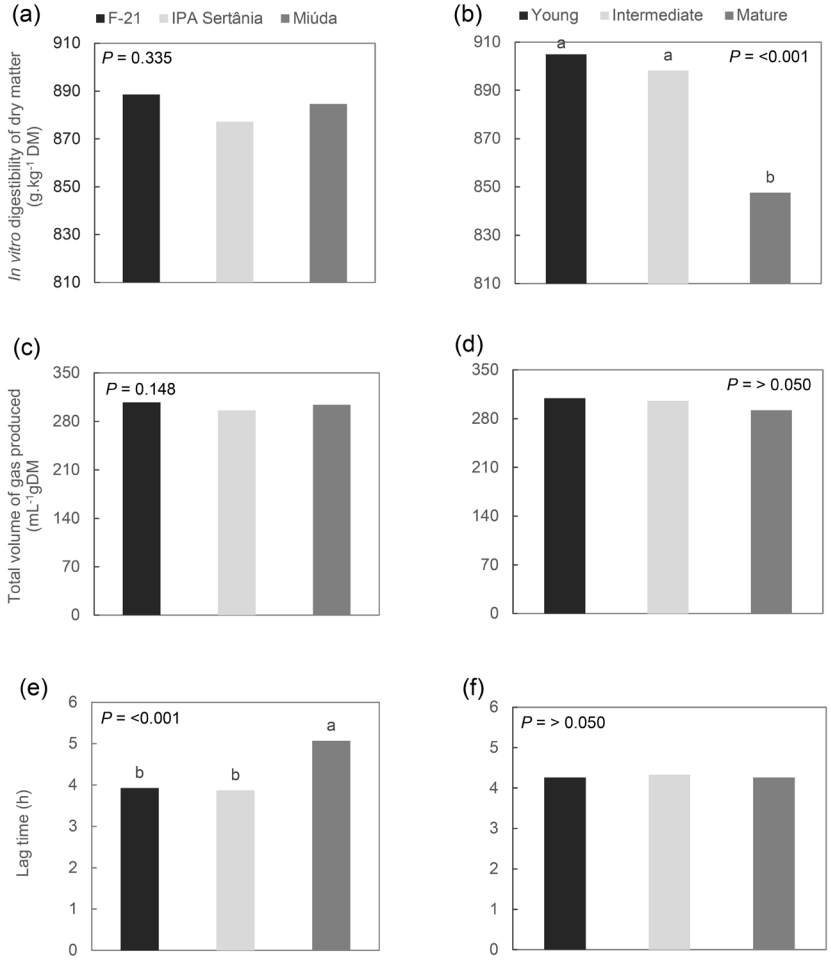

Figure 2. ***In vitro*** **gas production kinetics and** ***in vitro*** **digestibility of dry matter of spineless cactus of the genus** ***Nopalea*** **in function of different phenological phases.** ***In*** **vitro digestibility of dry matter (g.kg^{-1} Dry Matter) = (a) spineless cactus variety and (b) phenological phases; Total volume of gas produced (mL^{-1}g Dry Matter) = (c) spineless cactus variety and (d) phenological phases; Lag time (h) = (e) spineless cactus variety and (f) phenological phases. Different letters compare mean values for spineless cactus variety within each phenological phase and values for phenological phases within each spineless cactus variety by Tukey test (*P*<0.05).**

of spineless cactus. Generally, K and Ca are present at greater amounts compared to other nutrients (Dubeux Jr et al. 2021). Consequently, this variety had a lower OM value compared to F-21 and Miúda. Magalhães et al. (2021) also observed higher ash values for the IPA-Sertânia variety.

The lower EE content of the Miúda variety in relation to the other varieties in the intermediate stage was not expected since spineless cactus tends to have a lower EE content in the more mature stages, which can be explained by the storage of EE as a reserve of energy and carbon, used during periods of water or salt stress (Hernández-Urbiola et al. 2011). The variations in the EE levels observed in this study are, however, within the values reported in the literature, ranging from 8.6 to 32.00 g kg^{-1} DM (Cavalcante et al. 2014, Alves et al. 2016, Edvan et al. 2020, Magalhães et al. 2021).

The CP values observed in the IPA-Sertânia variety are considered within the range for the growth and development of ruminal microorganisms, from 60.0 to 70.0 g kg^{-1} DM (Silva et al. 2011). The CP values of the other varieties were below the recommended values for the development of ruminal microorganisms.

The values observed for NDF and ADF (Fig. 1c and 1g) are considered low for ruminant diets. According to Van Soest (1994), when fiber is found in insufficient amounts in the diet of ruminants, there may be a decrease in microbial efficiency, a low ruminal pH, and metabolic disorders. According to Reis et al. (2004), for beef cattle to maintain a good performance, 450 and 200 g kg^{-1} DM of NDF and ADF, respectively, are required. Therefore, fibrous foods should be offered additionally to spineless cactus, such as Tifton grass hay and soybean husks (Ramos et al. 2013).

Although the TC level differed between the varieties (Table II), it was generally high, irrespective of the phenological stages. This is in agreement with previous findings (Tosto et al. 2007, Costa et al. 2012, Wanderley et al. 2012, Edvan et al. 2020).

The highest proportions of the NFC and A + B1 fractions (g kg^{-1} TC) were observed for the variety Miúda, which is probably related to the lower proportions of NDF in this variety (Fig. 1c), especially in the young stage (Fig. 1d). The NFC and its fractions favor an increase in food intake by animals as they are quickly fermented in the rumen, improving energy supply (Silva et al. 2011); they are therefore considered as good sources of energy for the growth of microorganisms (Carvalho et al. 2007). But in all varieties are considered high, to the point of classifying this food as energetic (Ferreira et al. 2007). Mokoboki & Sebola (2017), studying five varieties of spineless cactus, also observed a difference in the NFC contents.

Regarding fraction B2, the IPA-Sertânia and Miúda varieties showed higher levels in the mature stage, which is also related to the higher NDF value identified in this phenological phase. Importantly, although this fraction is a part of fiber, it slowly provides energy to the rumen, which can compromise the efficiency of microbial synthesis and animal performance (Oliveira et al. 2012). However, in foods such as cactus pear, which has a low fibrous fraction, higher proportions of the B2 fraction should not affect rumen health, and depending on the complete diet, this aspect may even be beneficial.

The highest contents of fraction C in the cladodes of the mature stage can be attributed to the high proportions of the fractions of indigestible ADL at this stage (Table I). According to Van Soest (1994), the indigestible fraction of carbohydrates tends to increase with increasing plant maturity, and the retention of food in the rumen depends on the quality of dietary

fiber. Foods with a high content of low-quality fiber lead to a retention time greater than that necessary for adequate digestive efficiency.

The Vf1 (volume of gas produced by NFC degradation) was higher in the early phenological phases of both species as a function of the higher values of NFC and the A + B1 fractions of carbohydrates (Table II). They are inversely proportional to the fibrous carbohydrate values, which are generally higher in older cladodes as these fractions are responsible for sustaining the plant. However, this was not sufficient to influence the total gas production (observed or estimated by the bicompartmental model), both for the varieties and for the phenological phases (Table III and Fig. 2c and 2d).

Consequently, the IVDMD (Fig. 2), the lowest digestibility observed in the mature stage, may be related to the higher proportions of fibrous fractions (ADF and ADL) in this phase in the Miúda variety. According to Pinheiro et al. (2014), the increase in the proportion of lignin, for example, limits the digestibility of cellulose and hemicellulose (constituents of the cell wall) and, consequently, the digestibility of morphogenic structures and the plant as a whole. However, compared to other forages, spineless cactus has a high digestibility. Similar IVDMD values were observed by Magalhães et al. (2021) for the varieties Miúda (826.0 g kg^{-1}) and IPA-Sertânia (827.8 g kg^{-1}).

The latency time in the present study, which was higher for the Miúda variety (Fig. 2e) may be related to the pectin content (Fig. 1a) which was lower for this variety. Although pectin is a structural carbohydrate, it has a high solubility and, therefore, can be more easily degraded by ruminal microorganisms (Ramos et al. 2013, Magalhães et al. 2021). Thus, the higher levels observed for the F-21 and IPA-Sertânia varieties resulted in rapid microbial growth.

According to Tosto et al. (2015) the low latency time of spineless cactus may be associated with its physical-chemical characteristics since the soluble fraction constitutes the energy fraction for rapid fermentation, thus facilitating the adhesion and colonization of microorganisms to the substrate, resulting in the increased fermentation of fibrous carbohydrates and reducing the latency period. Thus, when compared to the values reported by Muniz et al. (2011) for bulky foods, they are considered low. Previous studies have reported the following values: Sabiá hay (20 mL), Mororó hay (20 mL), Leucena leaf hay (12.61 mL), Juazeiro hay (10.96 mL), oat hay (7.55 mL), spineless cactus silage (8.41 mL), and corn silage (5.23 mL).

CONCLUSION

The varieties IPA-Sertânia and Miúda have a high potential for use in animal feed because of their good nutritional quality. Irrespective of the variety, the mature cladodes have a higher fibrous fraction and a lower *in vitro* digestibility of dry matter.

Acknowledgments

The authors thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the granting of a postgraduate scholarship (Master degree) and the grant National Postdoctoral Program scholarships (Finance code 8882.316822/2019-01). We also thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for funding this research.

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How to cite

PESSOA DV ET AL. 2024. Nutritional value and kinetics of *in vitro* fermentation of spineless cactus of the genus *Nopalea* in different phenological phases. An Acad Bras Cienc 96: e20221001. DOI 10.1590/0001-3765202420221001.

Manuscript received on November 17, 2022;
accepted for publication on September 10, 2023

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