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Morphological and nutritional characterization of the cladodes of three varieties of forage cactus of the genus *Nopalea*

Caracterização morfológica e nutricional dos cladódios de três variedades de palma forrageira do gênero Nopalea

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ABSTRACT: The forage cactus is a plant of the cactus family, widely cultivated in the Brazilian semiarid, which stands out for its high productivity and nutritional value. Within this group, the genus *Nopalea* presents several varieties adapted to different edaphoclimatic conditions. This work aims to characterize by order of the cladode, three varieties of forage cactus of the genus *Nopalea*, cultivated under rainfed regime, through morphological and nutritional parameters. The study was conducted at the IPA Experimental Station in the city of Caruaru-Pernambuco State, Brazil. The experimental design was randomized blocks, with three replicates. The studied varieties were Miúda, F-21 and IPA-Sertânia. The number of total cladodes of the plant (NC), cladode length (CL), cladode width (CW), cladode area (CA), cladode thickness (CT), cladode volume (CV), cladode perimeter (CP), total fresh weight (FW), total dry weight (DW), total photosynthetic area (TPA), cladode area index (CAI), plant height (PH), plant width (PW), total fresh matter yield (FMY), total dry matter yield (DMY), total water accumulation (H_2O), survival (SV), dry matter (DM), mineral matter (MM), organic matter (OM), neutral detergent fiber (NDF), acid detergent fiber (ADF), protein (P), hemicellulose (HEM), nitrogen (N), potassium (K) and sodium (Na) were determined at two years of age of the plants. The results demonstrate the existence of differences between the orders of the cladodes for some morphological and nutritional characteristics, within the genotypes; as well as between the observed varieties for NC, CL, CW, CA, TPA, CAI, CT, CV, CP, PH, PW, SV, H_2O and ADF. This results are related to genetic variation among materials, except for H_2O contend, once that this experiment was carried under controlled water availability by the environment. This information is relevant to understand the influence of the order of the cladodes and the genetic variability of the morphological and nutritional characteristics of the genus *Nopalea*.

KEYWORDS: Bromatological composition, characterization of forages species, coexistence with the semiarid, genetic diversity, genetic pre-improvement of cactus.

RESUMO: *A palma forrageira é uma planta da família das cactáceas, amplamente cultivada no Semiárido brasileiro, que se destaca por sua alta produtividade e valor nutritivo. Dentro desse grupo, o gênero Nopalea apresenta diversas variedades adaptadas a diferentes condições edafoclimáticas. O objetivo deste trabalho é caracterizar, por ordem do cladódio, três variedades de palma forrageira do gênero Nopalea, cultivadas sob regime de sequeiro, por meio de parâmetros morfológicos e nutricionais. O estudo foi conduzido na Estação Experimental do IPA na cidade de Caruaru-PE. O delineamento experimental utilizado foi em blocos ao acaso, com três repetições. As variedades estudadas foram: Miúda, F-21 e IPA-Sertânia. O número de cladódios totais da planta (NC), comprimento do cladódio (CC), largura do cladódio (LC), área do cladódio (AC), espessura do cladódio (EC), volume do cladódio (VC), perímetro do cladódio (PC), peso fresco total (PF), peso seco total (PS), área fotossintética total (AFT), índice de área do cladódio (IAC), altura da planta (AP), largura da planta (LP), produtividade de matéria fresca total (PMF), produtividade de matéria seca total (PMS), acúmulo de água total (H_2O), sobrevivência (SB), a matéria seca (MS), matéria mineral (MM), matéria orgânica (MO), fibra em detergente neutro (FDN), fibra em detergente ácido (FDA), proteína (PB), hemicelulose (HEM), nitrogênio (N), potássio (K) e sódio (Na) foram determinados aos dois anos de idade das plantas. Os resultados demonstram a existência de diferenças entre as ordens dos cladódios para algumas características morfológicas e nutricionais, dentro dos genótipos; bem como entre as variedades observadas para o NC, CC, LC, AC, AFT, IAC, EC, VC, PC, AP, LP, SB, H_2O e FDA. Essa variação está relacionada à variação genética entre os materiais, exceto para H_2O, sugerida para ser controlada pelo ambiente. Essas informações são relevantes para entender a influência da ordem dos cladódios e a variabilidade genética das caraterísticas morfológicas e nutricionais do gênero Nopalea.*

PALAVRAS-CHAVE: *Composição bromatológica, caracterização de espécies forrageiras, convivência com o semiárido, diversidade genética, pré-melhoramento genético de cactus.*

Introduction

Forage cactus is a plant of the cactus family, widely cultivated in arid and semiarid regions, which stands out for its high productivity and nutritional value. Within this group, the genus *Nopalea* has several varieties adapted to different edaphoclimatic conditions. One of the distinctive morphological characteristics of this genus is the presence of cladodes, which are flattened and succulent branches that assume the function of leaves and carry out photosynthesis (ALVES et al., 2020a). Cladodes are organized into orders, which correspond to the number of growth cycles they have passed (ALVES et al., 2020b).

The morphological and nutritional characterization of forage cactus cladodes is important to assess the productive potential and nutritional value of this crop, which is a sustainable alternative for animal feed in arid and semiarid regions. Cladodes are the organs responsible for photosynthesis, respiration, and water and nutrient reserves in most of cactus plants. They vary in size, shape, weight, area, and volume according to the order of growth, genotype, and environmental conditions (QUEIROZ et al., 2015; MATOS et al., 2021; PINHEIRO et al., 2014).

The analysis of the morphological and nutritional parameters of the cladodes allows estimating the biomass production, the cladode area index, the efficiency of the use of solar radiation, the content of dry matter, crude protein, fiber, fat, minerals, and other components that influence on forage quality (PINHEIRO et al., 2014).

In Brazil, forage cactus is cultivated on about 97,000 hectares, mainly in the Northeastern states, where it stands out as a source of bulk food for cattle, goats, and sheep (ALVES, 2015; INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATISTICA, 2017). The national average production of dry matter is estimated at 20 t ha-1 year-1, but it may vary according to plant variety, management, and water availability (SILVA et al., 2015a). Among the most cultivated varieties in the country are Gigante, Redonda, IPA Clone-20 (*Opuntia ficus indica*), Orelha de Elefante Mexicana (*Opuntia stricta*), Miúda and IPA-Sertânia (*Nopalea cochenillifera*) (ALVES et al., 2020a).

Studies on forage cactus cultivation in Brazil have advanced in recent years, addressing aspects such as genetic diversity, vegetative propagation, irrigation, fertilization, pest, and disease control, harvesting and storage, processing and use in animal feed. However, further research is still needed to optimize the production system, improve nutritional quality, and add value to the crop (ALVES, 2015).

This study hypothesizes that there is variability between the orders of the cladode or phenological stage in the morphological and nutritional characteristics of the varieties of the genus *Nopalea*. Thus, this work aims to characterize, by cladode order, three varieties of forage cactus of the genus *Nopalea*, cultivated under rainfed regime, through morphological and nutritional parameters.

Materials and Methods

Experiment location

The experiment was carried out at the Experimental Station of the Agronomic Institute of Pernambuco (IPA), located in the municipality of Caruaru, Pernambuco state, Brazil. The station is at an altitude of 537 m, at geographic coordinates 08º14'12.2" S and 35º55'16.8" W. The climate in the region is Bsh - hot semiarid, according to the Köpen classification, with average annual precipitation of 507.3 mm, average annual temperature of 22.9 ºC, average relative humidity of 75.5% and average wind speed of 3.1 $m.s^{-1}$. (SILVA et al., 2019a; INSTITUTO NACIONAL DE METEOROLOGIA, 2021).

The soil in the experimental area is a regolith Neosol, with the following physical and chemical properties: coarse sand = 640 $g.kg^{-1}$; fine sand = 260 $g.kg^{-1}$; silt = 50 $g.kg^{-1}$; clay = 50 $g.kg^{-1}$; soil density = 1.67 $g.cm^{-3}$; particle density = 2.62 $g.cm^{-3}$; humidity at field capacity (-33 kPa) = 25.70 $g.kg^{-1}$; moisture at permanent wilting point (-1500 kPa) = 12.90 $g.kg^{-1}$; available water = 12.80 $g.kg^{-1}$; P = 24.00 $mg.dm^{-3}$; K^+ = 0.14 $cmolc.dm^{-3}$; Ca^{2+} = 1.00 $cmolc.dm^{-3}$; Mg^{2+} = 0.70 $cmolc.dm^{-3}$; Na^+ = 0.21 $cmolc.dm^{-3}$; Al^{3+} = 0.00 $cmolc.dm^{-3}$; H^+ = 3.62 $cmolc.dm^{-3}$; pH 7.20.

Plant material and conduct of the experiment

The materials used in the experiment are described in Table 1 and Figure 1. The clones cladodes were planted on March 14, 2019, using one cladode per hole. The experimental design was in randomized blocks, with three replications. Each block was composed of plots with plants of each variety. The experimental plot consisted of three rows of 4.00 m, spaced 1.00 m apart and 0.50 m between the plants in the row, totaling 24 plants in an area of 12.00 m^2. The central line defined the useful area, excluding the plant at the end of each line, resulting in 6 evaluated plants.

The soil was prepared by plowing followed by harrowing. Fertilization and soil correction were carried out according to the recommendations for palm cultivation in the state of Pernambuco, using 40 $kg.ha^{-1}$ of P_2O_5, 50 $kg.ha^{-1}$ of K_2O, 0.5 $t.ha^{-1}$ of limestone and 20 $t.ha^{-1}$ of tanned cattle manure (CAVALCANTI, 2008).

The experiment was conducted without irrigation. The agricultural practices consisted of periodic weeding with a hoe throughout the area. The rainfall in the experimental area is presented in Table 2. The evaluations of the morphological, nutritional, and productive characteristics were carried out two years after planting.

Determination of morphological characteristics and production

The following characteristics were evaluated in the second year of age of the plants: number of total cladodes in the plant (NC), cladode length (CL), cladode width (CW), cladode area (CA), cladode thickness (CT), cladode volume (CV), cladode

Table 1. Varieties of forage cactus of the genus *Nopalea* used in the study and cultivated in the state of Pernambuco, Brazil.

N°	Varieties	Species	Common name
1	**IPA-100004**	*N. cochenillifera*	**Miúda**
2	**IPA-200021**	*N. cochenillifera*	**F-21**
3	**IPA-200205**	*N. cochenillifera*	**IPA-Sertânia**

Figure 1. Forage cactus varieties used in the study and cultivated in the state of Pernambuco, Brazil. (a) Miúda, (b) F-21 and (c) IPA-Sertânia.

Table 2. Precipitation in the experimental area from 2019 to 2021.

Precip. (mm)	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	Total
2019	31.5	91.1	69.6	199.3	64.6	133.8	177.2	88.4	33.9	6.3	0.4	12.3	908.4
2020	113.3	24.9	238.7	201.2	96.4	204.8	87.7	47.6	34.6	6.5	10.3	16.2	1.082.2
2021	68.2	6.8	99.0	104.6	130.8	53.2	61.0	74.6	20.4	11.1	3.6	34.1	667.4

Data obtained by the IPA meteorological station located at the unit.

perimeter (CP), total fresh weight (FW), total dry weight (DW), total photosynthetic area (TPA), cladode area index (CAI), plant height (PH), plant width (PW), total fresh matter yield (FMY), total dry matter yield (DMY), total water accumulation (H_2O) and survival (SV).

The CL, CW, CT, CP^1, PH and PW measurements were made with a caliper and measuring tape (cm); those of FW and DW were made with a scale (g). CA, CV, CP, TPA, CAI, FMY, DMY and H_2O estimates were made based on formulas described in the literature, as indicated below:

- CA^1 = CL x CW x 0.7327 + 3.3339 (Miúda); CA^1 = CL x CW x 0.7108 + 3.4217 (F-21); CA^1 = CL x CW x 0.6972 + 19.389 (IPA-Sertânia) (cm^2) (MIRANDA et al., 2011);
- CA^2 = 3.1416 x CL/2 x CW/2 (cm^2) (SILVA, 2014);
- CV^1 = CA^1 x CT (cm^3) (ALVES, 2015);
- CV^2 = 4.1888 x CL/2 x CW/2 x CT (cm^3) (PATERLINI, 2018);
- CP^1 = measured with tape measure (cm) (ALVES, 2015);
- CP^2 = 3.1416 x CL/2 x [2 - E^2/2 + 3 x E^4/16] (cm) (SILVA, 2014);
- TPA^1 = CA^1 x NC (cm^2) (ALVES, 2015);
- TPA^2 = CA^2 x NC (cm^2) (ALVES, 2015);
- CAI^1 = TPA^1/soil area (ALVES, 2015);
- CAI^2 = TPA^2/ soil area (ALVES, 2015);
- FMY = FW x number of plants per hectare ($t.ha^{-1}$) (ALVES, 2015);
- DMY = DW x number of plants per hectare ($t.ha^{-1}$) (ALVES, 2015);
- H_2O = FMY - DMY ($t.ha^{-1}$) (ALVES, 2015);
- SV = [(final number of plants - initial number of plants)/ initial number of plants] x 100 (%) (ALVES, 2015).

Determination of nutritional characteristics

When the plants were two years old, the following nutritional parameters were evaluated: dry matter (DM), mineral matter (MM), organic matter (OM), neutral detergent fiber (NDF), acid detergent fiber (ADF), protein crude (P), hemicellulose (HEM), nitrogen (N), potassium (K) and sodium (Na).

N, K and Na analyses were performed following the methods by Malavolta, Vitti and Oliveira (1997), and the results were expressed $g.kg^{-1}$ or $mg.kg^{-1}$. DM, OM, MM, ADF, NDF, P and HEM analyses were performed according to Messias, Gomes and Santana (2013) and Silva et al. (2022), and the results were expressed in %.

Statistical analysis

The data obtained were submitted to analysis of variance (ANOVA) and the means were compared using the Tukey or Scott-Knott test at 5% significance level.

Data analyses were conducted using the program GENES® - Computational Application in Genetics and Statistics (CRUZ, 2001).

Results and Discussion

We observed significant differences in the Miúda variety (IPA-100004) by Tukey test ($p<0.05$) between the cladode orders for the characteristics CL, CW, CA^1, CA^2, CT, CV^1, CV^2, CP^1, CP^2, P and N. For the other characteristics, no significant differences were observed between the order of the cladode.

The average variation of the values for the characteristics evaluated between the order of the cladodes in the forage

cactus varieties were NC (2.0 to 15.0), CL (13.0 to 21.1 cm), CW (7.3 to 9.1 cm), CA^1 (72.8 to 145.9 cm^2), CA^2 (74.4 to 152.8 cm^2), CT (1.3 to 3.0 cm), CV^1 (94.6 to 403.7 cm^3), CV^2 (129.0 to 562.3 cm^3), CP^1 (33.0 to 49.7 cm), CP^2 (35.7 to 56.9 cm), FW (160.0 to 3651.7 g), DW (21.2 to 485.8 g), TPA^1 (291.0 to 4330.6 cm^2), TPA^2 (297.7 to 4536.1 cm^2), DM (88.6 to 89.0%), MM (7.6 to 10.5%), OM (78.3 to 81.4%), P (1.5 to 3.2%), NDF (38.0 to 50.6%), ADF (22.6 to 25.4%), HEM (15.0 to 28.0%), N (0.3 to 0.5%), K^+ (1.1 to 1.3%) and Na^+ (0.003 to 0.01%) (Table 3).

We also observed significant differences in the variety F-21 (IPA-200021) between cladode orders for the characteristics NC, CL, CT, CV^1, CV^2, CP^1, CP^2, FW, DW, TPA^1 and TPA^2. For the other characteristics, no significant differences were observed between the order of the cladode.

The average variation of the values for the characteristics evaluated between the order of the cladodes in this variety was NC (3.7 to 16.3), CL (18.2 to 23.4 cm), CW (9.5 to 10.9 cm), CA^1 (137.7 to 175.5 cm^2), CA^2 (148.4 to 190.2 cm^2), CT (1.4 to 3.5 cm), CV^1 (193.8 to 595.5 cm^3), CV^2 (278.4 to 859.9 cm^3), CP^1 (43.4 to 56.5 cm), CP^2 (50.5 to 62.9 cm), FW (545.0 to 5170.0 g), DW (45.5 to 579.8 g), TPA^1 (902.6 to 7,053.6 cm^2), TPA^2 (971.9 to 7,638.9 cm^2), DM (88.2 to 89.1%), MM (7 .9 to 10.9%), OM (77.3 to 80.7%), P (2.2 to 3.1%), NDF (36.1 to 45.9%), ADF (16.8 to 22.7%), HEM (14.9 to 23.3%), N (0.4 to 0.5%), K^+ (1.3 to 1.5%) and Na^+ (0.003 to 0.01%) (Table 4).

In the variety IPA-Sertânia (IPA-200205), significant differences were observed between cladode orders for the following morphological characteristics CL, CW, CT, CA^1, CA^2, CV^1, CV^2, CP^1, CP^2, DM, ADF and K^+. For the other

Table 3. Means of morphological and nutritional characteristics by cladode order of the Miúda forage cactus variety, IPA-100004 (*N. cochenillifera*) cultivated in the Brazilian semiarid - Caruaru, Pernambuco, Brazil, after completing 2 (two) years of age after sowing.

Characteristics	Cladodes				*QMR*	*DMS*
	1° order	2º order	3º order	4º order		
NC	**5.0 a**	**15.0 a**	**11.7 a**	**2.0 a**	**39.6**	**16.5**
CL	**19.2 ab**	**21.1 a**	**18.4 b**	**13.0 c**	**0.8**	**2.3**
CW	**8.5 a**	**9.1 a**	**8.5 a**	**7.3 b**	**0.2**	**1.1**
CA^1	**129.1 a**	**145.9 a**	**119.3 a**	**72.8 b**	**109.2**	**27.3**
CA^2	**134.8 a**	**152.8 a**	**124.3 a**	**74.4 b**	**125.5**	**29.3**
CT	**3.0 a**	**2.1 b**	**1.5 b**	**1.3 b**	**0.1**	**1.0**
CV^1	**403.7 a**	**307.4 ab**	**186.8 bc**	**94.6 c**	**4376.3**	**173.0**
CV^2	**562.3 a**	**429.5 ab**	**259.7 bc**	**129.0 c**	**8616.6**	**242.8**
CP^1	**47.4 a**	**49.7 a**	**44.1 a**	**33.0 b**	**8.0**	**7.4**
CP^2	**52.0 ab**	**56.9 a**	**49.7 b**	**35.7 c**	**5.3**	**6.0**
FW	**1,310.0 a**	**3,651.7 a**	**2,043.3 a**	**160.0 a**	**1919835.4**	**3623.8**
DW	**216.2 a**	**485.8 a**	**251.5 a**	**21.2 a**	**34227.0**	**483.9**
TPA^1	**1,194.3 a**	**4,330.6 a**	**2,925.8 a**	**291.0a**	**3232653.7**	**4702.4**
TPA^2	**1,246.8 a**	**4,536.1 a**	**3,056.4 a**	**297.7 a**	**3543590.2**	**4923.3**
DM	**87.9 a**	**89.0 a**	**88.7 a**	**88.6 a**	**1.1**	**2.8**
MM	**9.2 a**	**7.6 a**	**10.5 a**	**9.3 a**	**3.0**	**4.5**
OM	**78.7 a**	**81.4 a**	**78.3 a**	**79.3 a**	**4.9**	**5.8**
P	**1.5 b**	**2.5 ab**	**3.2 a**	**2.5 ab**	**0.4**	**1.6**
NDF	**38.0 a**	**38.7 a**	**50.6 a**	**42.1 a**	**81.9**	**23.7**
ADF	**25.4 a**	**23.7 a**	**22.6 a**	**24.6 a**	**69.2**	**21.7**
HEM	**24.8 a**	**15.0 a**	**28.0 a**	**22.0 a**	**57.3**	**19.8**
N	**0.3 b**	**0.4 ab**	**0.5 a**	**0.4 ab**	**0.01**	**0.26**
K^+	**1.3 a**	**1.1 a**	**1.2 a**	**1.2 a**	**0.1**	**0.9**
Na^+	**0.01 a**	**0.003 a**	**0.007 a**	**0.01 a**	**0.00004**	**0.01602**

NC: number of cladodes (unit); CL: cladode length (cm); CW: cladode width (cm); CA^1: cladode area (cm^2) (MIRANDA et al., 2011); CA^2: cladode area (cm^2) [CA^2 = (CL/2) x (CW/2) x 3.14159265358897] (SILVA, 2014); CT: cladode thickness (cm); CV^1: cladode volume (CV^1 = CA^1 x CT) (cm^3) (ALVES, 2015); CV^2: cladode volume [CV^2 = 4/3 x (CL/2) x (CW/2) x 3.1415926535897 x CT (cm^3) (PATERLINI, 2018); CP^1: cladode perimeter (tape measure measurement) (cm); CP^2: cladode perimeter (CP^2 = 3.1415926535897 x (CL/2) x (2 - E^2/2 + 3 x E^4/16) (cm) (SILVA, 2014); FW: total fresh weight (g); DW: total dry weight (g); TPA^1: total photosynthetic area (TPA^1 = CA^1 x NC) (cm^2); TPA^2: total photosynthetic area (TPA^2 = CA^2 x NC) (cm^2); DM: dry matter (%); MM: mineral matter (%); OM: organic matter (%); P: protein (%); NDF: neutral detergent fiber (%); ADF: acid detergent fiber (%); HEM: hemicellulose (%); N: nitrogen (%); K^+: potassium (%); Na^+: sodium (%). Means followed by the same letter, in the row, do not differ from each other by Tukey test, ($p<0.05$).

Table 4. Means of morphological and nutritional characteristics by cladode order of the forage cactus variety F-21, IPA-200021 (*N. cochenillifera*) cultivated in Caruaru, Pernambuco, Brazil, after completing 2 (two) years of age after sowing.

Characteristics	Cladodes				*QMR*	*DMS*
	1° order	2º order	3º order	4º order		
NC	4.3 b	16.3 a	20.7 a	3.7 b	11.6	8.9
CL	23.4 a	23.2 a	21.9 ab	18.2 b	2.2	3.8
CW	9.5 a	10.1 a	10.9 a	10.0 a	2.2	3.9
CA^1	165.2 a	175.5 a	174.9 a	137.7 a	240.1	40.5
CA^2	178.8 a	190.2 a	189.5 a	148.4 a	293.1	44.8
CT	3.5 a	2.0 b	1.7 bc	1.4 c	0.02	0.34
CV^1	595.5 a	361.4 b	297.0 b	193.8 c	1451.8	99.7
CV^2	859.9 a	522.4 b	429.1 b	278.4 c	3117.8	146.0
CP^1	56.5 a	54.4 a	52.0 a	43.4 b	10.6	8.5
CP^2	62.9 a	62.7 a	60.3 a	50.5 b	8.4	7.6
FW	2,078.3 bc	5,170.0 a	3,676.7 ab	545.0 c	838891.7	2395.5
DW	229.9 b	579.8 a	362.2 ab	45.5 b	15985.9	330.7
TPA^1	1,388.8 b	5,683.7 a	7,053.6 a	902.6 b	1017145.9	2637.7
TPA^2	1,503.1 a	6,158.0 a	7,638.9 a	971.9 b	1190316.9	2853.4
DM	88.2 a	89.1 a	88.6 a	88.2 a	1.1	2.7
MM	9.8 a	8.5 a	7.9 a	10.9 a	4.7	5.7
OM	78.5 a	80.6 a	80.7 a	77.3 a	4.7	5.7
P	3.1 a	2.2 a	2.3 a	3.1 a	1.1	2.8
NDF	45.9 a	36.1 a	39.4 a	38.6 a	106.1	26.9
ADF	22.7 a	21.2 a	16.8 a	19.7 a	24.3	12.9
HEM	23.3 a	14.9 a	22.6 a	18.9 a	71.08	22.1
N	0.5 a	0.4 a	0.4 a	0.5 a	0.03	0.44
K^+	1.3 a	1.3 a	1.4 a	1.5 a	0.07	0.70
Na^+	0.01 a	0.008 a	0.008 a	0.003 a	0.00001	0.00925

NC: number of cladodes (unit); CL: cladode length (cm); CW cladode width (cm); CA^1: cladode area (cm^2) (MIRANDA et al., 2011); CA^2: cladode area (cm^2) [CA^2 = (CL/2) x (CW/2) x 3.1415926535897] (SILVA, 2014); CT: cladode thickness (cm); CV^1: cladode volume (CV^1 = CA^1 x CT) (cm^3) (ALVES, 2015); CV^2: cladode volume [CV^2 = 4/3 x (CL/2) x (CW/2) x 3.1415926535897 x CT (cm^3) (PATERLINI, 2018); CP^1: cladode perimeter (tape measure measurement) (cm); CP^2: cladode perimeter (CP^2 = 3.1415926535897 x (CL/2) x (2 - E^2/2 + 3 x E^4/16) (cm) (SILVA, 2014); FW: total fresh weight (g); DW: total dry weight (g); TPA^1: total photosynthetic area (TPA^1 = CA^1 x NC) (cm^2); TPA^2: total photosynthetic area (TPA^2 = CA^2 x NC) (cm^2); DM: dry matter (%); MM: mineral matter (%); OM: organic matter (%); P: protein (%); NDF: neutral detergent fiber (%); ADF: acid detergent fiber (%): HEM: hemicellulose (%); N: nitrogen (%); K^+: potassium (%); Na^+: sodium (%). Means followed by the same letter, in the row, do not differ from each other by Tukey test, ($p<0.05$).

characteristics, no significant differences were observed between the order of the cladode.

The average variation of the values for the characteristics evaluated between the order of the cladodes in this variety was NC (7.0 to 9.0), CL (23.1 to 27.3 cm), CW (11.9 to 13.7 cm), CA^1 (212.4 to 277.8 cm^2), CA^2 (217.4 to 291.1 cm^2), CT (2.0 to 3.1 cm), CV^1 (421.9 to 801.3 cm^3), CV^2 (575.6 to 1,114.7 cm^3), CP^1 (56.1 to 65.7 cm), CP^2 (62.9 to 73.9 cm), FW (2,293.0 to 5,370.0 g), DW (196.1 to 670.4 g), TPA^1 (2,760.8 to 4,869.3 cm^2), TPA^2 (2,826.1 to 5,092.1 cm^2), DM (87.6 to 89.3%), MM (7.1 to 10.7%), OM (78.6 to 81.5%), P (2.5 to 3.4%), NDF (41.8 to 50.4%), ADF (22.4 to 33.8%), HEM (11.5 to 21.5%), N (0.4 to 0.5%), K^+ (0.71 to 1.4%) and Na^+ (0.004 to 0.009%) (Table 5).

In the study of the variability between the morphological and nutritional characteristics between the genotypes, it was observed mean variation of the significant values by the Scott-Knott test, ($p<0.05$) for the NC, CL, CW, CA, TPA, CAI, CT, CV, CP, PH, PW, SV, H_2O and ADF. This variation is related to genetic variation between materials; as the relationship between the genetic and environmental variation coefficient was above one for all these traits, with heritability values in the broad sense ranging from 81.0 to 99.7% (data not shown). This confirms the high genetic control over these traits (ALVES, 2015). However, H_2O presents values below one (data not shown), which suggests greater control of the environment in this specific characteristic.

The average variation of the values for the evaluated characteristics among the forage cactus varieties was NC (19.0 to 44.2), CL (18.9 to 26.4 cm), CW (8.6 to 13.1 cm), CA^1 (125.4 to 266.8 cm^2), CA^2 (130.9 to 278.6 cm^2), TPA^1 (3,938.1 to 7,219.2 cm^2), TPA^2 (4,109.8 to 7,810.3 cm^2), CAI^1 (0.8 to 1.4), IAC2 (0.8 to 1.6), EC (2.1 to 2.5 cm), VC1 (352.1 to 829.0 cm3), VC2 (307.5 to

Table 5. Means of morphological and nutritional characteristics by cladode order of the cactus pear variety IPA-Sertânia, IPA-200205 (*N. cochenillifera*) cultivated in Caruaru, Pernambuco, Brazil, after completing 2 (two) years of age after sowing.

Characteristics	Cladodes			*QMR*	*DMS*
	1° order	2º order	3º order		
NC	8.0 a	9.0 a	7.0 a	25.7	12.7
CL	27.3 a	26.2 ab	23.1 b	1.9	3.5
CW	12.5 ab	13.7 a	11.9 b	0.5	1.8
CA^1	265.0 ab	277.8 a	212.4 b	514.3	56.8
CA^2	276.6 ab	291.1 a	217.4 b	652.8	64.0
CT	3.1 a	2.1 b	2.0 b	0.04	0.56
CV^1	801.3 a	590.0 b	421.9 c	3659.3	151.6
CV^2	1,114.7 a	824.3 b	575.6 c	7520.7	217.3
CP^1	65.7 a	63.3 ab	56.1 b	13.7	9.3
CP^2	73.9 a	71.6 ab	62.9 b	13.1	9.1
FW	5,370.0 a	4,588.3 a	2,293.0 a	6492419.4	6384.6
DW	670.4 a	411.5 a	196.1 a	64993.8	638.8
TPA^1	4,167.5 a	4,869.3 a	2,760.8 a	6819041.4	6543.2
TPA^2	4,352.5 a	5,092.1 a	2,826.1 a	7402751.5	6817.5
DM	89.3 a	87.6 b	88.5 ab	0.3	1.4
MM	10.7 a	7.1 a	7.1 a	2.7	4.1
OM	78.6 a	80.5 a	81.5 a	1.5	3.1
P	2.5 a	2.9 a	3.4 a	0.6	1.9
NDF	41.8 a	50.4 a	43.9 a	29.2	13.5
ADF	30.3 ab	33.8 a	22.4 b	18.5	10.8
HEM	11.5 a	16.6 a	21.5 a	82.8	22.8
N	0.4 a	0.5 a	0.5 a	0.02	0.31
K^+	1.4 a	1.2 a	0.71 b	0.03	0.42
Na^+	0.007 a	0.009 a	0.004 a	0.00003	0.01447

NC: number of cladodes (unit); CL: cladode length (cm); CW: cladode width (cm); CA^1: cladode area (cm^2) (MIRANDA et al., 2011); CA^2: cladode area (cm^2) [CA^2 = (CL/2) x (CW/2) x 3.1415926535897] (SILVA, 2014); CT: cladode thickness (cm); CV^1: cladode volume (CV^1 = CA^1 x CT) (cm^3) (ALVES, 2015): CV^2: cladode volume [CV^2 = 4/3 x (CL/2) x (CW/2) x 3.1415926535897 x CT (cm^3) (PATERLINI, 2018): CP^1: cladode perimeter (tape measure measurement) (cm); CP^2: cladode perimeter (CP^2 = 3.1415926535897 x (CL/2) x (2 - E^2/2 + 3 x E^4/16) (cm) (SILVA, 2014); FW: total fresh weight (g); DW: total dry weight (g); TPA^1: total photosynthetic area (TPA^1 = CA^1 x NC) (cm^2); TPA^2: total photosynthetic area (TPA^2 = CA^2 x NC) (cm^2); DM: dry matter (%); MM: mineral matter (%); OM: organic matter (%); P: protein (%); NDF: neutral detergent fiber (%); ADF: acid detergent fiber (%); HEM: hemicellulose (%); N: nitrogen (%); K^+: potassium (%); Na^+: sodium (%). Means followed by the same letter, in the row, do not differ from each other by Tukey test, ($p<0.05$).

756.4 cm3), CP^1 (45.6 to 63.5 cm), CP^2 (51.3 to 71.7 cm), PH (68.8 to 83.0 cm). PW (79.7 to 108.8 cm), SV (61.1 to 100%), FW (7,058.3 to 11,470.0 g), DW (960.4 to 1,217.4 g), FMY (141. 2 to 229.4 $t.ha^{-1}$), DMY (19.2 to 24.4 $t.ha^{-1}$), H_2O (122.0 to 205.1 $t.ha^{-1}$), DM (88.5 to 88.6%), MM (8.3 to 9.3%), OM (79.3 to 80.2%), P (2.6 to 3.0%), NDF (40.0 to 45.4%), ADF (20.1 to 28.8%), HEM (16.5 to 23.8%), N (4.0 to 4.8%), K^+ (10.8 to 13.5%) and Na^+ (52.8 to 68.9%) (Table 6).

The variability of morphological and nutritional characteristics between botanical materials and among the order and/or phenological stage of cladodes within forage cactus varieties has been reported by several studies (ALVES, 2015; ALVES et al., 2007, 2017; SALES, 2018; SILVA, 2019a; SILVA et al., 2010, 2015a, 2015b, 2019b, 2022). The results obtained in this work for the characteristics evaluated align with those found by these authors.

The importance of morphological analysis in forage cactus of the genera *Nopalea* is related to the identification and classification of varieties cultivated in Brazil, which present a great genetic and phenotypic diversity (ALVES, 2015). In addition, morphological analysis allows knowing the variation of plant characteristics in different phenological stages (young, intermediate, and mature), which can influence the choice of adequate management and the rational use of this forage resource (BARROS, 2022). Morphological analysis can also help in assessing the productive potential and resistance to forage cactus pests and diseases (ALVES, 2015).

Bromatological analysis is the study of the chemical composition of plant biomass, which includes the determination of nutrients such as proteins, carbohydrates, lipids, fibers, minerals, and vitamins. The plant cladodes have long been considered an important source of nutrients for human and

Table 6. Means of morphological and nutritional characteristics of forage cactus varieties of the genus *Nopalea* cultivated Caruaru, Pernambuco, Brazil, after completing 2 (two) years of age after sowing.

Characteristics	Varieties			Minimum	Maximum	Average
	Miúda	F-21	IPA-Sertânia			
NC	31.3 b	44.2 a	19.0 b	11.5	49.5	31.5
CL	18.9 c	21.7 b	26.4 a	18.6	27.4	22.3
CW	8.6 c	10.1 b	13.1 a	8.5	13.8	10.6
CA^1	125.4 c	163.3 b	266.8 a	123.4	289.6	185.2
CA^2	130.9 c	176.7 b	278.6 a	128.7	304.4	195.4
TPA^1	3,938.1 b	7,219.2 a	4,873.7 b	2,961.6	8,088.3	5,343.6
TPA^2	4,109.8 b	7,810.3 a	5,074.8 b	3,089.1	8,752.1	5,665.0
CAI^1	0.8 b	1.4 a	1.0 b	0.6	1.6	1.1
CAI^2	0.8 b	1.6 a	1.0 b	0.6	1.8	1.1
CT	2.1 b	2.1 b	2.5 a	1.9	2.6	2.2
CV^1	352.1 c	466.4 b	829.0 a	243.9	927.6	549.2
CV^2	307.5 b	417.9 b	756.4 a	275.9	984.2	493.9
CP^1	45.6 c	51.6 b	63.5 a	44.4	66.7	53.6
CP^2	51.3 c	59.1 b	71.7 a	50.4	74.6	60.7
PH	68.8 b	83.0 a	72.0 b	62.5	92.5	74.6
PW	79.7 b	108.8 a	82.2 b	70.0	122.0	90.2
SV	100.0 a	61.1 b	100.0 a	33.3	100.0	87.0
FW	7,058.3 a	11,470.0 a	10,722.7 a	4,350.0	17,193.0	9,750.3
DW	960.4 a	1,217.4 a	1,147.3 a	521.5	1,663.7	1,108.4
TFMY	141.2 a	229.4 a	214.5 a	87.0	343.9	195.0
TDMY	19.2 a	24.4 a	23.0 a	10.4	33.3	22.2
H_2O	122.0 b	205.1 a	191.5 a	76.6	310.6	172.8
DM	88.6 a	88.5 a	88.5 a	87.6	89.3	88.5
MM	8.8 a	9.3 a	8.3 a	7.1	10.9	8.8
OM	79.8 a	79.3 a	80.2 a	77.3	81.5	79.8
P	2.6 a	2.7 a	3.0 a	1.5	3.8	2.8
NDF	43.9 a	40.0 a	45.4 a	36.1	55.0	43.1
ADF	24.1 b	20.1 c	28.8 a	16.8	33.8	24.3
HEM	23.8 a	19.9 a	16.5 a	11.5	31.7	20.1
N	4.0 a	4.5 a	4.8 a	2.0	6.0	4.4
K^+	11.9 a	13.5 a	10.8 a	7.1	14.6	12.1
Na^+	52.8 a	67.1 a	68.9 a	25.0	90.0	63.0

NC: number of cladodes (unit); CL: cladode length (cm); CW: cladode width (cm); CA^1: cladode area (cm^2) (MIRANDA et al., 2011); CA^2: cladode area (cm^2) [$CA^2 = (CL/2) \times (CW/2) \times 3.1415926535897$] (SILVA, 2014); TPA^1: total photosynthetic area ($TPA^1 = CA^1 \times NC$) (cm^2); TPA^2: total photosynthetic area ($TPA^2 = CA^2 \times NC$) (cm^2); CAI^1: cladode area index ($CAI^1 = TPA^1$/soil area); CAI^2: cladode area index ($CAI^2 = TPA^2$/soil area); CT: cladode thickness (cm); CV^1: cladode volume ($CV^1 = CA^1 \times CT$) (cm^3) (ALVES, 2015); CV^2: cladode volume [$CV^2 = 4/3 \times (CL/2) \times (CW/2) \times 3.1415926535897 \times CT$] ($cm^3$) (PATERLINI, 2018); CP^1: cladode perimeter (tape measure measurement) (cm); CP^2: cladode perimeter [$CP^2 = 3.1415926535897 \times (CL/2) \times (2 - E^2/2 + 3 \times E^4/16)$] (cm) (SILVA, 2014); PH: plant height (cm); PW: plant width (cm); SV: survival (%); FW: total fresh weight of the plant (g); DW: total dry weight of the plant (g); TFMY: total fresh matter yield (t/ha); TDMY: total dry matter yield (t/ha); H_2O: total water accumulation (t/ha); DM: dry matter (%); MM: mineral matter (%); OM: organic matter (%); P: protein (%); NDF: neutral detergent fiber (%); ADF: acid detergent fiber (%); HEM: hemicellulose (%); N: nitrogen ($g.kg^{-1}$); K^+: potassium ($g.kg^{-1}$); Na^+: sodium ($mg.kg^{-1}$). Means followed by the same letter, in the line, do not differ from each other by the Scott-Knott grouping test, ($p<0.05$)

animal food, in addition to having medicinal and industrial properties (SALES, 2018).

The importance of nutritional or bromatological chemical analysis in forage cactus of the genus *Nopalea* is related to the evaluation of the nutritional quality and energy value of the plant, as well as the identification of possible antinutritional or toxic factors that may affect the performance and health of the animals. (SALES, 2018). In addition, bromatological analysis allows knowing the variation in the chemical composition of the plant at different phenological stages (young, intermediate,

and mature), which can influence the choice of appropriate management and the rational use of this forage resource (SILVA, 2019b).

Conclusions

The results demonstrate the existence of differences between the cladode orders for some morphological and nutritional characteristics, within the genotypes, as well as between the observed varieties. This information is relevant to understanding the influence of the cladode order and the genetic variability of the morphological and nutritional characteristics of the genus *Nopalea*.

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