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In what proportions do semi-arid agroecosystems and production systems modify the bromatology of the 'Gigante' cactus pear?

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ABSTRACT: Edaphoclimatic conditions of agroecosystems, genotypic characteristics of the plant and the management system can modify the nutritional quality of cactus pears (*Opuntia ficus-indica* Mill). This work evaluated the influence of agroecosystems and production systems on the bromatological composition of cactus pear cladodes. Five agroecosystems were studied: 1 - Irrigated District of Ceraíma, Guanambi-BA (14° 17' 40" S; 42° 42' 44" W); 2 – Iuiu Valley, Iuiu-BA (14° 23' 50" S; 43° 27' 07" W); 3 - Maniaçu, Caetité-BA (13° 48' 50" S; 42° 24' 32" W); 4 - Baixio, Riacho de Santana-BA (13° 32' 08" S; 43° 09' 19" W); 5 - Morrinhos, Guanambi-BA (14° 14' 02" S; 42° 37' 08" W). Cactus pear tissue samples were collected from August to September 2017. A hierarchical design was used: plant plots were arranged in three repetitions at each cactus pear production system, represented by four farms within five agroecosystems, totaling 20 properties of traditional growers. The bromatological variables most affected by the agroecosystem were organic matter and ash in the cladodes. The production systems adopted by the traditional cactus pear growers affected most of the contents of dry matter, nitrogen, crude protein, and neutral detergent fiber. Plant genotype influenced the composition of neutral detergent fiber of the cladodes to a greater extent.
Keywords: environment; forage quality; Cactaceae; cropping systems.

Agroecossistemas do semiárido e sistemas de produção modificam a bromatologia da palma forrageira 'Gigante' em quais proporções?

RESUMO: As condições edafoclimáticas dos agroecossistemas de cultivo, características genotípicas da planta e o sistema de manejo adotado podem alterar a qualidade nutricional da palma forrageira. Este trabalho avaliou a influência dos agroecossistemas e sistemas de produção na composição bromatológica dos cladódios da palma forrageira (*Opuntia ficus-indica* Mill). Foram estudados cinco agroecossistemas: 1 - Distrito Irrigado de Ceraíma, Guanambi-BA (14° 17' 40" S; 42° 42' 44" O); 2 - Vale do Iuiu, Iuiu-BA (14° 23' 50" S; 43° 27' 07" O); 3 - Maniaçu, Caetité-BA (13° 48' 50" S; 42° 24' 32" O); 4 - Baixio, Riacho de Santana-BA (13° 32' 08" S; 43° 09' 19" O); 5 - Morrinhos, Guanambi-BA (14° 14' 02" S; 42° 37' 08" O). A coleta dos tecidos da palma forrageira foi realizada de agosto a setembro de 2017. Utilizou-se o delineamento hierárquico, com as parcelas de plantas dispostas em três repetições dentro do fator sistemas de produção de palma forrageira representado por quatro propriedades, dentro de cinco agroecossistemas, totalizando 20 propriedades de produtores tradicionais. As variáveis bromatológicas mais afetadas pelo agroecossistema de cultivo correspondem aos teores de matéria orgânica e do material mineral na planta. Os sistemas de produção adotados pelos produtores tradicionais de palma forrageira afetaram mais os níveis de matéria seca, nitrogênio, proteína bruta e fibra em detergente neutro. O genótipo da planta influenciou em maior proporção a composição da fibra em detergente neutro dos cladódios.
Palavras-chave: ambiente; qualidade da forragem; Cactaceae; sistemas de produção.

1. INTRODUCTION

Cactus pear is an important food source for livestock in the Brazilian semi-arid region due to its adaptability to edaphoclimatic adversities, its potential for producing green matter, and as an energy source for animals (PIMIENTA-BARRIOS et al., 2012; AGUIAR et al., 2015; MATOS et al., 2021). The expressive amount of water contained in cactus pear cladodes, the capacity of strategic food reserves, and the resistance to high daytime temperatures contribute to the expansion of cactus pear growing areas and research (LÉDO et al., 2019; ROCHA FILHO et al., 2021).

Despite the adaptive potential to semi-arid conditions and the improvements in cultivation practices over the years, there is still room for improvement in cactus pear production systems (LOPES et al., 2019; LÉDO et al., 2021). In addition to adaptability and resilience, it is necessary to seek practical solutions to optimize cactus pear production systems and improve the composition, quality, and efficiency of its forage in animal nutrition. Therefore, extending the benefits to growers is possible, allowing better consonance with economic, social, and environmental interrelations (ANDREU-COLL et al., 2020; MATOS et al., 2020).

Given its nutritional importance for feeding herds in the Brazilian semi-arid region and the influence of the environment on the development of the plant (ROCHA et al., 2020), the objective was to evaluate the influence of agroecosystems and production systems on the bromatological composition of cactus pear cladodes (*Opuntia ficus-indica Mill*).

2. MATERIAL AND METHODS

2.1. Location and characterization of the study area

The study was conducted on 20 family farms with a long tradition of growing cactus pears. The farms were distributed in five agroecosystems in the semi-arid region of Bahia, in the micro-region of Guanambi, Bahia, Brazil. The selected traditional populations are characterized by the everyday use and management of natural resources, especially farming (PEREIRA et al., 2010). The cactus pear cultivations in these agroecosystems are based on a historical relationship between the farming families and the local edaphoclimatic characteristics. This relationship has been passed down from generation to generation through site-specific praxis, which has also been influenced by other cultivation systems brought by families from other regions and states. Moreover, training by extension, research, and teaching agencies shaped the production systems from the perspective of low-input farming.

According to Köppen's classification, the predominant climate in this region is BSwh, a hot Caatinga climate with summer rains and a well-defined dry period. To a lesser extent, to the east, the Aw typology occurs with a rainy tropical forest climate characterized by dry winters and rainy summers (SEI, 2014). Considering the classification and description of global formation types, the local vegetation is characterized by the Dry Tropical Forest (FABER-LANGENDOEN et al., 2016). It is widely represented by broad-leaved, dry, deciduous, semi-deciduous and small-leaved or sclerophyllous, as well as semi-evergreen, dense to semi-dense forest. Evergreen trees with lower rainfall are associated with more strongly seasonal conditions, tropical climates or dry winds. Canopy height decreases, and canopy cover decreases as the climate dries until forests are reduced to open forests and low-lying (5 - 15 m) woodlands (FABER-LANGENDOEN et al., 2016).

The rainy season occurs from November to April, with six months of drought (dry season) from May to October (Table 1). The months of greatest water scarcity are from June to August.

Table 1. Rainfall and average monthly and annual temperature in the municipalities where the five agroecosystems studied are located, semi-arid region of Bahia - microregion of Guanambi-BA.
Tabela 1. Precipitação e temperatura média mensal e anual nos municípios onde estão os cinco agroecossistemas estudados no semiárido baiano - microrregião de Guanambi-BA.

Municipality	------------------------------------- Precipitation (mm) --												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Guanambi	114.8	74.0	93.4	26.7	7.0	1.3	0.2	0.3	5.3	41.9	146.	155.9	667.1
Iuiu	127.0	98.0	94.0	52.0	5.0	1.0	1.0	1.0	11.0	68.0	151.	173.0	781.0
Caetité	98.4	69.0	120.7	45.8	12.5	10.1	10.4	4.9	17.6	61.9	153.	164.6	769.5
Riacho de Santana	142.0	108.0	106.0	60.0	5.0	1.0	1.0	1.0	9.0	68.0	160.	174.0	837.0
	---------------------------------- Temperature (°C) -------------------------												Averag
Guanambi	26.4	26.9	26.9	26.6	25.5	24.4	24.0	24.7	26.1	27.2	26.4	26.3	25.9
Iuiu	24.5	24.5	24.4	23.6	22.2	21.0	20.7	22.0	23.5	24.5	24.5	24.3	23.3
Caetité	22.9	23.5	22.9	22.5	21.5	19.9	19.6	20.4	22.3	23.5	23.1	22.9	22.1
Riacho de Santana	24.4	24.4	24.2	23.6	22.2	21.1	20.8	22.0	23.5	24.5	24.4	24.2	23.3

Source: 1. Average annual rainfall recorded in Ceraíma, district of Guanambi. Weather Stations of CODEVASF (1982-2007) and IF Baiano campus Guanambi, BA (2008-2019) (mm $year^{-1}$); 2. Time series of average temperature considers the period from 1988-2019 in the Irrigated Perimeter of Ceraíma; Codevasf Weather Stations from 1982-2007; automatic weather station of IF Baiano Campus Guanambi from 2008 to 2019; 3. The climate data for Iuiu and Riacho de Santana come from several Brazilian and worldwide sources to estimate meteorological information in Brazil. A total of 2,400 weather stations have a time series of monthly temperature data spanning over 25 years between 1950 and 1990 (Alvares et al., 2013); 4. They accumulated rainfall and average monthly temperature of Caetité - climate normals in Brazil (1981-2010) (DINIZ et al., 2018; INMET, 2018).

2.2. Identification of the agroecosystems

Five agroecosystems were selected in local communities traditionally recognized by the history of cactus pear production (Table 2). Within each of these agroecosystems, the production systems of four families were selected, totaling 20 traditional properties (Table 3). The most used criteria to classify production or agroforestry systems are the spatial and temporal arrangement of the components, the importance and role of the components, the production objectives or results of the system and the social and economic characteristics (NAIR, 1993). In the present study, the cultivation of cactus pear in different agroecosystems, despite local specificities, had the common objective of producing forage to complement cattle feed, mainly during periods of greater food scarcity for the animals.

The agroecosystems were stratified based on soil characteristics (Table 2), relief, vegetation, altimetry, grower types, and cactus pear production systems: 1 - Ceraíma, Guanambi-BA (14° 17' 40" S, 42° 42' 44" W and 542 m of altitude); 2 - Iuiu Valley, Iuiu-BA (14° 23' 50" S, 43° 27' 07" W and 507 m of altitude); 3. Maniaçu, Caetité-BA (13° 48' 50" S, 42° 24' 32" W, and 936 m of altitude); 4 - Baixio, Riacho de Santana-BA (13° 32' 08" S, 43° 09' 19" W, and 482 m of altitude); 5 - Morrinhos, Guanambi-BA (14° 14' 02" S, 42° 37' 08" W, and 843 m of altitude).

2.3. Bromatological assessment

At harvest time, an average of 34 random samples of cladodes were collected in the plot, with approximately 40 g each. A cup saw with a diameter of 5.8 cm and a depth of 4.0 cm adapted to a battery-operated drill was used to remove a circular and uniform portion of the cladode tissue (SILVA et al., 2013; DONATO et al., 2014). Cladode tissue sampling was carried out from August to September 2017. These samples were collected within the useful area of each of the three replicates of the 20 production systems (Table 3).

Green matter samples were prepared and dried in a forced-air oven at 60 °C for 72 h and, subsequently, taken to a Wiley mill with a 1 mm mesh sieve. At the Bromatology Laboratory of the State University of Southwest Bahia (UESB), campus Itapetinga, the following fractions were determined in the dry samples (SILVA & QUEIROZ, 2009): DM - dry matter content; OM - organic matter; N - nitrogen; CP - crude protein; NDF - neutral detergent fiber; ADF - acid detergent fiber; EE - crude fat content or ether extract and AC - ash content.

Table 2. Physical and chemical attributes of soils from 20 traditional 'Gigante' cactus pear production systems in five agroecosystems in the semi-arid region of Bahia - microregion of Guanambi-BA.
Tabela 2. Atributos físicos e químicos dos solos de 20 sistemas tradicionais de produção de palma forrageira 'Gigante' em cinco agroecossistemas do semiárido baiano - microrregião de Guanambi-BA.

Agroecosystem	CS	FS	SIL	CLA	CDW	pH_{H2O}	pH_{KCl}
	($g\ kg^{-1}$)						
Ceraíma	280	390	170	160	30	5.78	5.12
Iuiu	60	80	500	360	110	6.25	5.68
Maniaçu	530	220	30	220	40	4.38	3.83
Riacho de Santana	610	220	80	90	10	4.50	3.88
Morrinhos	330	150	180	340	80	4.84	4.11
Average	360	210	190	230	60	5.15	4.52
SD	30	20	20	20	10	0.22	0.21
Agroecosystem	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H + Al
	($mg\ dm^{-3}$)			($cmol_c\ dm^{-3}$)			
Ceraíma	54.33	175.92	28.05	3.36	1.40	0.00	2.42
Iuiu	41.35	261.33	47.00	10.66	2.18	0.00	2.20
Maniaçu	11.59	56.17	3.94	0.83	0.35	0.45	3.44
Riacho de Santana	3.04	37.83	0.00	0.78	0.13	0.40	2.33
Morrinhos	24.15	140.83	1.54	3.04	0.91	0.18	4.57
Average	26.89	134.42	16.11	3.74	0.99	0.21	2.99
SD	24.96	106.53	12.59	1.00	0.20	0.10	0.46
Agroecosystem	SB	ECEC	CEC	V	m	SINa	SOM
	($cmol_c\ dm^{-3}$)			(%)			($g\ kg^{-1}$)
Ceraíma	5.33	5.33	7.75	67.89	0.00	1.40	16.20
Iuiu	13.72	13.72	15.92	85.80	0.00	1.50	28.50
Maniaçu	1.34	1.79	4.78	27.09	28.95	0.38	14.30
Riacho de Santana	1.01	1.41	3.34	30.02	29.39	0.00	7.20
Morrinhos	4.32	4.50	8.89	48.53	4.38	0.06	20.00
Average	5.14	5.35	8.14	51.87	12.54	0.67	17.20
SD	1.09	1.08	1.01	5.55	8.49	0.49	2.80
Agroecosystem	P-Rem ($mg\ L^{-1}$)	S	B	Cu	Mn	Fe	Zn
		($mg\ dm^{-3}$)					
Ceraíma	49.96	2.63	0.47	0.71	63.17	72.46	2.52
Iuiu	39.34	8.13	0.62	1.11	101.82	42.41	3.85
Maniaçu	47.00	2.01	0.68	0.83	19.78	50.45	1.66
Riacho de Santana	50.02	0.65	0.28	0.45	13.13	43.33	0.71
Morrinhos	35.67	1.93	0.81	1.47	77.09	25.06	4.71
Average	44.40	3.07	0.57	0.91	55.00	46.74	2.69
SD	2.42	4.77	0.10	0.17	14.22	14.24	1.23

Note: Agroecosystem = cactus pear cultivation environment; collection = the soils were sampled with a hoe, collecting three simple samples in the useful area of each repetition on the fields; layer = 0 - 0.20 m; environment = agroecosystems in which cactus pear fields were studied; CS = coarse sand; FS = fine sand; SIL = silt; CLA = clay; CDW = clay dispersed in water; pH_{H2O} = pH in water (1:2.5 ratio); pH_{KCl} = pH in KCl (1:2.5 ratio); P = phosphorus; K^+ = potassium; Na^+ = sodium; P, K^+ and Na^+ - Mehlich-1 extractant; Ca^{2+} = calcium; Mg^{2+} = magnesium; Al^{3+} = aluminum; Ca^{2+}, Mg^{2+} and Al^{3+} - KCl extractant – 1mol L^{-1}; H+Al = hydrogen plus aluminum –calcium acetate extractant 0.5 mol L^{-1} – pH 7.0; SB = sum of exchangeable bases; ECEC = effective cation exchange capacity; CEC = cation exchange capacity at pH 7.0; V = base saturation index; m = aluminum saturation index; SINa = sodium saturation index; SOM = soil organic matter – SOM = organic carbon x 1.724 - Walkley-Black method; P-Rem = remaining phosphorus, P concentration in the equilibrium solution after stirring the air-dried fine earth (ADFE) for 1 hour with a 10 mmol L^{-1} $CaCl_2$ solution, containing 60 mg L^{-1} of P, in a 1/10 ratio; S = sulfur – monocalcium phosphate in acetic acid extractant; B = boron (hot water extractant); Cu = copper; Mn = manganese; Fe = iron; Zn = zinc; Cu, Mn, Fe and Zn – Mehlich-1 extractant.

2.4. Statistical analysis

A hierarchical model design was used considering the data dependence of each production system in agroecosystems (Figure 1). The bromatological characteristics are associated with the 'Gigante' cactus pear plants in an agroecosystem, representing a specific production system. The hierarchical model is used when the contents of factor B (production systems) are not the same as those of factor A (agroecosystems), i.e., each factor A level is combined with different contents of factor B.

In addition to the analysis of variance, the hierarchical model, as it deals with random effects, makes it possible to estimate the components and composition of the total variance. When determining how much of the explanation for the variation is contained in the different factors of the hierarchical contents, the last hierarchical level is treated as a sampling error, represented by the plant (RIBEIRO JÚNIOR & MELO, 2008). Thus, it is possible to quantify the proportion of the influence of agroecosystems and production systems on the bromatological composition of the cactus pear plant because the phenotypic expression is the result of genotype under the influence of environmental conditions such as soil, climate, and management.

For the statistical analysis, we used the software SAEG (System of Statistical Analysis), version 9.0, of the Federal University of Viçosa, using the ANOVA/Nested Hierarchical Models procedure (RIBEIRO JÚNIOR; MELO, 2008). In the case of variances significantly different from zero, the Tukey test (p≤0.05) was used to compare the means of the variables.

Table 3. Characterization of 'Gigante' cactus pear production systems and soil textural classes in five agroecosystems in the semi-arid region of Bahia - microregion of Guanambi-BA.
Tabela 3. Caracterização dos sistemas de produção de palma forrageira 'Gigante' e classes texturais do solo em cinco agroecossistemas do semiárido baiano - microrregião de Guanambi-BA.

P	Location	Dp	Lh	Sp. (m)	Man.	Irrig.	Textural Class	Weeding
				Ceraíma – Guanambi-BA				
1	Ceraíma	2013	2016	1.60 x 0.40	16	Y	Sandy loam	MC / CC
2	Ceraíma	2012	2016	1.10 x 0.40	70	N	Sandy loam	MC / CC
3	Ceraíma	2014	2016	0.80 x 0.50	90	N	Sandy clay loam	MC / CC
4	Ceraíma	2014	2016	1.10 x 0.50	--	N	Sandy loam	MC / CC
				Iuiu Valley – Iuiu-BA				
5	Agreste	2014	2016	1.50 x 0.40	20	N	Clayey	MC / CC
6	Agreste	2016	---	2.00 x 0.10	15	Y	Loam silty	MC
7	Poço de Paulo	2016	---	1.80 x 0.10	16	Y	Clay loam	MC
8	Agreste	2015	---	1.80 x 0.10	16	Y	Loam clay silty	MC / CC
				Maniaçu – Caetité-BA				
9	Junquinho	2016	----	1.60 x 0.50	17	N	Sandy clay loam	MC
10	Cardoso	2012	2015	1.50 x 0.90	90	N	Sandy loam	MC
11	Tabuleiro	2013	2016	1.30 x 0.90	10	N	Sandy loam	MC
12	Barauninha	2014	2016	1.50 x 0.60	18	N	Sandy clay loam	MC
				Baixio – Riacho de Santana-BA				
13	Massal	2013	2015	2.50 x 1.50	---	N	Sandy loam	MC
14	Várzea da Pedra	2015	---	1.00 x 0.90	16	N	Sandy	MC / CC
15	Massal	2015	---	1.50 x 1.10	50	N	Loamy sand	MC
16	Massal	2012	2016	1.40 x 0.80	90	N	Loamy sand	MC
				Morrinhos – Guanambi-BA				
17	Sacoto	2005	2016	2.00 x 0.80	---	N	Clay loam	MC
18	Distrito	2013	2016	1.00 x 0.60	---	N	Sandy clay loam	MC
19	Distrito	2010	2016	1.40 x 1.40	15	N	Sandy clay loam	MC
20	Distrito	2010	2016	2.80 x 0.80	48	N	Sandy clayey	MC / CC

OBS.: - Growers 1, 3 and 4 have already used insecticides without technical assistance; - Growers 5 and 7 fertilize plants with urea and bovine manure; - Grower 7 started irrigation in July 2017; - Grower 12 has already used ammonium sulfate for fertilization, in addition to bovine manure; - In Maniaçu, there was a strong incidence of parrots that feed on cactus pear in the region; - Grower 17 uses urea for fertilization every two years. - Growers 1, 3, 9 and 12 have already used mineral oil to control pests and diseases. The collection of experimental samples from the production systems was carried out between August and September 2017. Except for growers 8, 10, 13, 14 and 15, who harvested the cladodes within two years, the others did so with an interval of just one year after the last harvest.

NOTES: P = Production system of each grower; Dp = date of planting; Lh = date of last harvest. When absent, it indicates that it has yet to be harvested; Sp. = spacing; Man. = amount of bovine manure applied to cactus pear plants in the last cycle (Mg ha^{-1}); Irrig. = adoption of irrigation practices: Y – irrigation, N – no irrigation; MC = manual weed control by hoeing; CC = chemical weed control.

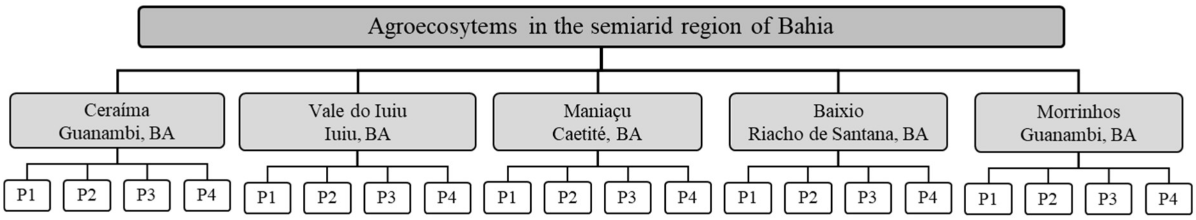

Figure 1. Scheme of the experiment in hierarchical design.
Figura 1. Esquema do experimento em delineamento hierárquico.
Source: Elaborated by the authors.

3. RESULTS

Ether extract (EE) contents in the cladodes were not affected by agroecosystems and production systems (p≤0.05) (Tables 4 and 5). The average EE content was 36.5 g kg^{-1} (CV = 15.96) (Table 5). The nutritional quality of the cactus pear results from the interrelationship between the agroecosystems (environment), the production system adopted by the grower (management), and the biological characteristics of the plants. The stratification of agroecosystems or agroforestry systems is associated with the structure, function (product), socioeconomic nature or ecological (environmental) distribution of the systems, which demonstrates the interrelationships in their components (NAIR, 1993). Thus, socioeconomic and ecological stratification reflected the organization of systems according to prevailing local conditions (socioeconomic or ecological). A production or agroforestry system reflects the specific location of a practice, characterized by the environment, plant species, cultivars and their layout, management, and socioeconomic functioning. Agricultural or agroforestry practices denote a distinct arrangement of components in space and time; practices with similar characteristics are found in various systems in different situations.

Table 4. Analysis of variance in hierarchical design of the bromatological characteristics of the cladodes of 'Gigante' cactus pear from 20 traditional production systems distributed in five agroecosystems in the semi-arid region of Bahia - microregion of Guanambi-BA
Tabela 4. Análise de variância em delineamento hierárquico das características bromatológicas dos cladódios da palma forrageira 'Gigante' de 20 sistemas tradicionais de produção distribuídos em cinco agroecossistemas do semiárido baiano – microrregião de Guanambi-BA

Variable	Sources of Variation							
	Agroecosystem (DF = 4; F_{tab} = 2.61)			Grower/Agroecosystem (DF = 15; F_{tab} = 1.92)			Plant/Grower (DF = 40)	
	Ms	%	F_{calc}	Ms	%	F_{calc}	Ms	%
DM	103.47*	19.59	25.68	48.43*	63.21	12.02	4.03	17.21
OM	326.73*	87.58	178.09	7.64*	6.37	4.16	1.83	6.04
AC	326.73*	87.58	178.09	7.64*	6.37	4.16	1.83	6.04
N	0.32*	25.95	19.45	0.11*	49.17	6.93	0.02	24.88
CP	12.59*	25.95	19.45	4.49*	49.17	6.93	0.65	24.88
NDF	44.24*	11.73	6.97	24.48*	43.03	3.85	6.35	45.24
ADF	35.44*	35.27	11.00	6.73*	17.23	2.09	3.22	47.50
EE	0.50^{ns}	1.27	1.48	0.44^{ns}	9.17	1.31	0.34	89.55

Note: Agroecosystem = cultivation environment; grower = production system and management practices adopted by the grower; plant = plant performance and genotype; DF = degrees of freedom; F_{tab} = F-table; F_{calc} = F-calculated; Ms = mean square; % = percentage of composition of the total variance that determines how much the variation explains the different hierarchical contents; Environment = study sites of pear cactus fields; Grower/Environment = cactus pear production system for each traditional producer within their respective environments; Plant/Grower = variance of the residue, which in this case refers to the effects attributed to the plants of each grower; DM = dry matter; OM = organic matter; AC = ash content; N = nitrogen; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; EE = crude fat content or ether extract; ns = not significant; * = significance level of 5%.

The average nitrogen content was 11.2 g kg^{-1} (CV = 11.46%), which was affected to a greater extent by the particularities of production systems (49.17%) over environmental and plant effects (Table 4). The cactus pear expressed the highest nitrogen content in Maniaçu (13.9 g kg^{-1}) and the lowest in Morrinhos (9.1 g kg^{-1}). The highest crude protein (CP) content was recorded in Maniaçu (87.1 g kg^{-1}) and the lowest in Morrinhos (59.3 g kg^{-1}). Iuiu was the only agroecosystem where the variation was insignificant for CP contents among growers, unlike Maniaçu, where a greater contrast was observed for this characteristic (Table 5).

Traditional cactus pear production systems have altered, to a greater extent, the contents of dry matter, nitrogen, crude protein, and neutral detergent fiber. Dry matter (DM) was affected more by the production system (63.21%), according to the composition of the total variance (Figure 2 and Table 4).

The overall average of organic matter (OM) contents was 852.40 g kg^{-1}, with a coefficient of variation (CV) of only 1.59%. The plants in Maniaçu and Riacho de Santana had the highest contents of organic matter (OM), with 894.4 and 893.0 g kg^{-1}, respectively (Table 5) ($p \leq 0.05$) followed by Morrinhos (874.4 g kg^{-1}), Ceraíma (828.0 g kg^{-1}) and, finally, Iuiu (772.4 g kg^{-1}).

Agroecosystems mainly affect the contents of organic and ash content (AC) in the plant, and the values have an inverse relation in its composition. The plants in Iuiu had the highest average ash content (AC= 227.6 g kg^{-1}) in the plant, unlike Maniaçu (105.7 g kg^{-1}) and Riacho de Santana (107.0 g kg^{-1}), which had the lowest contents (Table 5). The contents of OM and AC were influenced by the cultivation of the agroecosystem in 87.58% and showed an inverse correlation with each other (Table 4 and Figure 2).

Soil organic matter (SOM) showed a positive correlation with AC in 61% and an inverse correlation, in this same proportion, with the OM content in the cladodes (Table 6). The average contents of neutral detergent fiber (NDF) remained low, with 192.1 g kg^{-1} (Table 5). NDF is affected in 45.24% by the intrinsic characteristics of the plant and 43.03% by the production system.

Acid detergent fiber (ADF) is affected in 47.50% by plant biology and 35.27% by environmental conditions. Maniaçu, with the highest ADF value in plant tissues, is an exception among the other agroecosystems, where the production systems caused significant differences ($p \leq 0.05$) in ADF (Table 5).

4. DISCUSSION

Ether extract (EE) contents did not differ between the cactus pear fields established in the agroecosystems and within the respective production systems ($p \leq 0.05$) (Tables 4 and 5). This result is corroborated by Silva et al. (2013), who observed the absence of EE variation with different spacing and chemical fertilization. The average EE content was 36.5 g kg^{-1} (CV = 15.96) (Table 5), exceeding the average of 28.6 g kg^{-1} detected by Silva et al. (2013) and 29.8 g kg-1 by Cavalcante et al. (2014).

This is justified because, in all production systems, only the cultivar 'Gigante' was used, and the composition of the total variance shows that the variation in the EE contents is concentrated in the genotypic characteristics of the cactus pear plants (89.55%) (Figure 2). However, despite the use of a single cultivar and vegetative propagation, there are different clones of 'Gigante' cactus pear (SANTOS et al., 2020), or even somaclonal variation resulting in plants with different characteristics expressed by the phenotype, for example, cladode shape, plant height, greater presence of thorns, among others. A similar pattern occurs in breeding techniques, such as polyploidy, hybridization, sexual reproduction and apomixy, contributing to increasing genetic variability (LYRA et al., 2015).

The detection of genetic dissimilarity in genotypes of the genera *Opuntia* and *Nopalea* is performed by molecular marker technique (GARCÍA-ZAMBRANO et al., 2018). Rocha et al. (2020) detected a genetic similarity between the varieties 'Gigante' and 'Redonda,' both *Opuntia ficus-indica* Mill species considered similar under the same cultivation conditions. These genotypes are morphologically similar because the cultivar 'Redonda' originates from 'Gigante.' In estimating genetic dissimilarity, only the genotypic constitution was considered, not the phenotypic constitution, which the environment can influence (ROCHA et al., 2020). In this study, the production systems were established using cladodes/clones of the cultivar 'Gigante' from these locations. 'Gigante' is the predominant cultivar in regional cultivation, although there may be different clones or somaclonal variations within the same clone.

Table 5. Bromatological characteristics of 'Gigante' cactus pear cladodes cultivated in 20 traditional production systems in five agroecosystems in the semi-arid region of Bahia - microregion of Guanambi-BA
Tabela 5. Características bromatológicas dos cladódios da palma forrageira 'Gigante' cultivada em 20 sistemas tradicionais de produção em cinco agroecossistemas do semiárido baiano – microrregião de Guanambi-BA

Agroecosystem		DM	OM	MM	N	CP	NDF	ADF	EE
		---------- $g\ kg^{-1}$ ----------							
---------- Agroecosystem (environment) ----------									
Ceraíma		105.4 b	828.0 c	172.1 b	10.8 b	67.4 bc	185.0 b	139.0 ab	36.3
Iuiu		92.6 b	772.4 d	227.6 a	10.9 b	68.0 bc	184.7 b	116.2 c	34.0
Maniaçu		93.4 b	894.4 a	105.7 d	13.9 a	87.1 a	221.2 a	151.1 a	37.1
Riacho de Santana		161.9 a	893.0 a	107.0 d	11.1 b	69.4 b	170.3 b	108.8 c	39.5
Morrinhos		97.4 b	874.4 b	125.6 c	9.5 c	59.3 c	199.2 ab	123.6 bc	35.4
Média		110.1	852.4	147.6	11.2	70.2	192.1	127.8	36.5
DP		20.1	13.5	13.5	1.3	8.0	25.2	18.0	5.8
CV (%)		18.23	1.59	9.18	11.46	11.46	13.12	14.05	15.96
Agroecosystem	P	---------- Production systems (grower/agroecosystem) ----------							
	1	61.8 b	823.6 ab	176.4 ab	10.8	67.4 ab	208.3	155.8	36.8
Ceraíma	2	134.5 a	837.4 a	162.6 b	9.9	61.6 b	180.9	130.6	40.9
	3	84.3 b	803.5 b	196.5 a	13.2	82.3 a	179.7	136.6	30.4
	4	141.1 a	847.2 b	152.8 b	9.3	58.1 b	171.0	133.0	37.3
	5	192.8 a	762.5 b	237.5 a	10.3	64.6	231.7 a	128.6	36.0
Iuiu	6	55.0 b	764.7 b	235.3 a	9.5	59.5	178.2 ab	107.8	27.0
	7	65.7 b	762.1 b	237.9 a	12.0	75.0	159.9 b	108.5	35.3
	8	56.7 b	800.3 a	199.7 b	11.6	72.7	169.0 b	120.1	38.0
	9	105.8 ab	897.2	102.8	11.2	70.0 c	165.3 b	121.5 b	38.4
Maniaçu	10	63.3 b	878.8	121.2	12.5	78.0 bc	265.4 a	184.1 a	38.2
	11	112.6 a	907.8	92.2	14.4	89.9 b	219.8 ab	146.7 ab	33.3
	12	91.7 ab	893.6	106.4	17.7	110.7 a	234.3 a	152.2 ab	38.5
	13	130.8 b	884.6	115.4	12.5	78.4 a	158.7	97.5	41.6
Riacho de	14	166.3 ab	894.6	105.4	12.5	77.9 a	202.1	117.9	35.4
Santana	15	174.4 ab	895.5	104.5	8.3	52.0 b	164.8	112.5	38.6
	16	176.0 a	897.1	102.9	11.1	69.3 ab	155.8	107.4	42.5
	17	140.6 a	903.1 a	96.9 b	9.9	62.0 a	174.1	114.7	32.9
Morrinhos	18	109.1 ab	872.0 b	128.0 a	7.0	44.0 b	183.7	119.0	35.9
	19	69.1 b	861.0 b	139.0 a	11.1	69.5 a	221.0	141.9	40.6
	20	70.8 b	861.6 b	138.4 a	9.8	61.6 ab	217.9	118.7	32.2

Note: Agroecosystem = cactus pear cultivation environment; P = cactus pear production system for each traditional grower; DM = dry matter content in the cladodes; OM = organic matter; AC = ash content; N = nitrogen content; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; EE = crude fat content or ether extract. Except for growers 8, 10, 13, 14 and 15, who harvested two-year-old cladodes, the others did so with an interval of just one year after the last harvest. Averages followed by the same letter in the column for each agroecosystem do not differ based on the Tukey test ($p \leq 0.05$). The absence of letters in the column indicates that the variable did not present significant differences for the referred agroecosystem.

Organic N is the main form of this element in soil, originating from the decomposition of organic matter in peptides and proteins, acidic amino acids, and urea (HAWKESFORD et al., 2012). N contents were mostly affected by the particularities of production systems (49.17%), overcoming the effects of environments and plants (Table 4), even though there are no differences between the production systems identified by the Tukey test (Figure 2 and Table 5). The average N content was 11.2 g kg^{-1} (CV = 11.46%), surpassing the averages of 6.1 g kg^{-1} and 8.7 g kg^{-1} detected by Cavalcante et al. (2014) and Pessoa et al. (2013), respectively.

Among the agroecosystems, the cactus pear expressed the highest N content in Maniaçu (13.9 g kg^{-1}) and the lowest in Morrinhos (9.1 g kg^{-1}), while the other three agroecosystems did not differ from each other. Furthermore, for crude protein (CP), the highest content was recorded in Maniaçu (87.1 g kg^{-1}) and the lowest in Morrinhos (59.3 g kg^{-1}). Despite the low average soil fertility in Maniaçu (Table 2), the use of lower manure rates in Morrinhos (Table 3) may have influenced this result, as corroborated by Donato et al. (2014) and Barros et al. (2016).

In Morrinhos, only 50% of growers used manure, with an average amount of 15.75 Mg ha^{-1}, while in Maniaçu and Iuiu, 100% of growers applied an average of 33.75 Mg ha^{-1} and 16.75 Mg ha^{-1}, respectively. In Riacho de Santana, with an average of 39.00 Mg ha^{-1}, and Ceraíma, 44.00 Mg ha^{-1}, 75% of the growers used manure (Table 3). In experiments carried out in Ceraíma, the application of manure at increasing rates (0, 30, 60, and 90 Mg ha^{-1}) increased soil organic matter contents (PADILHA JÚNIOR et al., 2020), N contents (DONATO et al, 2016; LÉDO et al., 2020), and total N and CP contents of 'Gigante' cactus pear (DONATO et al., 2014; BARROS et al., 2016). This proves the beneficial effect of this practice by traditional farmers, resulting in high amounts of N and P added to the soil (LÉDO et al., 2021). This N and P interaction is synergistic in terms of absorption because both nutrients, in adequate amounts, increase yields more sharply than in isolated applications (SILVA et al., 2013), influencing photosynthesis and carbon metabolism, which are essential in N assimilation.

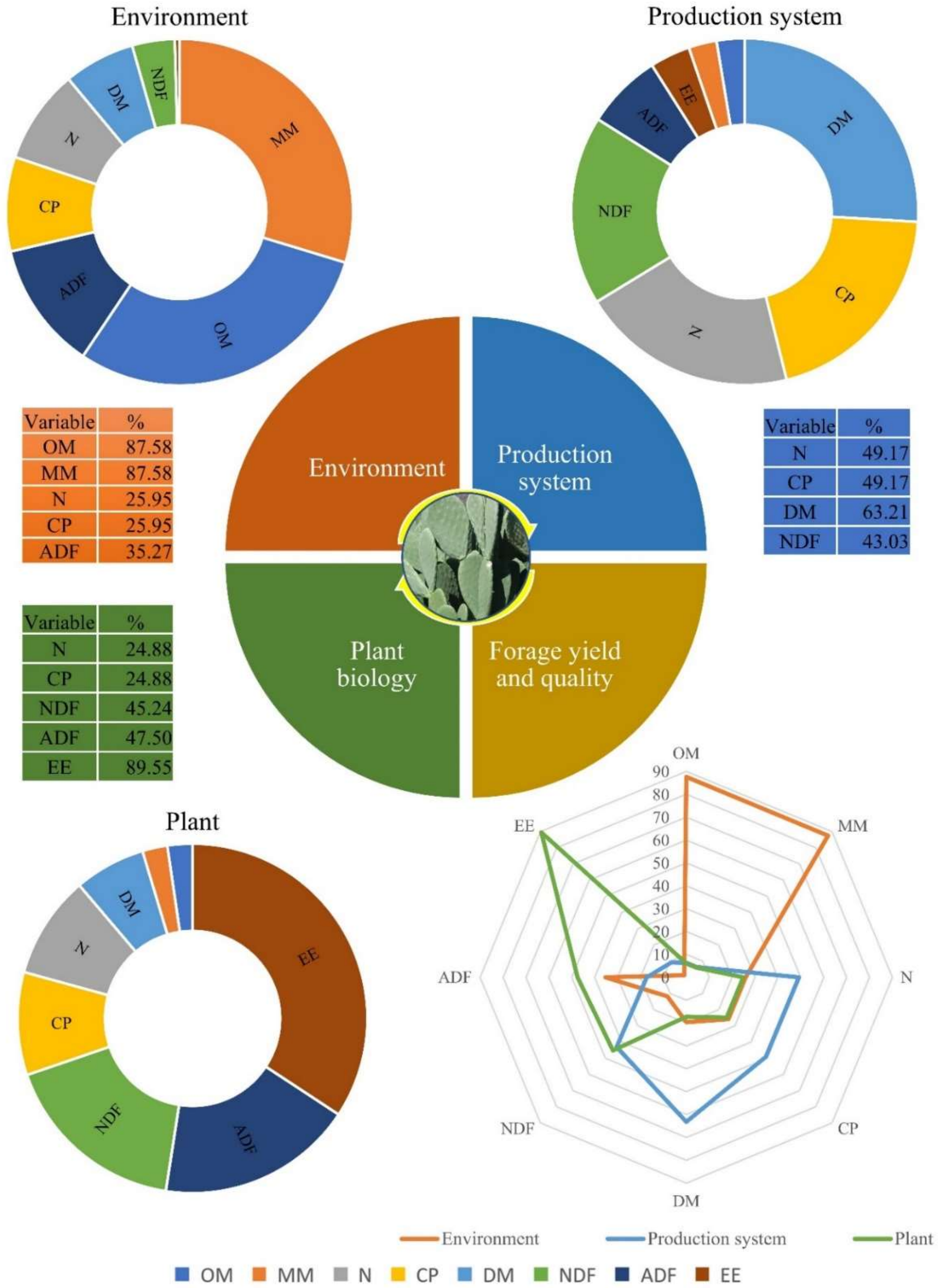

Figure 2. Composition of total variance or how much the variation in the agroecosystems, production systems and genotype of the plants explains the quality of the cladodes (bromatological composition) for forage.
Figura 2. Composição da variância total ou quanto da explicação da variação da qualidade dos cladódios (composição bromatológica) para uso como forragem está contida nos agroecossistemas, sistemas de produção e genótipo das plantas.
Source: Elaborated by the authors.
Note: DM = dry matter; OM = organic matter; AC = ash content; N = nitrogen; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; EE = crude fat content or ether extract.

Cactus pear is traditionally considered a forage with a low CP content, on average 51.0 g kg^{-1} (WANDERLEY et al., 2012; CAVALCANTE et al., 2014). However, CP contents can reach up to 120 g kg^{-1} when using fertilization and cultural treatments that promote the availability of nutrients, mainly N (SILVA et al., 2013; DONATO et al., 2014).

In experiments conducted with the adoption of a technical management system in the Ceraíma region at the campus IF Baiano in Guanambi, average CP values were higher, on average, 120.0 g kg^{-1} (SILVA et al., 2013; DONATO et al., 2014) and 102.0 g kg^{-1} (AGUIAR et al., 2015). In contrast, the general average CP content of the cactus pear fields in the present work was 70.2 g kg^{-1} (Table 5). It has been shown that the use of cattle manure as fertilizer (DONATO et al., 2014; BARROS et al., 2016) or chemical fertilization containing N-P or N-P-K favors an increase in CP contents in cactus pear (SILVA et al., 2013).

Iuiu was the only agroecosystem where the CP contents of cactus pear did not vary significantly among growers, differing from Maniaçu, where this characteristic showed greater contrast in the tissues of the plants (Table 5). The production systems adopted by the growers affected to a greater extent (49.17%) the composition of CP contents in the cladodes when compared to the specificities in the agroecosystems and intrinsic characteristics of the plants, i. e., genetic characteristics of the 'Gigante' cactus pear used by each grower (Figure 2 and Table 4).

These results indicate the relationship between the environment and the production systems in the bromatological composition of forage cactus pear. Tegegne (2001) found that, unlike fertilized cactus pear fields, CP contents of *Opuntia stricta* Haw. were so low that mineral and protein supplementation in animal feed was necessary. Generally, research on the bromatological composition of cactus pear disregards the effects of the production system, so food recommendation tables used in animal nutrition ignore the socioenvironmental variables of forage production and use.

Other authors corroborate these results when reporting that CP is a difficult factor to isolate in breeding programs, as it is influenced by soil fertility and crop management (MONDRAGÓN-JACOBO; PÉREZ-GONZÁLEZ, 2001).

Dry matter (DM) content was higher in the fields in Riacho de Santana (161.9 g kg^{-1}). The other agroecosystems were at a second level, with statistically similar contents ($p \leq 0.05$), ranging from 92.6 to 105.4 g kg^{-1} of DM (Table 5). Less turgid plants can justify this higher DM content in Riacho de Santana due to a more intense water deficit and lower nutrient input in the soil. In addition, it is possible that the largest albedo caused by the coarsest texture, with a clay content of only 90 g kg^{-1} (Table 2) and the largest spacing used between plants, for example, 2.5 x 1.5 m (Table 3), contributed to the increase in thermal and radiation stresses.

Dry matter is mostly affected by the production system adopted on the property (63.21%), according to the composition of the total variance (Figure 2 and Table 4). This result corroborates the decrease in DM contents through increasing rates of manure or chemical fertilization (DONATO et al., 2014). Increasing cattle manure rates up to 90 Mg ha^{-1} year^{-1} increases CP contents and acid detergent fiber (ADF) and decreases the DM contents in the 'Gigante' cactus pear (BARROS et al., 2016).

The Maniaçu and Riacho de Santana fields showed the highest organic matter contents (OM), with 894.4 and 893.0 g kg^{-1}, respectively (Table 5). Then, in decreasing order: ($p \leq 0.05$), Morrinhos (874.4 g kg^{-1}), Ceraíma (828.0 g kg^{-1}) and Iuiu (772.4 g kg^{-1}). The general average of OM contents was 852.40 g kg^{-1}, with a coefficient of variation (CV) of only 1.59%, which can be considered low according to the classification of Pimentel-Gomes and Garcia (2002). OM content was affected in 87.58% by the agroecosystems in which the cactus pear was grown according to the total composition of the variance and the prerogative that there was no fertilization variable (Figure 2 and Table 4).

OM values are close to the 840.7 g kg^{-1} found by Cavalcante et al. (2014) in Frei Paulo, Sergipe state, to the 868.70 g kg^{-1} (CV = 1.80%) found by Silva et al. (2013) in Guanambi, Bahia state, to the 874.30 g kg^{-1} found by Wanderley et al. (2012) in Arco Verde, Pernambuco state, and to the 880.8 g kg^{-1} found by Pessoa et al. (2013) in Recife, Pernambuco, all located in Brazil.

In contrast, the fields in Iuiu showed the highest average contents of ash content (AC= 227.6 g kg^{-1}) in the cladodes, unlike Maniaçu (105.7 g kg^{-1}) and Riacho de Santana (107.0 g kg^{-1}), which showed the lowest AC contents (Table 5). This is due to the richer mineral composition of the eutrophic soils of Iuiu (Table 2). This condition follows the same logic for the agroecosystems in which the soils are dystrophic and psamitic (Table 3), which exhibited lower AC contents, as in Riacho de Santana and Maniaçu (Table 5).

With an inverse correlation between OM and AC, both contents are influenced in 87.58% by the cultivation agroecosystem, demonstrating the importance of soil characteristics in the cultivation environment, especially the contents of macro- and micronutrients, granulometry, and others (Tables 2, 4 and 6). Soil organic matter (SOM) showed a positive correlation of 61% with AC contents and an inverse correlation at the same proportion with OM content in the cladodes (Table 6).

The contents of OM and AC between the fields of the growers in Maniaçu were similar, just like in Riacho de Santana (Table 5). Aguiar et al. (2015), Silva et al. (2013) and Wanderley et al. (2012) observed average AC contents of 151.00, 131.30, and l25.70 g kg^{-1}, respectively, which corroborate with the average of 147.60 g kg^{-1} observed in the present study (Table 5).

Despite having soils with low water and nutrient retention capacity (Table 2), Maniaçu stood out for presenting the fields with the highest average content of crude protein (CP = 87.1 g kg^{-1}) and neutral detergent fiber (NDF = 221.2 g kg^{-1}), while showing statistically similar acid detergent fiber to that of Ceraíma (ADF = 151.1 and 139.0 g kg^{-1}), respectively (Table 5).

The best bromatological attributes of the cactus pear plants cultivated in Maniaçu are in line with the effects of the most expressive doses of organic fertilizer (cattle manure) used in the production systems when compared to the other agroecosystems (Table 2) (SILVA et al., 2013; DONATO et al., 2014; BARROS et al., 2016).

Table 6. Correlations between altitude of cultivation areas (ALT), soil organic matter (SOM) content and chemical composition of 'Gigante' cactus pear from 20 traditional production systems in five agroecosystems in the semi-arid region of Bahia - microregion of Guanambi-BA
Tabela 6. Correlação entre a altitude das áreas de cultivo (ALT), teores de matéria orgânica do solo (MOS) e composição bromatológica da palma forrageira 'Gigante' de 20 sistemas de produção tradicionais em cinco agroecossistemas do semiárido baiano – microrregião de Guanambi-BA

Variable	DM	OM	AC	N	CP	NDF	ADF	EE	SOM
OM	0.315**	1							
AC	-0.315**	-1.000**	1						
N	-0.188^{ns}	0.103^{ns}	-0.103^{ns}	1					
CP	-0.188^{ns}	0.103^{ns}	-0.103^{ns}	1.000**	1				
NDF	-0.262*	0.074^{ns}	-0.074^{ns}	0.302**	0.302**	1			
ADF	-0.299*	0.072^{ns}	-0.072ns	0.368**	0.368**	0.763**	1		
EE	0.224*	0.238*	-0.238*	0.026^{ns}	0.026^{ns}	-0.016^{ns}	0.059^{ns}	1	
SOM	-0.039^{ns}	-0.613**	0.613**	-0.188^{ns}	-0.188^{ns}	0.160^{ns}	-0.020^{ns}	-0.315**	1
ALT	-0.318**	0.475**	-0.475**	0.221*	0.221*	0.457**	0.410**	-0.020^{ns}	-0.027^{ns}

Note: DM = dry matter content in the cladodes; OM = organic matter; AC = ash content; N = nitrogen content; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; EE = crude fat content or ether extract; SOM = soil organic matter - SOM = organic carbon x 1,724 - Walkley-Black; ALT = altitude of the cactus pear cultivation area. ns = not significant; significance level: ** = 1% and * = 5%.

Additionally, despite the need for specific ecophysiological studies for the region, it appears that these results also benefit from the higher altitude of Maniaçu (936 m) than the other agroecosystems (Ceraíma 542 m, Iuiu 507 m, Riacho de Santana 482 m, and Morrinhos 843 m). In these regions, the nights are cooler, which is more consistent with the altitude of the center of origin of the cactus pear. Higher altitudes favor the growth and development of the cactus pear in the semi-arid region because of the lower nighttime temperatures and the higher relative humidity (FARIAS et al., 2005). Santos et al. (2006) observed that species of the genus *Opuntia* have more adaptation restrictions to low altitude regions, and the consequent high temperatures at night and reduced thermal amplitude of the air can cause low productivity and death of plants.

This climatic condition better meets the crop´s physiological requirements for CO_2 uptake (SANTOS et al., 2013). These data corroborate the fact that the altitude of the cactus pear cultivation areas has the highest positive correlations with the levels of OM, NDF, and ADF (47, 46, and 41%, respectively. (Table 6)).

In this work, the average contents of NDF and DM remained low, with 192.1 and 110.1 g kg^{-1}, respectively (Table 5). These contents were lower than those found by other authors, with averages ranging from 283.0 to 318.7 g kg^{-1} of NDF (WANDERLEY et al., 2012; PESSOA et al., 2013; CAVALCANTE et al., 2014; AGUIAR et al., 2015). Pessoa et al. (2020) studied the content of NDF in different phenological phases of 'Gigante' cactus pear and observed 266.20 g kg^{-1} of NDF in the early phase, 331 g kg^{-1} in the intermediate phase and 417.5 g kg^{-1} of NDF in the mature phase. NDF is affected in 45.24% by the intrinsic characteristics of the plant (genotype) and in 43.03% by the production system adopted by the grower. Thus, environmental specificities have little influence (11.73%) on the composition of this important attribute for the bromatological quality of the cactus pear (Figure 2 and Table 4).

With the highest ADF value, Maniaçu is an exception among the other agroecosystems, where there were no significant differences (p≤0.05) in the contents between the site's cactus pear fields (Table 5). The higher altitudes of the Maniaçu agroecosystem, with the consequent occurrence of lower night temperatures, may favor higher ADF content in the plant, considering that it is affected in 47.50% by the plant's genotype and in 35.27% by environmental conditions. Thus, the production system adopted by the grower has little influence (17.23%) on the composition of this attribute (Figure 2 and Table 4).

The bromatological variables showed low to medium variability, according to the classification of Pimentel-Gomes and Garcia (2002). OM exhibited the lowest variation coefficient, 1.59%, and the maximum value was reached with 18.23% of DM, even considering the environmental and production system specificities (Table 5).

5. CONCLUSIONS

The particularities in production systems mostly affect nitrogen and dry matter contents.

The cactus pear cultivation environment predominantly influences organic matter and ash contents.

Environmental characteristics and cropping systems influence crude protein.

Environmental specificities have little effect on the composition of neutral detergent fiber in cactus pear.

Acid detergent fiber content is most affected by plant genotype and environmental characteristics.

The grower's technological level and the environmental conditions affect the bromatological composition of cactus pear.

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