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In situ ruminal degradability of forage cactus-based diets associated with pornunça silage

Degradabilidade ruminal *in situ* de dietas a base de palma forrageira associada à silagem de pornunça

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Highlights

Forage cactus showed higher rates of disappearance and degradation parameters.
Pornunça silage has a higher NDFi content in its composition.
The pornunça silage in its minimum portion positively affects the degradation.

Abstract

The knowledge of ruminal degradation kinetics of forage cactus-based diets associated with *Euphorbiaceae* species of the genus *Manihot* assist in understanding nutrient quality and use, contributing to the indication of combinations of these ingredients in ruminant diets. This study aimed to evaluate the in situ ruminal degradability of diets with increasing association of forage cactus Elephant Ear (MEE) and pornunça (*Manihot* sp.) silage, as well as to analyze and evaluate the indigestible neutral detergent fiber (FDNi) content of forage cactus MEE and pornunça silage. The treatments consisted of diets with cactus pear associated with pornunça silage in the roughage portion in the proportions of 375, 250, 125 and 0 g kg^{-1} of DM. The feed was composed of 50% roughage and 50% concentrate of dry matter. Incubation times of 0, 6, 12, 24, 48, 96, and 144 hours were evaluated for the ingredients and 0, 2, 4, 6, 8, 12, 24, 48, 72, and 96 hours for the diets. Incubation to obtain the iNDF was given for 288 hours. The experimental design

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consisted of randomized blocks, with three replications. Regarding roughage ingredients, MEE showed higher average disappearance, potential degradability (PD), and effective degradability (ED) in relation to pornunça silage, as well as lower NDFi content. The proportion of 375 g kg^{-1} MEE and 125 g kg^{-1} pornunça silage provided higher fractions a, b, and c, increasing ED considering the three passage rates, with higher PD. In conclusion, the association between MEE and pornunça silage at a proportion of 375 g kg^{-1} MEE and125g kg^{-1} pornunça silage of the roughage portion increases the *in situ* degradability of dry matter, crude protein, and neutral detergent fiber.
Key words: *Opuntia stricta* Haw. *Manihot* sp. *Euphorbiaceae.* Semi-arid.

Resumo

O conhecimento da cinética de degradação ruminal de dietas compostas por palma-forrageira associadas com espécies de Euphorbiaceae do gênero Manihot auxiliam na compreensão da qualidade e aproveitamento dos nutrientes, com contribuição para a indicação de combinações destes ingredientes em dietas para ruminantes. Objetivou-se avaliar a degradabilidade ruminal *in situ* de dietas com crescente associação de palma-forrageira Orelha de Elefante Mexicana (OEM) e silagem de pornunça (*Manihot* sp.), assim como, avaliar o teor de fibra em detergente neutro indigestível (FDNi) da palma OEM e da silagem de pornunça. Os tratamentos consistiram em dietas com palma forrageira associada à silagem de pornunça na porção volumosa nas proporções de 375, 250, 125 e 0 g kg^{-1} na MS. A dieta foi composta por 50% de volumoso e 50% de concentrado da matéria seca. Foram avaliados os tempos de incubação de 0, 6,12, 24, 48, 96 e 144 para os ingredientes e 0, 2, 4, 6, 8 ,12, 24, 48, 72 e 96 para as dietas. A incubação para a obtenção do FDNi foi realizada por 288 horas. O delineamento experimental utilizado foi em blocos casualizados, com três repetições. Quanto aos ingredientes volumosos, a palma OEM apresentou maior desaparecimento médio, degradabilidade potencial (DP) e degradabilidade efetiva (DE) em relação à silagem de pornunça, bem como menor teor de FDNi. A proporção de 375 g kg^{-1} OEM e 125 g kg^{-1} de silagem de pornunça propiciou maiores frações a, b e c, atuando no aumento da DE considerando as três taxas de passagem, com maior DP. Conclui-se que à associação de palma OEM e silagem de pornunça na proporção de 375 g kg^{-1} OEM e 125 g kg^{-1} da silagem de pornunça da porção volumosa aumenta a degradabilidade *in situ* da matéria seca, proteína bruta e fibra em detergente neutro.
Palavras-chave: *Opuntia stricta* Haw. *Manihot* sp. *Euphorbiaceae.* Semiárido.

Introduction

Forage cactus (*Opuntia* sp. and *Nopalea* sp.) is an important forage resource in the Brazilian semi-arid region, being the basis for feeding of herds due to its drought tolerance, water reserve, and ease of propagation (Marques et al., 2017).

The cultivar Mexican Elephant Ear cactus (*Opuntia stricta* Haw) has considerable forage production potential and resistance to cochineal scale (R. C. Silva et al., 2018), with considerable soluble carbohydrate contents. Diets based on forage cactus, due to its water, fiber, and protein contents, should be associated with other ingredients to promote

proper functioning and maintenance of ruminal microbiota and rumination (Gouveia et al., 2015) and water and feed intake (T. S. Silva et al., 2021).

Pornunça (*Manihot* sp.) is a perennial plant native to the Brazilian semi-arid region, with potential for forage production, contributing to the protein and fiber intake, as it has 161 g kg^{-1} crude protein (CP) and 269 g kg^{-1} neutral detergent fiber (NDF), respectively (G. G. P. de Carvalho et al., 2017). It should be used in the form of silage or hay, as strategies to reduce the hydrocyanic acid content, compound that depending on the amount ingested, can cause the death of animals due to its toxicity.

A study included 300 g kg^{-1} of maniçoba hay (Manihot pseudoglaziovii), a plant of the same genus as pornunça, in cactus-based feed for sheep (Gouveia et al., 2015), while other study included 330 g kg^{-1} to 385 g kg^{-1} of maniçoba hay, equivalent to 390 g kg^{-1} to 428 g kg^{-1} of the roughage portion of cactus-based diets for lactating cows (Ramos et al., 2015). The authors observed that cactus associated with maniçoba offered in both forage conservation states maintains effective dry matter intake, without negative metabolic changes in protein, energy and minerals, as well as reducing the cost of supplementation, supplying the nutritional requirements of lactating cows. However, the degrees of association of pornunça in the diet with forage cactus need to be verified through the analysis of nutrient utilization.

The degradability evaluation of ingredients and diets allows for an estimate of the ruminal degradation rate of nutrients in foods due to their quality and availability. Assessing the degradability of MEE and pornunca and their combinations in diets is important to aid in the successful formulation of ruminant diets balanced for the release of CP and carbohydrate in the rumen. This study aimed to investigate the *in situ* ruminal degradability of forage cactus MEE -based diets associated with pornunça silage at different inclusion levels in the roughage portion.

Material and Methods

This research was approved by the Ethics Committee on the Use of Animals (CEUA) of Embrapa Semi-Arid under the number 02/2020.

The test was carried out in the Animal Metabolism sector and the laboratory analyses were carried out at the Laboratory of Animal Nutrition of Embrapa Semi-Arid, located in Petrolina-PE, Brazil, at the geographic coordinates of 9°04'10'' S and 40°19'10'' and altitude of 350 m. Two adult Sindhi cattle with an average body weight of 500 kg, cannulated ruminally, fed a diet based on Mexican Elephant Ear cactus (MEE), pornunça silage and concentrate during the adaptation period and incubations. The roughage:concentrate ratio of the diet was 50:50 (% DM).

Samples of the forage cactus MEE were obtained from a cultivated area located at the Caatinga Experimental Field, belonging to Embrapa Semi-Arid, Petrolina-PE, Brazil. The cactus was harvested after 12 months of regrowth. At harvest, basal cladode was preserved in the plant. The harvested cladodes were chopped before being fed to the animals.

The pornunça intended for silage was cut at a height of 40 cm from the ground level and this forage material obtained was ground to 2 cm of granulometry (Chopper PP-35, Itapira, Brazil) and ensiled in 200 L plastic containers, at a density of 660 kg of fresh matter $m^{-3\%}$ and stored for 60 days.

Dried samples were processed in a 1 mm mesh sieve knife mill (Wiley, Marconi, MA-580, Piracicaba, Brazil). Ground samples were dried at 105º C for dry matter (DM) (method 967.03); mineral matter (MM) (method 942.05), crude protein (CP) (method 981.10), and ether extract (EE) (method 920.29) (Association on Official Analytical Chemists [AOAC], 2016); neutral detergent fiber (NDFap) with corrections for protein and ash (Licitra et al., 1996; Mertens, 2002), neutral detergent insoluble nitrogen (NDIN) and acid detergent insoluble nitrogen (ADIN) (Licitra et al., 1996), acid detergent fiber (ADF) (Van Soest et al., 1991), and lignin (method 973.18) (AOAC, 2012).

Non-fibrous carbohydrates (NFC) were calculated using NDF corrected for ashes and protein by the equation NFC = 100 – [CP + NDFap + EE + MM] (Hall, 2000). The total carbohydrates (TCHO) were calculated to by the equation TCHO = 100 – (CP + EE + MM), while fibrous carbohydrates (FC) were obtained by the difference between TCHO and NFC (Sniffen et al., 1992). Cellulose (CEL) and hemicellulose (HEM) fractions were estimated by the equations CEL = ADF – lignin, and HEM = NDF – ADF (Van Soest et al., 1991). Table 1 shows the chemical compositions of the ingredients.

The diets were formulated to meet the nutritional requirements of lambs for a daily gain of 200 g per day (National Research Council [NRC], 2007). These were calculated to be isoproteic, with a content of 70% of total digestible nutrients (TDN) and 15% of crude protein (CP) and contain the following proportions of pornunça silage and MEE in the total diet: 375 g kg^{-1} MEE and 125 g kg^{-1} pornunça silage, 250 g kg^{-1} MEE and 250 g kg^{-1} pornunça silage, 125 g kg^{-1} MEE and 375 g kg^{-1} pornunça silage, and 0 g kg^{-1} MEE and 500 g kg^{-1} pornunça silage. Due to the low content of DM, NDF and physically effective fiber, forage cactus was not added individually. The concentrate portion consisted of soybean meal, ground corn grain and wheat bran (Table 2).

Pornunca silage and chopped MEE material was dried to constant weight in a forced-air ventilation oven at 55º C, processed in a knife mill with 2 mm porosity sieves, weighed and incubated. They were placed in nylon bags with a porosity of 60 µm and dimensions of 12 x 8 cm (Mehrez & Ørskov, 1977). A total of 4 g of sample were used in each bag in quadruplicates at 0, 6, 12, 24, 48, 96 and 144 hours of incubation for pornunça and cactus silage. The diets were incubated at 0, 2, 4, 6, 8, 12, 24, 48, 72 and 96 hours. Degradability tests were performed in a randomized block design, with three repetitions for diets and ingredients (forage cactus and pornunça silage) per animal, with each repetition performed at different times. The samples were removed from the rumen after the stipulated time of incubation.

Table 1
Chemical composition of pornunça silage, Mexican Elephant Ear cactus, ground corn grain, soybean meal and wheat bran

Nutrient	Ingredients (g kg^{-1})				
	Pornunça silage	Forage cactus	Ground corn grain	Soybean meal	Wheat bran
DM	250.3	75.7	881.8	886.4	876.4
OM[1]	916.6	810.2	988.5	936.1	957.9
MM[1]	83.3	179.7	11.5	63.9	42.1
CP[1]	119.8	34.8	92.0	490.0	171.3
EE[1]	44.5	17.7	41.4	34.5	21.1
NDFap[1]	554.0	297.1	99.9	131.8	459.6
ADF[1]	396.5	107.8	29.5	86.6	132.7
Lignin[1]	132.4	8.1	27.7	15.6	38.6
NDIN[2]	17.0	6.9	335.7	53.1	178.7
ADIN[2]	9.3	4.5	38.5	24.6	37.1
NFC[1]	207.8	442.0	749.2	275.6	327.0
TCHO[1]	755.6	781.1	857.6	428.0	733.7
CEL[1]	259.8	93.5	37.0	81.8	87.3
HEM[1]	155.5	237.6	81.0	69.3	330.2

[1]Dry matter; [2]Total nitrogen. DM, dry matter; OM, organic matter; MM, mineral matter; CP, crude protein; EE, ether extract; NDFap, ash and protein-free neutral detergent fiber; ADF, acid detergent fiber; NDIN, neutral detergent insoluble nitrogen; ADIN, acid detergent insoluble nitrogen; NFC, non-fibrous carbohydrates; TCHO, total carbohydrates; CEL, cellulose; HEM, hemicellulose.

The nylon bags with the samples were placed in tulle bags tied at their end by a rope and identified according to the time to be removed. After removal, the bags were placed in cold water to stop the microbial activity, washed in running water until completely clean, and pre-dried in an oven at 55 °C for 72 hours. For the time 0 or the soluble fraction, the bags containing samples were immersed in a water bath at 39 °C for 1 hour. The bags were washed in running water, following the same procedure used for those bags placed in the animals' rumen, dried in a forced-air circulation oven at 55 °C for 72 hours, and weighed.

Calculations were performed to determine the potential degradability: PD = a + b (1 − e^{-ct}), where PD is the potential degradability, a is the soluble-water fraction, b is the insoluble-water fraction, but potentially degradable, c is the fraction b degradation rate, t is the incubation time in hours, and e is the natural log of −ct (Orskov & Mcdonald, 1979). Moreover, the effective degradability was calculated as ED = a + (b × c)/(c + k), where ED is the potential degradability and k is the passage rate. The passage rate was estimated considering 2, 5, and 8% per hour.

Table 2
Proportion of ingredients and chemical composition of diets with different levels of association of pornunça silage and Mexican Elephant Ear cactus

Ingredient/ Nutrient	Diets (g kg^{-1} DM)			
	750:250	500:500	250:750	0:1000
Centesimal composition				
Pornunça silage	125.0	250.0	375.0	500.0
Forage cactus	375.0	250.0	125.0	0.0
Ground corn grain	160.0	140.0	120.0	98.0
Soybean meal	190.0	240.0	285.0	332.0
Wheat bran	150.0	120.0	95.0	70.0
Total	1000	1000	1000	1000
Chermical composition				
DM	164.8	195.5	255.1	370.3
OM[1]	867.9	899.3	897.5	921.2
MM[1]	156.8	132.7	108.6	84.5
CP[1]	150.1	150.2	150.8	150.6
EE[1]	25.4	32.1	38.8	45.2
NDFap[1]	368.2	432.5	496.7	560.9
ADF[1]	146.7	175.5	204.0	322.2
Lignin[1]	30.5	54.5	70.0	87.9
NDIN[2]	18.3	20.8	20.0	19.9
ADIN[2]	7.0	8.6	10.8	8.0
NFC[1]	348.7	259.4	170.2	129.1
TCHO[1]	711.9	704.4	715.8	740.1
CEL[1]	113.7	110.0	133.2	317.0
HEM[1]	219.0	280.5	342.5	206.2

[1]Dry matter; [2]Total nitrogen. DM, dry matter; OM, organic matter; MM, mineral matter; CP, crude protein; EE, ether extract; NDFap, ash and protein-free neutral detergent fiber; ADF, acid detergent fiber; NDIN, neutral detergent insoluble nitrogen; ADIN, acid detergent insoluble nitrogen; NFC, non-fibrous carbohydrates; TCHO, total carbohydrates; CEL, cellulose; HEM, hemicellulose.

The indigestible neutral detergent fiber was determined for the diet ingredients (forage cactus and pornunça silage) by the *in situ* ruminal incubation carried out in triplicates in non-woven fabric bags (100 g/m^2) and removed after 288 hours of incubation. After removal, the bags were washed, dried in a forced-air ventilation oven at 55 °C for 72 hours, and weighed.

Descriptive analysis was performed to assess the degradability of ingredients (pornunça silage and MEE). Linear and quadratic regression analyses were performed after the analysis of variance to evaluate the inclusion of forage cactus and pornunça silage in the diets. Statistical Analysis System [SAS] (2002) was used. The mathematical model used for the randomized

block design was: Yijk = μ + Ti + Bj + Eijk, where Yijk is the value relative to unit k that received treatment *i* in block *j*, μ is the overall mean, Ti is the effect of treatment *i*, Bj is the effect of block *j*, Eijk is the error contribution verified in unit *j* receiving treatment i in block *j*.

Results and Discussions

The iNDF of MEE and pornunca silage was 100 and 376 g/kg DM, respectively (Table 3). The low iNDF of forage cactus (Table 3) is attributed to its high NFC content (442.0 g kg^{-1}), shown in Table 1, and lower NDF and ADF contents. On the other hand, the higher NDF, ADF, and lignin contents in the pornunça silage can explain its higher iNDF, with 376.3 g kg^{-1}, acting in the reduction of the digestible fraction of the cell wall due to the lignin concentration. The iNDF of forage cactus was close to that found in other study with 94.7 g kg^{-1} (Siqueira et al., 2017) and 118.3 g kg^{-1} DM and 133.4 g kg^{-1} DM for the MEE and Miúda genotypes (R. C. Silva et al., 2018).

Table 3
Indigestible neutral detergent fiber (iNDF) (g kg-1DM) of the Mexican Elephant Ear cactus and pornunça silage

Ingredient	Mean	Max	Min	S.E.M[1]
Forage cactus	100.9	103.4	98.5	1.130
Pornunça silage	376.3	408.5	344.0	14.630

[1]S.E.M, standard error of the mean.

Figures 1a to c show that the disappearance DM, CP and NDF in MEE was apparently faster and greater than the disappearance of the same variables in pornunca silage. The forage cactus has to the low NDF, ADF and cellulose contents with values of 297.1, 107.8 and 93.5 g kg^{-1} of DM, respectively (Table 1), possibly explaining its high disappearance rate of dry matter and neutral detergent fiber, combined with its low contents neutral detergent insoluble nitrogen (NDIN) and acid detergent insoluble nitrogen (ADIN), contributing to a greater mean disappearance of crude protein. The high degradation rate of NDF for the forage cactus may be related to the low lignin concentration, which reached 8.1 g kg^{-1} in DM (Table 2). On the other hand, pornunça silage had higher lignin (132.4 g kg^{-1}) and cellulose contents (259.8 g kg^{-1}), which are structural carbohydrates of the cell wall.

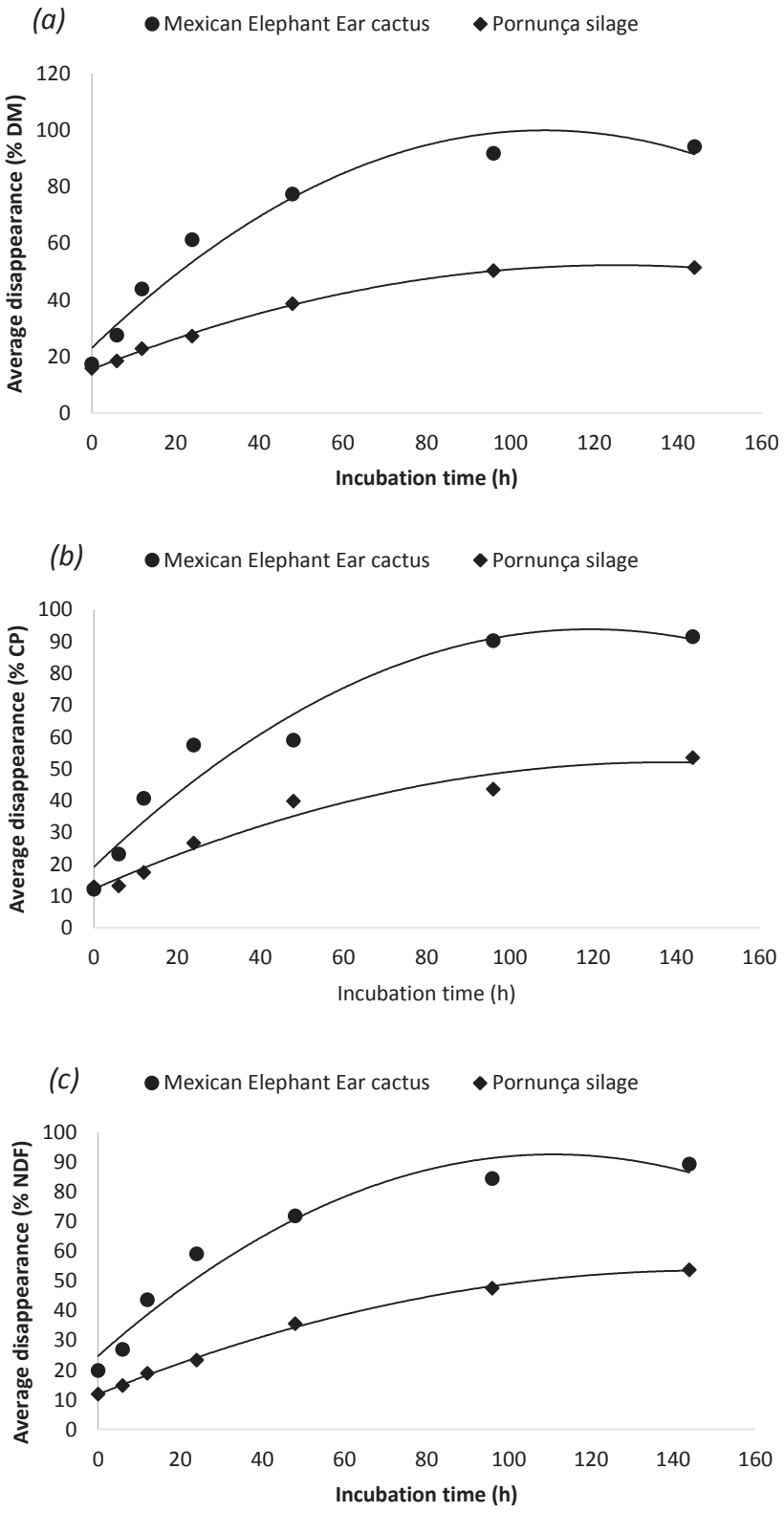

Figure 1. Average disappearance (%) of dry matter (DM) (a), crude protein (CP) (b) and neutral detergent fiber (NDF) (c) of Mexican Elephant Ear cactus and pornunça silage.

The forage cactus MEE showed a soluble fraction similar to that of pornunça silage in DM, but its b fraction and the degradation rate of fraction b were higher, resulting in a higher effective degradability (ED) when considering the three passage rates. The potential degradability (PD) of DM of the forage cactus was also higher than that of the pornunça silage, with a value of 95%, while the conserved pornunça reached 62% (Table 4). Was reported superior degradation parameters for the cultivar MEE, except for fraction b (42.32%) and PD (87.96%). Tosto et al. (2015) found a PD of DM of 87% with the addition of 31.2% of forage cactus, potentially degradable insoluble fraction (B) of 75% and degradation rate of fraction B of 0.06 h^{-1} (Magalhães et al., 2021), being higher than the values observed for MEE in the present study.

The forage cactus MEE was also superior for ruminal degradability of CP and NDF (Table 4) compared to pornunça silage. Were found reported values for the parameters of ruminal degradation of CP of prickly pear variety *Opuntia ficus-indica* of 59.12% for fraction a, 29.98% for fraction b, and 0.065%/h for fraction b degradation rate (c) (Herrera-Torres et al., 2021), which are higher than those found in the present study, except for the soluble fraction. According to the same authors, the low lignin content commonly found in forage palm allows for greater protein degradation, since there is no complexation of this nutrient in high amounts, conferring greater activity of proteolytic bacteria.

Table 4
Means of degradation parameters, effective degradability (ED) and potential degradability (PD) of dry matter (DM), crude protein (CP) and neutral detergent fiber (NDF) of Mexican Elephant Ear cactus and pornunça silage (%)

	Degradation parameters					ED (DM)		PD (%)
	a	b	c	R^2	0.08*	0.05*	0.02*	
Forage cactus	0.15	0.80	0.003	0.99	0.65	0.47	0.38	0.95
Pornunça silage	0.15	0.47	0.001	0.99	0.35	0.25	0.22	0.62
						ED (CP)		PD (%)
Forage cactus	0.15	0.79	0.003	0.96	0.58	0.41	0.33	0.94
Pornunça silage	0.11	0.45	0.002	0.97	0.32	0.23	0.19	0.55
						ED (NDF)		PD (%)
Forage cactus	0.19	0.70	0.003	0.99	0.62	0.46	0.39	0.89
Pornunça silage	0.11	0.51	0.001	0.99	0.31	0.22	0.18	0.62

a = soluble fraction, b = potentially degraded fraction, c = fraction "b" degradation rate. *Effective degradability for rate of passage of 2, 5 and 8% /h. R^2 = Determination coefficient.

The CP degradation parameters were higher in a study for maniçoba hay (Menezes et al., 2012) compared to the pornunça silage in the present study, with the same behavior observed for the ruminal degradability of NDF, except for fractions a and b and PD.

Forage cactus is rich in non-fibrous carbohydrates, being composed in one portion of starch (471.5 g kg of DM) (Magalhães et al., 2021) and pectin (268.55 g kg of DM) (Pinho et al., 2018), respectively, providing a high degradation rate in an extensive and fast way, favoring a higher passage rate and, consequently, intake similar to concentrate foods (A. L. Silva et al., 2019).

The average disappearance of DM from diets containing different pornunça silage levels (Figure 2a) showed no difference up to 4 hours of incubation, but a decreasing linear effect was observed from 6 to 96 hours of incubation. In other words, the disappearance of DM reduced as the pornunça silage increased in the roughage portion.

Diets with higher forage cactus contents present higher average disappearance due to the high NFC content, rapidly degraded in the rumen (Matias et al., 2020), besides pornunça silage having higher ADF and lignin contents than forage cactus, leading to less degradation. The ruminal degradability of food DM determines the supply of nutrients from degradation, which are vital for ruminal microorganisms and hence animals (Harun, 2019).

The average disappearance of DM, CP and NDF from diets containing different pornunça silage levels (Figure 2a, 2b and 2c) reduced as the pornunça silage increased in the roughage portion. The diet with 375 g kg^{-1} MEE and 125 g kg^{-1} pornunça silage had higher disappearance of CP. Diets with 250, 375, and 500 g kg^{-1} pornunça silage inclusion had higher NDIN and ADIN values (Table 2), representing the nitrogen fraction bound to fiber, which may have reduced protein degradation. The higher NDF and lignin contents in diets with increasing pornunça silage inclusions (Table 3) also can explain reduced the disappearance the NDF in roughage portion.

The degradation parameters linearly decreased as the proportion of pornunça silage increased in the diet (Table 5). The diet with 375 g kg^{-1} MEE and 125 g kg^{-1} pornunça silage provided higher fractions a, b, and c and higher ED and PD.

Diets with higher proportions of pornunça silage reduced DM degradability. This effect was due to the higher concentration of total carbohydrates (TCHO), which have a large participation of components related to the cell wall (e.g., cellulose and hemicellulose) of pornunça silage, promoting longer colonization time of ruminal microorganisms for their adhesion to food particles, resulting in longer degradation time (Macêdo et al., 2018). Moreover, the low iNDF content of forage cactus contributed to the higher degradation, while pornunça silage presents this indigestible component in a higher amount (Table 3).

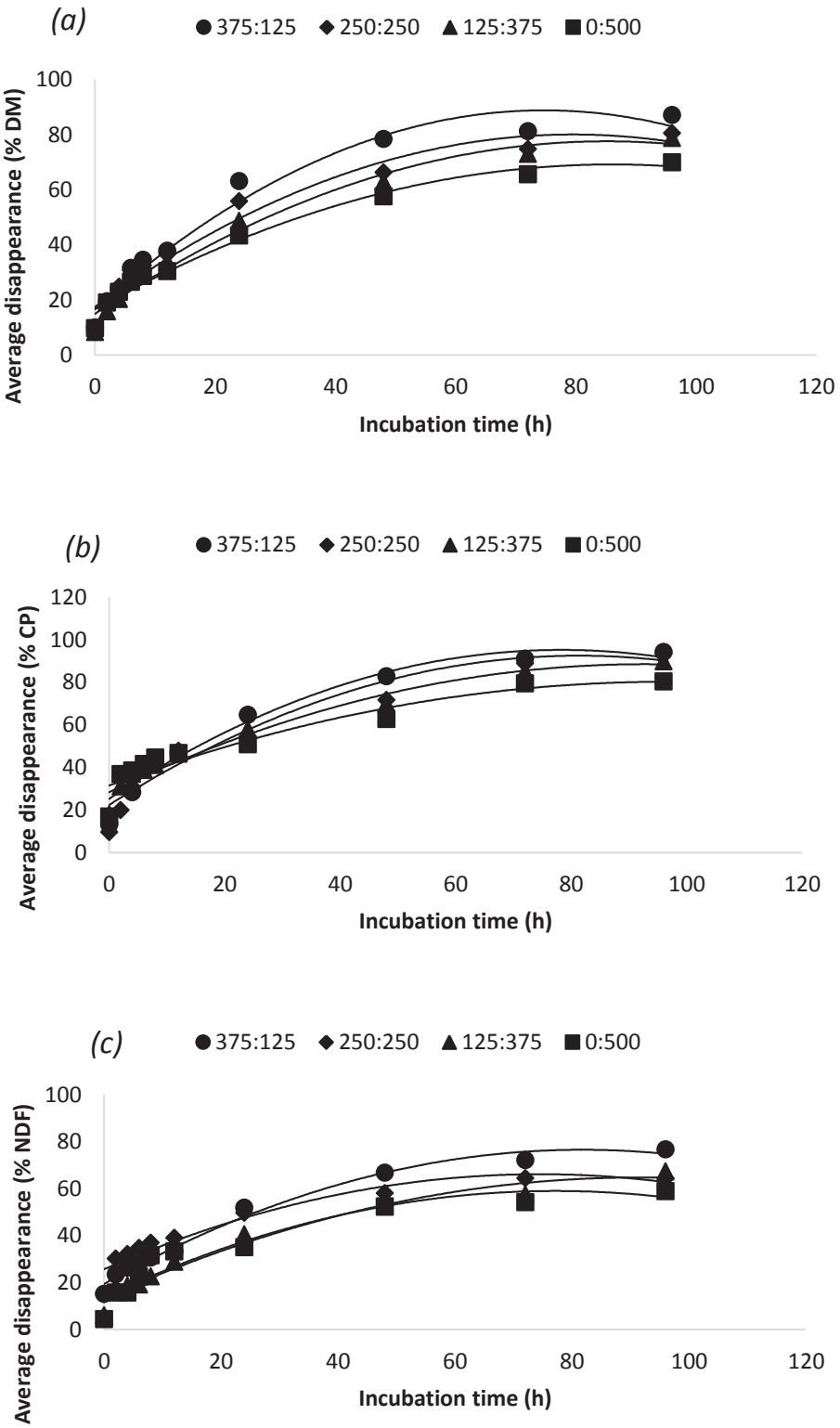

Figure 2. Average disappearance (%) of dry matter (DM) (a), crude protein (CP) (b) and neutral detergent fiber (c) from diets with different levels of forage cactus association (forage cactus:pornunça silage).

Table 5
Means of degradation parameters, effective degradability (ED) and potential degradability (PD) of dry matter (DM) of diets with different levels of Mexican Elephant Ear cactus and pornunça silage (%)

Parameters	Dry matter					P- Value	
	375:125	250:250	125:375	0:500	S.E.M	L	Q
a	0.28	0.23	0.18	0.16	0.002	<.0001[1]	<.0001
b	0.54	0.48	0.38	0.35	0.009	<.0001[2]	<.0001
c	0.02	0.02	0.02	0.02	0.001	0.2337[3]	0.3059
ED (0.08)*	0.82	0.71	0.56	0.51	0.009	<.0001[4]	<.0001
ED (0.05)*	0.80	0.69	0.55	0.49	0.009	<.0001[5]	<.0001
ED (0.02)*	0.79	0.68	0.54	0.48	0.009	<.0001[6]	<.0001
PD (%)	0.82	0.71	0.57	0.51	0.009	<.0001[7]	<.0001

a = soluble fraction, b = potentially degraded fraction, c = fraction "b" degradation rate. *Effective degradability for rate of passage of 2, 5 and 8% /h. S.E.M = standard error of mean. L = linear effect, Q = quadratic effect. Significance to P ≤0.05; Equations: [1]$\hat{Y}$ = 31.155 - 3.959X, R^2 = 0.97; [2]$\hat{Y}$ = 60.985 - 6.784X, R^2 = 0.97; [3]$\hat{Y}$= 2.93, R^2 = 0.95; [4]$\hat{Y}$ = 91.515 -10.763X, R^2 = 0.97; [5]$\hat{Y}$ = 90.135 - 10.687X, R^2 = 0.97; [6]$\hat{Y}$ = 88.835 - 10.613X, R^2 = 0.97; [7]$\hat{Y}$ = 92.465 - 10.807X, R^2 = 0.97.

These values corroborate with other research, who evaluated the DM degradability parameters of diets with different levels of forage cactus and buffelgrass, with values of 38.30% for fraction a, 47.10% for fraction b, 0.06% for the degradation rate of fraction b, and 85.40% of PD for the diet with a higher proportion of forage cactus (624.0 g kg^{-1}) (Macêdo et al., 2018); the increase in fibrous roughage led to a reduction in these parameters, as observed in the present study. Different levels of maniçoba silage, euphorbiaceous similar to pornunça, added to sugarcane-based diets, promoted an increase in DM degradation, presenting DP of 613.1 g kg^{-1} DM and ED of 465.6 g kg^{-1} (F. A. L de Carvalho et al., 2018), these values being, respectively, close to and higher than those found here. The authors justify this behavior by the increase in DM content, lower fibrous constituents and the higher NFC content observed in silage with maniçoba in relation to conserved sugarcane.

A quadratic effect was observed for fractions a and c of CP, but the diet with 375 g kg^{-1} MEE showed higher values for these and the other degradation parameters (Table 6). The ED of CP in the diet with 500 g kg^{-1} pornunça silage was lower compared to the other levels, which may be related to the lower values of the slowly degradable fraction (b). However, it presented a higher fraction a when related to the other treatments.

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The potential degradability (PD) of CP for the diet with a higher proportion of forage cactus stood out as higher, as observed in the average disappearance of CP (Figure 2b), the low NDF, ADF, and lignin contents, as well as the iNDF of the forage cactus (Table

3), since these constituents are indigestible and/or slowly degradable (Khan & Ahring, 2019). The diet with a proportion of 375 g kg^{-1} MEE and 125 g kg^{-1} pornunça silage showed higher effective degradability of CP for the three passage rates.

Table 6
Means of degradation parameters, effective degradability (ED) and potential degradability (PD) of crude protein (CP) of diets with different levels of Mexican Elephant Ear cactus and pornunça silage (%)

Parameters	Crude protein					P- Value	
	375:125	250:250	125:375	0:500	S.E.M	L	Q
a	0.15	0.12	0.11	0.13	0.001	<.0001	<.0001[1]
b	0.61	0.57	0.54	0.46	0.009	<.0001[2]	<.0001
c	0.03	0.02	0.02	0.03	0.001	0.0795	0.0309[3]
ED (0.08)*	0.75	0.68	0.63	0.58	0.009	<.0001[4]	<.0001
ED (0.05)*	0.73	0.67	0.62	0.57	0.009	<.0001[5]	<.0001
ED (0.02)*	0.72	0.66	0.60	0.57	0.009	<.0001[6]	<.0001
PD (%)	0.76	0.69	0.64	0.59	0.010	<.0001[7]	<.0001

a = soluble fraction, b = potentially degraded fraction, c = fraction "b" degradation rate. *Effective degradability for rate of passage of 2, 5 and 8% /h. S.E.M = standard error of mean. L = linear effect, Q = quadratic effect. Significance to P ≤0.05; Equations: [1]$\hat{Y} = 20.813 - 7.0005X + 1.2575X^2$, $R^2 = 0.97$; [2]$\hat{Y} = 66.17 - 4.702X$, $R^2 = 0.96$; [3]$\hat{Y} = 3.4 - 1.158X + 0.27X^2$, $R^2 = 0.99$; [4]$\hat{Y} = 79.8 - 5.51X$, $R^2 = 0.99$; [5]$\hat{Y} = 78.25 - 5.388X$, $R^2 = 0.99$; [6]$\hat{Y} = 76.61 - 5.085X$, $R^2 = 0.97$; [7]$\hat{Y} = 80.715 - 5.545X$, $R^2 = 0.99$.

An increase was observed in the fraction a of NDF in the diet with a proportion of 375 g kg^{-1} MEE and 125 g kg^{-1} pornunça silage. This behavior was also observed for the parameters of fraction b degradation rate (c) , ED at 2, 5 and 8% of passage rate, and PD, except for the potentially degraded fraction, which did not differ between treatments (Table 7). The passage rate tends to increase, according to an increase in the forage cactus inclusion in the diet, due to its high NFC and pectin contents, thus minimizing the action of microorganisms and, consequently, fiber digestion (Siqueira et al., 2017).

The results obtained in this research demonstrate that the increased inclusion of the forage cactus MEE in diets with pornunça up to 375 g kg^{-1} in the roughage portion increases the disappearance and potential and effective degradability of DM, CP, and NDF. Pornunça silage can be considered a viable source of protein, and it may have allowed considerable synchronization of nitrogen source for ruminal microorganisms, together with the energy supply provided by forage cactus.

Table 7
Means of degradation parameters, effective degradability (ED) and potential degradability (PD) of neutral detergent fiber (NDF) of diets with different levels of Mexican Elephant Ear cactus and pornunça silage (%)

Parameters	Neutral detergent fiber					P- Value	
	375:125	250:250	125:375	0:500	S.E.M	L	Q
a	0.19	0.17	0.05	0.04	0.003	<.0001[1]	<.0001
b	0.40	0.37	0.38	0.39	0.008	0.8687[2]	0.9733
c	0.01	0.02	0.02	0.02	0.001	0.0031	0.0111[3]
ED (0.08)*	0.58	0.54	0.43	0.42	0.009	<.0001[4]	<.0001
ED (0.05)*	0.57	0.52	0.42	0.41	0.009	<.0001[5]	<.0001
ED (0.02)*	0.56	0.51	0.41	0.40	0.008	<.0001[6]	<.0001
PD (%)	0.59	0.55	0.44	0.43	0.009	<.0001[7]	<.0001

a = soluble fraction, b = potentially degraded fraction, c = fraction "b" degradation rate. *Effective degradability for rate of passage of 2, 5 and 8% /h. S.E.M = standard error of mean. L = linear effect, Q = quadratic effect. Significance to P ≤0.05; Equations: [1]$\hat{Y} = 25.95 - 5.84X$, $R^2 = 0.90$; [2]$\hat{Y} = 43.707$, $R^2 = 0.78$; [3]$\hat{Y} = 0.2625 + 0.9365X - 0.1475X^2$, $R^2 = 0.99$; [4]$\hat{Y} = 64.28 - 5.989X$, $R^2 = 0.91$; [5]$\hat{Y} = 62.855 - 5.921X$, $R^2 = 0.92$; [6]$\hat{Y} = 61.555 - 5.864X$, $R^2 = 0.92$; [7]$\hat{Y} = 65.305 - 6.038X$, $R^2 = 0.91$.

Conclusion

The increasing inclusion of pornunça silage decreases the effective degradability, as well as the potential degradability with an increase in iNDF. Diets with 125 g kg^{-1} pornunça silage and 500 g kg^{-1} MEE in the roughage portion promote higher disappearance of dry matter and crude protein, neutral detergent fiber, and potential and effective degradability.

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