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The Inclusion of Pigeon Pea Hay Improves the Quality of Giant Cactus Harvested at Different Times

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Abstract: The objective of this study was to evaluate the effects of giant cactus harvest time and the inclusion of pigeon pea hay in improving the ensiling process and the nutritional composition of cactus silage. In total, 40 polyvinyl chloride-PVC mini-silos (10 × 40 cm) were used. Mini-silos were distributed in a 2 × 5 factorial scheme, referent to 2 harvest times (18 and 24 months) and 5 levels (0, 10%, 20%, 30%, and 40%) of pigeon pea hay inclusion in a randomized design. Effluent losses ($p < 0.001$) showed a negative linear effect as the inclusion of pigeon pea hay increased. Gas losses ($p < 0.001$), dry matter (DM) recovery ($p < 0.001$), and pH ($p < 0.001$) revealed the interactive effects between the pigeon pea hay inclusion and the harvest time. The DM content was higher in the giant cactus harvested at 24 months. The difference in nutritional composition promoted by the harvest time did not affect the silage quality. The gradual inclusion of pigeon pea hay improved the fermentative and bromatological characteristics of giant cactus silage. It is important to highlight that the inclusion of pigeon pea hay contributed to the increase in pH without affecting the necessary acidity for ideal conservation.

Keywords: bromatological characteristics; fermentation; mixed silage; ruminant nutrition; semiarid

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Citation: Saldanha, R.B.; de Carvalho, G.G.P.; Rodrigues, C.S.; Silva, T.V.B.S.; Pina, D.d.S.; Alba, H.D.R.; Santos, S.A.; Tosto, M.S.L.; Romão, C.d.O. The Inclusion of Pigeon Pea Hay Improves the Quality of Giant Cactus Harvested at Different Times. *Agronomy* **2024**, *14*, 1039. https://doi.org/10.3390/agronomy14051039

Academic Editor: Tao Shao

Received: 3 April 2024
Revised: 22 April 2024
Accepted: 13 May 2024
Published: 14 May 2024

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1. Introduction

The temperature of the Earth's surface is increasing at a rate of 0.15 °C–0.20 °C per decade since 1970, with predictions made through climate models of 0.25 °C in the period 2020–2050 [1]. These climate changes and anthropogenic activities are the main factors of land degradation and desertification in tropical and subtropical climate areas [2]. In addition, in the Brazilian semi-arid region, the amount of rainfall is around 800 mm/year [3].

These climatic conditions result in lower availability and the lower nutritional quality of food sources for ruminants, mainly in pasture-based production systems [4]. In this sense, it is necessary to explore the forages that adapt to those climatic conditions that ensure the production of biomass for feeding ruminants [5].

In arid and semi-arid environments, several varieties of cactus have appeared as alternative forages for livestock feeding. The nopal cactus (*Opuntia fícus-indica* (L.) Mill) cv. giant or giant cactus is tolerant to high temperatures and drought conditions as a result of phenological and physiological adaptations that increase the capacity of this plant to store and not lose water [6]. The giant cactus has a moderate propagation capacity, high production potential, high palatability [7], and low water and nutrient requirements [8].

The production of this forage can reach 379.83 t/ha every two years [9]. The chemical composition of the cladodes presents approximately 10% dry matter (DM), 4.9% DM of crude protein (CP), 31.8% DM of neutral detergent fiber (NDF), 20.3% DM of acid detergent fiber (ADF), 61.8% DM of non-fibrous carbohydrates (NFC), and 62% of total digestible nutrients (TDN) as energy nutrients available for rumen fermentation [10,11].

The nutritional profile of the giant cactus can vary according to many parameters; however, under the same management conditions, harvest age is the most important factor in obtaining a greater nutritional profile [12]. According to a review by Dubeux Jr. et al. [11], the giant cactus harvested at one year has higher CP and NFC content and lower DM and NDF content than the one harvested at 2 years.

As a consequence of its high water content, the use of this alternative forage in the ruminant diet reduces water intake [13] and decreases competition between humans and animals for water availability in arid and semi-arid environments. The high production of biomass favors the storage of this forage to be used in times of a low availability of water and food for ruminants [14]. However, the high water content in the giant cactus is a negative parameter for the silage process [11]. High-moisture forages promote unwanted fermentation processes that result in the increased production of butyric acid and promote the growth of undesirable bacteria, such as clostridia and enterobacteria species [15]. In this sense, to improve the silage process of the giant cactus, there is the possibility of using other plant species with characteristics to increase the DM content and the nutritional profile (mainly protein) of the ensiled material [16]. Adding legume hay can not only control moisture but can also increase the protein supply from the silage [16].

Pigeon pea is a legume with a production of 12 tons/ha/year in the dry season of the year and CP contents that vary from 16 to 20%, thus showing great forage potential for ruminant feeding [17]. This forage is adapted to semi-arid climates, which favors its alternative production and storage potential as hay due to its DM (88.8–91.8% DM), CP (12.2–16.7% DM) and NDF (78.6% DM) content [18]. These parameters make pigeon pea a potential alternative to improve the nutritional characteristics of ensiled materials with low nutritional profiles. This can be corroborated by Pereira et al. [19], who observed an increase of 0.095% of CP for each percentage unit of pigeon pea mixed with sugarcane for silage production.

In this context, our hypothesis is that harvesting a giant cactus at half a year of age will have the most ideal nutritional profile for ruminant feeding. Furthermore, we hypothesize that the use of pigeon pea will improve the fermentation parameters and the nutritional characteristics of giant cactus silage. For this reason, our objective was to evaluate the effects of the harvest age on the giant cactus and the inclusion of different levels of pigeon pea hay on the improvement of the silage process and the nutritional composition of giant cactus silage.

2. Materials and Methods

2.1. Location and Experimental Design

The experiment was carried out at the facilities of the "Instituto Federal de Educação, Ciência e Tecnologia Baiano", Santa Inês Campus, located at BR 420 (Santa Inês—Ubaíra), Santa Inês—BA. Laboratory analyses were performed at the Animal Nutrition Laboratory, which belonged to the Veterinary Medicine and Animal Nutrition School of the "Universidade Federal da Bahia", Salvador—BA.

The experimental design used to evaluate this study was a completely randomized design with a 2 × 5 factorial scheme, with the factors represented by the two harvest times of cladodes (18 and 24 months) and the five levels (0, 10%, 20%, 30%, and 40%) of pigeon pea hay inclusion in the silage of the giant cactus.

In total, 40 polyvinyl chloride-PVC mini-silos were used (4 replicates per treatment). The mini-silos have the dimensions of 10 cm in diameter and 40 cm in height. The lids of the mini-silos are equipped with Bunsen valves to allow the gases produced in the fermentation process to escape.

2.2. Forage Used and Silage Process

The forage cactus used in this experiment was the nopal cactus (*Opuntia fícus-indica* (L.) Mill) cv. giant or giant cactus. The cactus was harvested at the ages of 18 and 24 months. The giant cactus harvest was carried out in the early hours of the day, using all the cladodes of the plant, keeping only the primary cladode in the field. Cactus cladodes were shredded in a stationary forage machine with a cutting size of 2 cm.

The pigeon pea plant was harvested 15 cm from the ground and cut immediately on a stationary forage machine. The chopped pigeon pea (65.9% moisture) was then exposed to the sun for dehydration (3 days; 6 h/d) and hay production.

Both the fresh giant cactus and the pigeon pea hay were weighed separately, obtaining the proportion determined in each treatment. Immediately, ingredients were manually homogenized and ensiled with the necessary compaction to reach a density of 700 kg/m^3. At the bottom of each mini-silo, 1.5 kg of sand was placed and separated from the ensiled material by a polyethylene mesh to avoid contamination of the ensiled material. All silos were weighed before and after filling and closing to quantify effluent production and DM recovery. The mini-silos were closed and kept in a covered environment (avoiding exposure to light) and at room temperature (28 °C) for 60 days until the mini-silos were opened. The mini-silos were weighed before and after opening.

2.3. Fermentative Parameters

The loss of material in the form of gases formed in the fermentation process was obtained by the difference in weight before and after the ensiling process [20]. The production of liquid effluents was obtained from the weight of the liquid retained in the sand [21]. Dry matter recovery was estimated as the percentage of dry matter in the silo at the time of opening compared to the dry matter of the material before being ensiled [20].

The hydrogen potential (pH) of the samples was quantified according to the methodology of Bolsen et al. [22], using a portable digital pHmeter.

2.4. Chemical Analysis

The samples of ingredients (fresh giant cactus and pigeon pea hay) and samples of the ensiled material were collected, dried in a forced-air oven (55 °C for 72 h), and stored at −20 °C for further analysis. To determine the chemical composition of the material before being ensiled (Table 1), dried samples were ground with 1 mm and 2 mm sieves. The material was analyzed to determine the DM (method 934.01), ash (method 930.05), ether extract (EE; method 920.39), and crude protein (CP; method 981.10), following the methodologies of the Association of Official Analytical Chemists [23].

Table 1. Chemical composition of the pigeon pea and experimental treatments before ensiling.

Chemical Composition (% DM)	Pigeon Pea Hay	Pigeon Pea Hay Inclusion Level (%)				
		0	10	20	30	40
Cactus harvested at 18 months						
Dry matter (% as fed)	91.26	5.48	12.64	20.18	27.85	35.29
Ash	4.35	14.60	8.26	6.09	5.61	4.71
Crude protein	6.49	4.15	5.81	6.14	6.37	6.69
Ether extract	1.52	2.06	1.76	1.77	1.47	1.43
Neutral detergent fiber	72.04	21.00	49.57	65.99	63.73	65.83
Non-fibrous carbohydrates	16.75	58.18	34.60	20.02	22.82	21.33
Total digestible nutrients	47.56	68.82	56.69	50.01	51.11	50.06
Cactus harvested at 24 months						
Dry matter (% as fed)	91.26	6.37	14.02	22.91	34.15	37.32
Ash	4.35	13.31	8.16	6.35	4.50	4.94
Crude protein	7.33	4.00	7.01	7.50	7.22	7.52
Ether extract	1.46	0.89	1.33	1.57	1.66	2.12
Neutral detergent fiber	59.70	21.75	49.83	54.78	55.97	59.70
Non-fibrous carbohydrates	27.17	60.05	33.67	29.80	30.09	25.72
Total digestible nutrients	53.68	67.66	57.17	55.26	55.15	54.18

Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were estimated according to Mertens [24] and Licitra et al. [25]. The lignin content was estimated according to Van Soest et al. [26]. Non-digestible NDF (iNDF) was obtained using the methodology of Mertens [24]. The total carbohydrates and non-fibrous carbohydrate (NFC) content was determined as proposed by Sniffen et al. [27]. Total digestible nutrients (TDNs) were estimated using the equation proposed by Cappelle et al. [28], using the following formula: TDN = 74.49–0.5635 ADF.

2.5. Statistical Analyses

The PROC MIXED of SAS (Statistical Analysis System, version 9.4) was used. The results were subjected to analysis of variance and the comparison of means between harvesting time was performed using Tukey's test. The effects of the pigeon pea inclusion were studied using polynomials contrasts—linear and quadratic.

The 0.05 level was determined as the critical probability level, and the values between 0.05 and 0.10 were considered as trends.

3. Results

3.1. Fermentative Parameters

The effluent losses (kg/ton; $p < 0.001$) showed a negative linear effect, decreasing by 4.31 kg/ton as the inclusion of pigeon pea increased. On the other hand, gas losses (%; $p < 0.001$), DM recovery ($p < 0.001$), and pH ($p < 0.001$) showed interactive effects between the inclusion level of pigeon pea and the harvest time of the giant cactus (1.5 vs. 2 years) (Table 2).

Table 2. Fermentation parameters of the giant cactus silage from different harvest times and with increasing levels of the inclusion of pigeon pea hay.

Item	Inclusion Level of Pigeon Pea Hay, % (P)					Harvest Time (I)		SEM [1]	p-Value [2]			
									P		I	P × I Interaction
	0	10	20	30	40	18	24		L [3]	Q [4]		
Gas losses (%) [5]	0.87	0.61	0.51	0.71	0.72	0.53	0.83	0.049	0.277	0.001	<0.001	<0.001
Effluent losses (kg/ton) [6]	174.29	129.09	129.15	32.58	6.80	96.70	92.06	10.566	<0.001	0.051	0.418	0.193
Dry matter recovery (%) [7]	76.90	91.71	88.66	87.72	89.73	90.36	83.53	1.328	<0.001	<0.001	<0.001	<0.001
pH [8]	4.15	3.73	3.70	4.16	4.15	4.06	3.90	11.814	0.032	<0.001	0.006	<0.001

[1] SEM—Standard error of the mean; [2] p-values less than 0.05 were considered significant; [3] L—Linear; [4] Q—Quadratic; Regression equations: [5] $\hat{Y} = 0.8439 - 0.02384x + 0.000541x^2$, r^2; = 0.98; [6] $\hat{Y} = 180.68 - 4.3149x$, r^2; = 0.92; [7] $\hat{Y} = 79.2525 + 0.8882x - 0.01679x^2$, r^2; = 0.96; [8] $\hat{Y} = 4.0773 - 0.03336x + 0.000944x^2$, r^2; = 0.98.

Although the inclusion of pigeon pea hay promoted a quadratic and linear effect on gas losses with the giant cactus harvested at 18 ($p = 0.012$) and 24 months ($p < 0.001$), respectively, the interaction effect showed that, except for the zero-inclusion level of pigeon pea hay ($p = 0.064$), gas losses were different when the harvest ages were compared. The behavioral effect observed in the pH parameter was similar to the interaction effect observed in gas losses, except for there being no differences between the harvest ages in the inclusion of 20% pigeon pea hay ($p = 0.877$). The recovery of DM showed a quadratic effect at both harvest ages; however, no differences ($p = 0.717$) were observed between the harvest ages (1.5 vs. 2 years) with the inclusion of 10% pigeon pea hay (Table 3).

Table 3. Unfolding of the interactions of the fermentation parameters of the silages.

Item	Pigeon Pea Hay Inclusion Level (%)					p-Value [1]	
	0	10	20	30	40	L [2]	Q [3]
Gases losses (%)							
18 months	0.98	0.58	0.83	0.37	0.39	<0.001	0.012
24 months	0.76	0.64	0.69	1.05	1.04	<0.001	0.061
p-value	0.064	<0.001	0.009	<0.001	<0.001		
Dry matter recovery (%)							
18 months	72.76	91.62	94.14	99.15	94.15	<0.001	<0.001
24 months	81.04	91.81	83.19	76.30	85.32	<0.001	<0.001
p-value	<0.001	0.877	<0.001	<0.001	<0.001		
pH							
18 months	4.82	4.03	3.72	3.79	3.93	<0.001	<0.001
24 months	3.40	3.43	3.68	4.53	4.38	<0.001	0.551
p-value	<0.001	<0.001	0.717	<0.001	<0.001		

[1] *p*-values less than 0.05 were considered significant; [2] L—Linear; [3] Q—Quadratic.

3.2. Chemical Composition of Silage

The inclusion of pigeon pea hay promoted a quadratic effect for the contents of ADF ($p < 0.001$), hemicellulose ($p < 0.001$), and TDN ($p < 0.001$). The maximum ADF and hemicellulose content was observed with the inclusion of 31% pigeon pea hay. On the other hand, the minimum TDN content was observed with the inclusion of pigeon pea hay at 32.5%. The harvest age effect was observed, resulting in high ADF concentrations ($p < 0.001$) and low TDN concentrations ($p < 0.001$) when an 18-month-old giant cactus was ensiled (Table 4).

Table 4. Chemical composition of the giant cactus silage from different harvest times and with increasing levels of inclusion of pigeon pea hay.

Chemical Composition (% DM)	Inclusion Level of Pigeon Pea Hay, % (P)					Harvest Time (I)		SEM [1]	p-Value [2]			
									P		I	P × I Interaction
	0	10	20	30	40	18	24		L [3]	Q [4]		
Dry matter (% as fed) [5]	5.58	14.88	22.09	28.01	33.98	21.03	20.79	1.734	<0.001	<0.001	0.416	<0.001
Ash [6]	17.36	8.22	6.18	5.57	5.01	9.22	7.72	0.811	<0.001	<0.001	<0.001	<0.001
Crude protein [7]	4.29	6.01	6.81	6.91	6.72	6.05	6.25	0.189	<0.001	<0.001	0.003	<0.001
Ether extract [8]	1.75	1.83	2.30	3.00	2.81	1.85	2.83	0.147	<0.001	0.133	<0.001	<0.001
Neutral detergent fiber [9]	27.27	50.58	57.59	60.87	61.08	54.77	48.19	2.215	<0.001	<0.001	<0.001	0.001
Acid detergent fiber [10]	17.80	33.08	37.49	38.74	39.78	36.41	30.34	1.432	<0.001	<0.001	<0.001	0.536
Lignin [11]	5.21	12.80	14.09	15.61	14.98	12.68	12.40	0.722	<0.001	<0.001	0.354	0.030
Hemicellulose [12]	10.10	17.70	20.08	21.23	21.44	18.30	17.92	0.769	<0.001	<0.001	0.272	0.136
Cellulose [13]	12.51	21.91	24.17	22.74	25.43	23.95	18.75	1.015	<0.001	<0.001	<0.001	0.002
Non-digestible NDF [14]	7.82	31.54	37.86	41.71	43.33	34.21	30.70	2.273	<0.001	<0.001	<0.001	0.010
Total carbohydrates [15]	76.67	83.56	84.27	84.61	85.58	82.77	83.11	0.620	<0.001	<0.001	0.207	<0.001
Non-fibrous carbohydrates [16]	49.86	32.97	25.96	24.04	23.64	28.10	34.48	1.903	<0.001	<0.001	<0.001	<0.001
Total digestible nutrients [17]	65.05	55.85	53.37	52.66	51.34	54.21	57.10	0.861	<0.001	<0.001	<0.001	0.606

[1] SEM—Standard error of the mean; [2] *p*-values less than 0.05 were considered significant; [3] L—Linear; [4] Q—Quadratic; Regression equations: [5] $\hat{Y} = 5.7481 + 0.9319x - 0.00588x^2$, r^2; = 0.99; [6] $\hat{Y} = 16.6670 - 0.8025x + 0.01316x^2$, r^2; = 0.99; [7] $\hat{Y} = 4.3488 + 0.1897x - 0.00329x^2$, r^2; = 0.99; [8] $\hat{Y} = 1.6305 + 0.03588x$, r^2; = 0.99; [9] $\hat{Y} = 29.2494 + 2.1566x - 0.03451x^2$, r^2; = 0.99; [10] $\hat{Y} = 18.7304 + 1.4176x - 0.02292x^2$, r^2; = 0.99; [11] $\hat{Y} = 5.7502 + 0.6868x - 0.01158x^2$, r^2; = 0.99; [12] $\hat{Y} = 10.5912 + 0.7232x - 0.01154x^2$, r^2; = 0.99; [13] $\hat{Y} = 13.5338 + 0.7592x - 0.01229x^2$, r^2; = 0.99; [14] Non-digestible neutral detergent fiber, $\hat{Y} = 9.5209 + 2.1649x - 0.03383x^2$, r^2; = 0.99; [15] $\hat{Y} = 77.4210 + 0.5376x - 0.00873x^2$, r^2; = 0.99; [16] $\hat{Y} = 49.6284 - 1.7620x + 0.02798x^2$, r^2; = 0.99; [17] $\hat{Y} = 64.2666 - 0.8020x + 0.01234x^2$, r^2; = 0.99.

Interactions were observed between the inclusion level of pigeon pea hay and the harvest time of the giant cactus ($p < 0.01$) for several of the nutrients evaluated in the silages of this study; except for the ADF, hemicellulose, and TDN contents (Table 4).

The decomposition of the interactions showed that, regardless of the harvest time (18 and 24 months), the nutrients had quadratic effects ($p < 0.05$) in the function of the increasing levels of pigeon pea inclusion, except for the ether extract content of the giant cactus harvested at 24 months (Table 5).

Table 5. Unfolding of the interactions of the chemical composition of the silages.

Chemical Composition (% DM)	Pigeon Pea Hay Inclusion Level (%)					*p*-Value [1]	
	0	10	20	30	40	L [2]	Q [3]
Dry matter (% as fed)							
18 months	4.85	14.32	21.88	28.94	33.49	<0.001	0.005
24 months	6.32	15.44	22.29	27.07	32.80	<0.001	<0.001
p-value	0.019	0.108	0.516	0.004	0.008		
Ash							
18 months	20.59	8.63	6.24	5.67	4.96	<0.001	<0.001
24 months	14.13	7.80	6.12	5.46	5.06	<0.001	<0.001
p-value	<0.001	0.064	0.769	0.596	0.801		
Crude protein							
18 months	5.21	5.65	6.37	6.53	6.47	<0.001	<0.001
24 months	3.37	6.37	7.24	7.28	6.98	<0.001	<0.001
p-value	<0.001	<0.001	<0.001	<0.001	<0.001		
Ether extract							
18 months	1.72	1.58	1.92	2.32	1.73	<0.001	<0.001
24 months	1.79	2.09	2.69	3.68	3.90	<0.001	0.579
p-value	0.526	<0.001	<0.001	<0.001	<0.001		
Neutral detergent fiber							
18 months	28.01	54.53	61.15	64.59	65.55	<0.001	<0.001
24 months	26.52	46.64	54.02	57.15	56.61	<0.001	<0.001
p-value	0.215	<0.001	<0.001	<0.001	<0.001		
Non-Digestible NDF							
18 months	9.25	32.74	37.33	44.13	47.58	<0.001	<0.001
24 months	6.40	30.35	38.38	39.30	39.08	<0.001	<0.001
p-value	0.092	0.154	0.583	0.011	<0.001		
Lignin							
18 months	5.87	13.56	13.37	15.81	14.80	<0.001	<0.001
24 months	4.54	12.04	14.82	15.42	15.16	<0.001	<0.001
p-value	0.062	0.036	0.043	0.565	0.596		
Hemicellulose							
18 months	13.82	25.02	26.61	24.41	29.91	<0.001	0.001
24 months	11.21	18.79	21.74	21.07	20.95	<0.001	<0.001
p-value	0.023	<0.001	<0.001	0.002	<0.001		
Total carbohydrates							
18 months	72.45	83.80	85.19	85.64	86.76	<0.001	<0.001
24 months	80.89	83.31	83.36	83.58	84.39	<0.001	0.014
p-value	<0.001	0.409	0.004	0.001	<0.001		
Non-fibrous carbohydrates							
18 months	44.40	29.28	24.89	20.74	21.21	<0.001	<0.001
24 months	55.32	36.67	27.02	27.35	26.06	<0.001	<0.001
p-value	<0.001	<0.001	0.073	<0.001	0.001		

[1] *p*-values less than 0.05 were considered significant; [2] L—Linear; [3] Q—Quadratic.

The dry matter content of the silages showed quadratic behavior with respect to the inclusion of pigeon pea hay being similar between the giant cactus harvest ages and the inclusion levels of approximately 10% to 20%. The CP content was similar between the harvest ages at the inclusion level of approximately 9% pigeon pea hay. The contents of EE and NDF showed a similar behavior with polynomial effects and similar values only at the inclusion level of approximately 0% pigeon pea hay (Table 5).

4. Discussion

4.1. Fermentative Parameters

In this study, the contents of DM and NFC were higher in the giant cactus harvested at 24 months than that harvested at 18 months. In the silage fermentation process, the homofermentative bacteria produce lactic acid without the loss of DM. However, the silage microbiota is also composed of heterofermentative bacteria (*Lactobacillus parabuchneri* and

Lactobacillus buchneri) that in an acid environment (pH 3.8) promotes higher losses of dry matter with gas production at a rate of 0.52 mol CO_2/mol of lactic acid [29]. This can be corroborated by the lower pH (3.90) and lower DM recovery (7.56% lower) observed in the silage of the giant cactus harvested at 24 months. The mucilage content may be responsible for the fact that no differences have been observed in the loss of effluents in the silage of the giant cactus at different harvest times. The moisture content in young cladodes is higher than in older cladodes [30,31].

The mucilage present in the cactus is a heterogeneous polysaccharide [32] or arabinogalactan-type polysaccharide composed of proteins, carbohydrates, and minerals, produced naturally [33]. The chemical composition of the mucilage gives it the physical characteristics of hydrocolloid gum that give it the properties of flexibility, biodegradability, bioavailability, and non-toxicity [34]. The mucilage also has a high water retention capacity, which is directly related to the water content of the cladode [35]. A property of the mucilage is to expel oxygen from the silo, which results in the inhibition of fungal growth, avoiding nutrient losses and excessive fermentation [36]. Mucilage has a high binding capacity, thus increasing the density of the compacted material, and thus reducing the space to retain oxygen [37].

The inclusion of pigeon pea hay in the silage of the giant cactus linearly increased the DM content, decreasing effluent losses. If the DM content of the material to be ensiled is less than 28%, the probability of negative fermentation processes that result in higher effluent losses increases [38]. The use of hay to reduce effluent losses was also observed by Brito et al. [39], Jesus et al. [40], and Borges et al. [38].

According to Kung et al. [41], the pH close to 4.2 is considered as an indicator of the ideal fermentation, avoiding gas and effluent losses. Although in this study the pH was lower than this value, the DM recovery was not affected. According to Machado et al. [42], DM recoveries can be accepted at intervals ranging from 80 to 99%, as observed in this study.

Gas losses increased linearly as pigeon pea hay was included in giant cactus silage harvested at 24 months. At the same time, DM recovery decreased from a 7.3% inclusion of pigeon pea hay. In this case, the increase in pH could promote the growth of undesirable bacteria, such as clostridia, that, when fermenting the silage DM, produce hydrogen gas [43].

The quadratic behaviour of pH with the inclusion of pigeon pea hay in giant cactus silage harvested at 18 months correlates with the quadratic behaviour of gas losses and DM recovery. The observed minimum values of gas losses and pH were observed in the pigeon pea hay inclusion level of 29.1% and 26.3%, respectively. The maximum value for DM recovery was observed at the level of 27.8%. We can explain this result with the DM content of 27.85% of the ensiled material when 30% pigeon pea hay is included. This dry matter value is close to the optimal value of 28% DM for obtaining an ideal fermentation profile [38].

4.2. Chemical Composition of the Silage

Although the harvest time promotes differences in the DM of cactus plants [12], in this study, the harvest time did not promote changes in giant cactus silage, probably due to the silage process. A greater gas production was observed in the giant cactus harvested at 24 'months, which resulted in a greater loss of DM. Consequently, although the DM content of the giant cactus prior to silage was different, the DM content of the silage was similar between harvest times.

As well as the changes observed in the silage DM, some nutrients were modified in the silage process due to the initial chemical composition [41] of the cactus at different harvest times. This theory can be corroborated by the content of CP and EE, which are opposite in the silage and in the material prior to being ensiled. Furthermore, the NDF is lower in the giant cactus silage harvested at 24 months and similar in the original material. In this sense, it is possible to affirm that the changes were the result of fermentation, mainly of the NDF [44]. Therefore, the highest content of the NDF in the giant cactus harvested at

24 months was degraded in the silage process, promoting the production of nutrients for microbial development, which may explain the higher CP and EE in the silage of the giant cactus harvested at 24 months, which should be the result of the higher growth rate of the microbes. This idea can be corroborated by the higher gas production and lower cellulose content with this treatment.

The differences in the contents of ash, NFC, and TDN between silages follow the behavior of the chemical composition of the material prior to silage. This can be corroborated by similar effluent losses between treatments. It is important to consider that the higher effluent losses are the response to the higher metabolism of NFC [45].

The interactions showed that the DM, ash, CP, EE, NDF, iNDF, lignin, hemicellulose, CT, and NFC content of the silages are results of the chemical composition of the pigeon pea hay included in the silage of giant cactus. These results are similar to the results of Barros et al. [46], Brito et al. [39], Jesus et al. [40], and Matias et al. [47], who evaluated cactus silage with the inclusion of other plant sources with the aim of increasing the DM content and/or the nutritional composition of the silage. The pigeon pea was also studied in the improvement of sugarcane silage [19], resulting in higher levels of CP, NDF, ADF, and hemicellulose from the inclusion of this source resulting in a superior chemical composition of the silage.

These findings indicate the importance of processing the whole plant and the vegetative stage at different harvest times because these changes compromise the availability of nutrients for an adequate silage process. Furthermore, 24-month harvested cactus silages improve the development of microbial proteins, thus increasing the availability of amino acids for ruminant nutrition [48].

5. Conclusions

The difference in nutritional composition promoted by the harvest age of the giant cactus did not result in significant changes in silage quality. The gradual inclusion of pigeon pea hay until up 40% (as fed) resulted in the improvement of the fermentative and bromatological characteristics of the giant cactus silage.

Author Contributions: Conceptualization, G.G.P.d.C., D.d.S.P. and C.S.R.; Methodology, G.G.P.d.C., R.B.S. and C.S.R.; D.d.S.P.; Software, D.d.S.P.; Validation, G.G.P.d.C., D.d.S.P. and C.S.R.; Formal Analysis, T.V.B.S.S., S.A.S. and R.B.S.; Investigation, T.V.B.S.S. and R.B.S.; Resources, G.G.P.d.C. and C.S.R.; Data Curation, G.G.P.d.C., D.d.S.P., S.A.S. and M.S.L.T.; Writing—Original Draft Preparation, R.B.S. and T.V.B.S.S.; Writing—Review and Editing, G.G.P.d.C., D.d.S.P., C.S.R., M.S.L.T., C.d.O.R. and H.D.R.A.; Visualization, G.G.P.d.C., C.S.R. and H.D.R.A.; Supervision, G.G.P.d.C., C.S.R. and H.D.R.A.; Project Administration, G.G.P.d.C., D.d.S.P. and C.S.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created.

Conflicts of Interest: The authors declare no conflicts of interest.

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