Journal of the Professional Association for Cactus Development

The inclusion of cactus pear changes the fermentation process, chemical composition and aerobic stability of arboreal cotton silages

Daniel Ânderson de Souza Melo[1], Ana Clara Silva Pinheiro Leite[1], Raquel da Silva Lima[1], Jessica Maria da Conceição da Silva Rodrigues[2], Cleyton de Almeida Araújo[3], Diego de Sousa Cunha[4], Claudenilde de Jesus Pinheiro Costa[1], Moema Kelly Nogueira de Sá[1], André Luiz Rodrigues Magalhães[1], Fleming Sena Campos[5]

[1]Animal Science Department, Universidade Federal do Agreste de Pernambuco, UFAPE, Garanhuns-PE, Brazil.
[2]Animal Science Department, Universidade Federal do Sudoeste da Bahia, UESB, Itapetinga – BA, Brazil.
[3]Animal Science Department, Universidade Federal do Vale do São Francisco – UNIVASF, Petrolina, PE, Brazil.
[4]Animal Science Department, Universidade Federal do Tocantins, UFT, Araguaiana - TO, Brazil.
[5] Business post doctorate - PDI/CNPq, Animal Production Department, Empresa Brasileira de Pesquisa Agropecuária - Embrapa Semiárido, Petrolina – PE, Brazil.
*Corresponding Author: flemingcte@yahoo.com.br

Citation: de Souza-Melo, D. A., Pinheiro-Leite, A. C., da Silva-Lima, R., da Conceição-da Silva Rodrigues, J. M., de Almeida-Araújo, C., de Sousa-Cunha, D., Pinheiro-Costa, C. D., Nogueira-de Sá, M. K., Rodrigues-Magalhães, A. L., Sena-Campos, F. 2022. The inclusion of cactus pear changes the fermentation process, chemical composition and aerobic stability of arboreal cotton silages. *Journal of the. Professional Association for Cactus Development. 24*: 70-82. https://doi.org/10.56890/jpacd.v24i.435

Associate Editor: Fernando de Jesús Carballo-Méndez

Technical Editor: Tomas Rivas-Garcia

Received: 11 March 2021

Accepted: 04 April 2022

Published: 29 April 2022

Abstract. The objective was to evaluate the fermentation process, nutritional quality, and aerobic stability of mixed silages of arboreal cotton and cactus pear. This was a completely randomized design, with five levels of inclusion of cactus pear (0, 15, 30, 45, and 60%) in the arboreal cotton silage and four replications per treatment, totaling 20 experimental units. Data were submitted to analysis of variance and regression at a 5% probability level for type I error. The inclusion of cactus pear resulted in increased losses from gases (P<0.001), effluents (P<0.001), buffering capacity (P<0.001), aerobic stability (P = 0.010), and pH upward trend (P<0.001). There was a decreasing linear effect on dry matter recovery (P<0.001), pH (P<0.001), ammonia nitrogen (P <0.001), the maximum difference in the temperature of the silage in relation to the environment (P = 0.005) and maximum pH (P<0.001) of silages. The inclusion of cactus pear affected the maximum temperature (P<0.001) of silages in a quadratic way. There was a decreasing linear effect of dry matter (P<0.001), ether extract (P<0.001), Organic matter (P<0,001), crude protein (P = 0,002) and neutral detergent fiber corrected for ash and protein (P = 0.030). The use of cactus pear promoted an increasing linear effect for the levels of mineral matter (MM) (P<0.001), corresponding to an increase of 0,271%, for each 1% inclusion of cactus pear. The increase in the proportions of cactus pear in the silages promoted an increasing linear effect for mineral matter (P<0,001). The inclusion of cactus pear by up to 60% in arboreal cotton silages alters the fermentation profile with increased fermentation losses and nutritional reduction. However, it still presents characteristics of good quality silages.

Keywords: *Fermentation losses; Forage preservation; Gossypium hirsutum L.; Opuntia stricta Haw.*

Introduction

The silage making technique is able to mitigate the effect of the scarcity of pastures on animal production. Thus, silage provides the optimization of areas for forage cultivation, enabling the preservation of large amounts of forage quickly and efficiently (Grant and Adesogan, 2018).

Among the forages most used in preservation as silages are corn and sorghum (Silva *et al*., 2015; Calixto-Junior *et al*., 2017; Silva-Elias *et al*., 2017). However, in arid and semi-arid regions, the cultivation of these forages is sometimes impracticable due to the negative water balance in the region.

In this way, crassulacean acid metabolism forage plants, like the cactus pear, represent a viable alternative in the production of biomass in this scenario. It is estimated a planting area that comprises between 500 and 600 thousand hectares of cactus pear cultivation (Dubeux-Junior *et al*., 2013; Dubeux-Junior, 2016). In this sense, several studies have demonstrated the importance and viability of preserving cactus pear as silage, whether combined with other crops or in the form of a total diet (Nobre *et al.,* 2018; Borges *et al*., 2019; Pereira *et al*., 2019; Brito *et al*., 2020; Matias *et al*., 2020; Silva-Santos *et al*., 2020).

However, some factors such as the high moisture (85.0 to 90.8%) of cactus pear (Monteiro *et al*., 2014; Monteiro *et al*., 2019; Santos *et al*., 2020; Moura *et al*., 2020) is considered a limiting factor in the fermentation process, even with the presence of mucilage. In this context, the search for alternatives that favor the preservation and optimization of the nutritional input of the food to be preserved is necessary. Thus, arboreal cotton emerges as a food strategy right after the plume harvest, in which it is destined for animal feed (Beltrão *et al*., 2010) with an average production of 6,456 and 3,227 kg DM ha^{-1} (Wanjura *et al*., 2014). The use of arboreal cotton makes it possible to include the fiber and protein fraction in the mass to be ensiled, in addition to contributing to decreasing water activity inside the silo.

Thus, this study hypothesized that the inclusion of up to 60% cactus pear in arboreal cotton silages enables the nutritional increase of the silage and improves the fermentation profile. In this context, the objective was to evaluate the effect of the inclusion of cactus pear on the fermentation process, nutritional quality, and aerobic stability of arboreal cotton silage.

Material and Methods

Experimental site

The experiment was carried out at the Animal Nutrition Laboratory (LANA) and at the experimental farm of the Universidade Federal do Agreste de Pernambuco (UFAPE) in the municipality of Garanhuns, state of Pernambuco - Brazil located in the mesoregion of Agreste Meridional de Pernambuco, at 8º 53' 25'' South Latitude and 36º 29' 34'' West Longitude.

Experimental design

This was a completely randomized design, consisting of five levels of inclusion of cactus pear (0, 15, 30, 45, and 60%) in the arboreal cotton silage and four replications per treatment, totaling 20 experimental units.

For silage making, arboreal cotton [*Gossypium hirsutum* L.var. marie-galante (Hutch)], processed in a stationary forage harvester, and the cactus pear clone Orelha de Elefante Mexicana, IPA-200016 (OEM), *Opuntia stricta* Haw, which was processed in machine chopper (PP-35, Pinheiro máquinas, Itapira, Sao Paulo, Brazil) to an average particle size of approximately 2.0 cm (Figure 1A e 1B). The processed material was used for chemical analysis according to Table 1.

https://www.jpacd.org Electronic ISSN: 1938-6648

Figure 1. Arboreal cotton **(A)**; cactus pear **(B)**; experimental silo **(C)**

Arboreal cotton (leaves and stems) was harvested 24 months after planting, in its second cut, being considered a diameter of 7 mm for cutting the stem of the plants. For cactus pear, the material was cut from the first order cladodes one year after planting. After harvesting, the material was crushed, homogenized manually, and deposited in experimental silos. During this process, a 500-g aliquot was taken from the original sample with non-ensiled material.

Experimental silos were made of polyvinyl chloride (PVC) tubes, measuring 10 cm in diameter and 50 cm in length (Figure 1C). To eliminate the gases formed inside, silos were equipped with a Bunsen valve attached at their top. To drain the effluents, 1 kg of sand protected by cotton fabric was placed at the bottom of each experimental silo, avoiding the contact of the material with the sand. Silos were opened after 90 days, and 10 cm silage at the ends of the silos was discarded.

Table 1. Chemical-bromatological composition of cactus pear and tree arboreal cotton silage.

	Cactus pear	**Arboreal cotton**
Dry matter (%NM)	7.48	30.82
Mineral matter (%DM)	15.27	5.90
Organic matter (%DM)	84.72	94.09
Ether extract (%DM)	1.96	2.36
Crude protein (%DM)	7.43	16.72
Neutral detergent insoluble fiber (%DM)	28.07	44.31
Acid detergent insoluble fiber (%DM)	17.77	36.14
Total carbohydrates (%DM)	79.52	75.01
Non-fiber carbohydrates (%DM)	54.55	30.71

NM – Natural Matter; **DM** – Dry Matter

Upon silo opening, silage density was evaluated as described by Jobim *et al*. (2007). Losses by effluents, gases and the recovery of dry matter were determined according to equations described by Zanine *et al*. (2010): GL = (WSSc– WOs)/(FM x FDM) x 10000, where: GL = gas losses (% DM), WSSc = Weight of the sealed silo at the closing (kg), WOs = Weight of the opened silo (kg), FM = Forage mass (kg) and FDM = Forage DM concentration (%). The equation obtained for effluent losses was: EL = [(WEBo – WEb) – (WEBc– Tb)]/FWs × 1000, where: EL = effluent losses (kg/t FM); WEBc= Weight of empty bucket + weight of sand at the closing (kg); WEBo= Weight of empty bucket + weight of sand at the opening (kg); WEb= Weight of empty bucket (kg); FWs = Forage weight at the sealing (kg). Dry matter recovery (DMR): DMR = (FMSo x DMf)/(FMS x DMs) × 100, where: DMR= Dry matter recovery rate (%); FMSo = Forage mass at silo opening (kg); DMf = Forage dry matter concentration at silo opening (%); FMS = Forage mass at silo sealing (kg); DMs = Forage dry matter concentration at silo sealing (%).

The silage mass temperature was measured according to the methodology described by Santos (2014), pH according to Silva and Queiroz (2002), and Ammonia Nitrogen (NH_3-N) according to Bolsen *et al*. (1992). The buffering capacity (BC) was determined by the methodology established by Mizubuti *et al*. (2009).

The ensiled mass density was obtained using the equation: Dens = m/V, where: Dens = density; m = ensiled material weight expressed in kg; V = ensiled material volume expressed in kg/m^3. The volume of the silos was determined by means of the area and height of the PVC tubes, obtaining values expressed in cubic centimeters (cm^3) and grams (g) that were converted into the cubic meters and kilograms, respectively, in order to express the density in kg m^{-3}.

Bromatological composition

Samples from natural and silage material after silo opening were pre-dried in a forced-air ventilation oven at 55 °C for 72 h. To determine the content of 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), the methodology recommended by AOAC (2016) were used. The content of neutral detergent insoluble fiber (NDF) and acid detergent insoluble fiber (ADF) were determined according to Van Soest *et al*. (1991) with modifications proposed by Senger *et al*. (2008) using an autoclave with the temperature of 110 °C for 40 min. Total carbohydrates (TC) were obtained by the equation of Sniffen *et al*. (1992), non-fiber carbohydrates (NFC) according to Hall (2001): NFC = 100 - (% CP +% EE +% MM + NDF) and hemicellulose using the equation of AOAC (1995): HEM = NDF - ADF.

Aerobic stability (AE) was assessed using the methodology adapted from Kung Júnior (2000), which used plastic bottles with a capacity of 4 L representing each experimental unit; the bottles contained approximately 2 kg forage, kept in a closed room, under controlled temperature at 24 ± 1 °C. Aerobic stability followed one-hour intervals over a 96-hour period (Santos, 2014). Values of pH were determined according to Silva and Queiroz (2002), at intervals of 6 hours until 96 hours of exposure to air (Araújo *et al.,* 2020a).

The variables temperature and maximum pH determined at silo opening; time to reach maximum temperature and pH; the maximum difference between the temperature of the silage and the environment; time for the temperature and pH of the silage to show an upward trend and the time for the silage to raise the temperature by 2 °C were analyzed according to the methodology of Jobim *et al*. (2007).

Statistical Analysis

Data were analyzed using the PROC Generalized Linear Models from the Software Statistical Analysis System (SAS, 2015) subjected to analysis of variance and regression at the level of 5% probability. The significance of parameters estimated by the models and the values of the coefficients of determination were used as criteria for selecting the regression models. The following statistical model was used: $Y = \mu + Tj + eij$, where: μ = overall mean; Tj = effect of inclusion of cactus pear; eij = residual error.

Results and Discussion

The inclusion of cactus pear provided an increasing linear effect ($P<0.001$) for gas losses (GL), resulting in an increase of 59.52% in relation to the treatment of arboreal cotton alone. Effluent losses (EL) showed an increasing linear effect (P <0.001), which represents an increase in EL of 0.92 Kg t^{-1} MF, for each 1% cactus pear added to the silage. The dry matter recovery (DMR) presented a decreasing linear effect (P<0.001), promoting a reduction of 21.85% for the treatment of 60% inclusion of cactus pear in relation to silage of cotton alone. The density (DENS) of the silage had no effect (P> 0.05) with the inclusion of cactus pear (Table 2).

Gas losses reflect the fermentation process, since all fermentation processes, with the exception of homolactic bacteria fermentation, generate gas losses (Pahlow *et al*., 2003). The increase in GL may be associated with the biochemical profile of mucilage present in cactus pear. This gel contains a substance rich in xylose, arabinose, glucose, galactose, and uronic acid (Felkai-Haddache *et al*., 2016; Kalegowda *et al*., 2017), substances that are easily fermented generating gas.

Table 2. Fermentation losses of silage of arboreal cotton with inclusion levels of cactus pear.

Variables	Inclusion levels of cactus pear (%)					SEM	P-value	
	0	15	30	45	60		L	Q
GL[1]	8.82	8.83	10.20	12.63	14.07	0.53	<0.001	0.067
EL[2]	7.29	12.04	46.21	54.62	55.44	6.78	<0.001	0.205
DMR[3]	96.06	95.02	82.23	78.32	75.04	2.78	<0.001	0.679
Dens	609.37	653.30	637.12	659.15	639.16	15.67	0.206	0.147

SEM= Standard Error of the Mean; **L**= Linear; **Q** = Quadratic; Significance at 5% de probability; **GL** = gas losses (%DM); **EL** = efluent losses (Kg/t MF); **DMR** = dry matter recovery (%MS); Dens: Density (Kg m^{-3}). Equations: [1]$\hat{y}$= 8.052500 + 0.095383x, R^2= 0.92; [2]$\hat{y}$= 7.345000 + 0.925933x, R^2= 0.86; [3]$\hat{y}$= 97.086000 – 0.391633x, R^2= 0.92.

Cactus pear mucilage in several studies has been associated with water retention capacity, thus decreasing EL (Gusha *et al*., 2013; Brito *et al*., 2020; Silva-Santos *et al*., 2020); however, this effect was not observed in this study. The EL may have increased due to silage density in the present study, with densities greater than 600 kg m^3, given that the compaction process also results in losses (Amaral *et al*., 2007). The increase in gas losses is related to undesirable fermentation, through the production of gases by secondary microorganisms associated with the high-water activity in the ensiled material (Araújo *et al*., 2020b). GL and EL reduced the recovery of dry matter, due to the fermentation process generating losses of organic matter through the process of percolation and degradation of nutritional components.

The silage Buffering capacity (BC) was altered with the inclusion of cactus pear, showing an increasing linear effect (P<0.001), in maximum values of 80.64 E.mg NaOH/100 g DM, promoting a 36.58% increase in BC for 60% treatment when compared to 0% treatment (Figure 2A). The pH behavior, on the other hand, was opposite to that of BC, with a reduction (P<0.001) of 0.006 for each 1% inclusion of cactus pear (Figure 2B). There was a quadratic effect (P<0.001) for Ammonia nitrogen (NH_3-N) in silages, with a minimum production of 18.40% in the inclusion of 60% cactus pear (Figure 2C). The inclusion of cactus pear did not change the silage temperature at the silo opening (P>0.05).

https://www.jpacd.org Electronic ISSN: 1938-6648

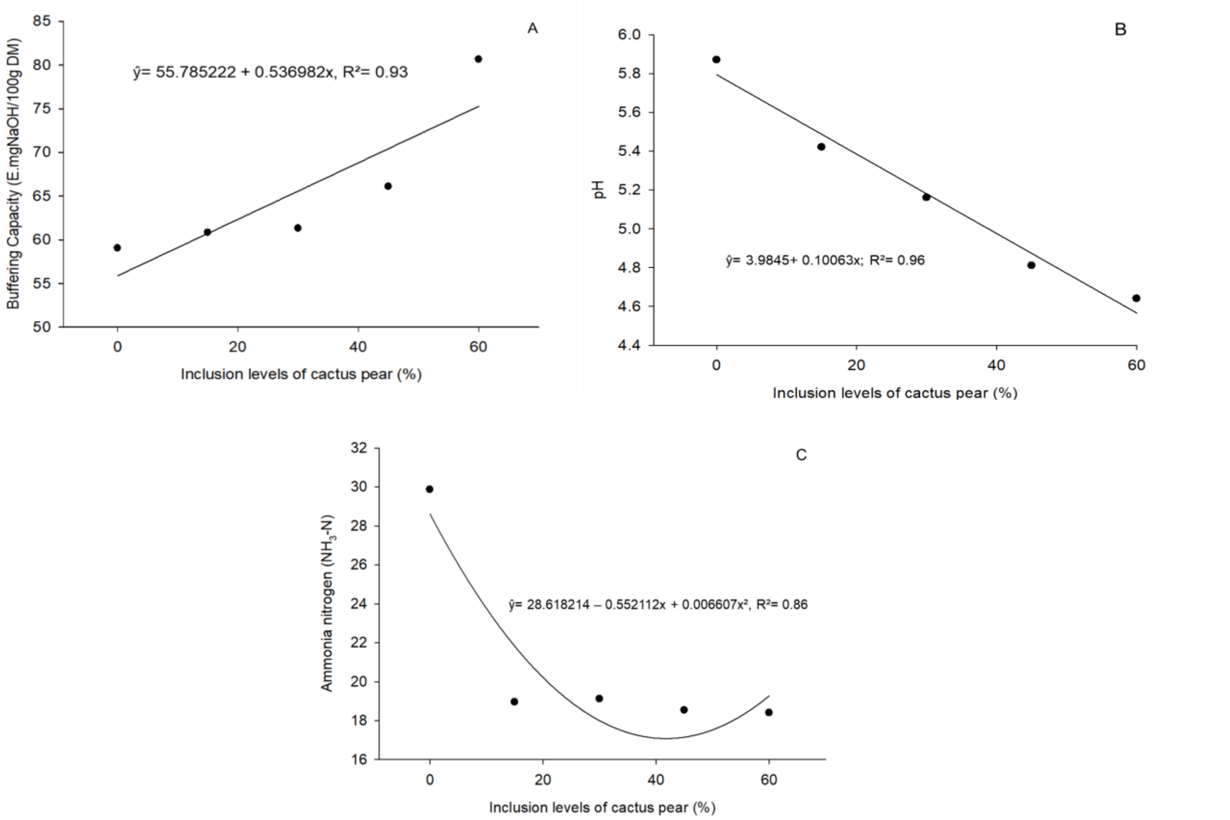

Figure 2. Buffering capacity **(A)**, hydrogen potential **(B),** and Ammonia nitrogen **(C)** in silage of arboreal cotton with inclusion levels of cactus pear. R^2 (determination coefficient).

The increasing effect of buffering capacity on silages may be related to the carbon dioxide activity in the cactus pear, due to its crassulacean acid metabolism (CAM) (Corrales-García *et al*., 2004). This effect results in mucilage with a pH of 5.54 and high content of total sugars (Manhivi *et al*., 2018). Thus, characterizes cactus pear silages with a pH of 5.3 to 7.6 and a lactic acid concentration of 5.4 to 13.69% (Mciteka, 2008). In addition to the cactus pear making it possible to increase cations, such as K^+, Ca^{2+} and Mg^{2+}, in this way these cations, when combined with organic acids, have a direct action on neutralizing the pH, increasing the buffering capacity of the silage (Pirhofer-Walzl *et al*., 2011).

Ammonia nitrogen was reduced with the inclusion of cactus pear, this effect may be related to a decline in the activity of the protein matrix inside the silo, associated with a drop in pH (Zhang *et al.,* 2020), causing a decrease in the proteolysis and deamination of nitrogen compounds by means of plant enzymes and/or bacteria of the genus *Clostridium* (Pahlow *et al*., 2003; Ali *et al*., 2020).

The use of cactus pear promoted a decreasing linear effect ($P<0.001$) for the maximum pH recorded during exposure to oxygen, with a reduced rate of 19.16 and 17.91% for inclusion levels of 30 and 60% cactus pear, respectively. The upward trend in pH values during exposure to oxygen showed a quadratic behavior ($P = 0.011$), giving an increase of 18 hours for silages with 30% cactus pear when compared to the level of 0%. The use of cactus pear decreased ($P = 0.008$) the heating of the silage during exposure to the aerobic environment, with a reduction of 0.019 °C for each 1% cactus pear inclusion. The aerobic stability (AE) showed a quadratic behavior ($P = 0.024$); as the cactus pear was added, the silage showed greater aerobic stability, with an increase of 3 hours. The use of cactus pear did not change ($P>0.05$) time to reach the maximum pH, time to reach the maximum temperature of the silage, and tendency to increase the silage temperature (Table 4).

Table 4. Aerobic stability of silage of arboreal cotton with inclusion levels of cactus pear.

Variables	Inclusion levels of cactus pear (%)					SEM	P-valor	
	0	15	30	45	60		L	Q
MT[1]	29.00	26.00	26.00	27.00	27.00	0.12	<0.001	<0.001
TRMST	80.75	72.50	76.00	71.75	73.75	3.26	0.173	0.313
MDT[2]	2.85	2.32	1.32	1.95	1.97	0.17	0.012	0.008
TITS	80.75	72.50	76.00	71.75	73.75	3.26	0.173	0.313
AE[3]	92.25	93.00	96.00	94.50	95.25	0.84	0.018	0.024
pH maximum[4]	7.20	7.39	5.82	6.28	5.91	0.25	<0.001	0.362
T maximum pH	85.50	96.00	82.50	91.50	90.00	3.81	0.710	0.910
UP pH[5]	63.00	67.50	81.00	85.50	78.00	3.04	<0.001	0.011

SEM= Standard Error of the Mean; **L**= Linear; **Q** = Quadratic; Significance at 5% de probability; **MT** = maximum temperature (°C); **TRMST** = Time to reach maximum silage temperature (h); **MDT** = Maximum difference in the temperature of the silage in relation to the environment (°C); **TITS** = Tendency to increase the temperature of the silage (h); **AE** = aerobic stability (h); **T maximum pH** = Time to reach maximum pH (h); **UP pH** = pH upward trend (h). Equations: [1]$\hat{y}$= 28.557142 – 0.134286x + 0.001905x^2, R^2= 0.66; [2]$\hat{y}$= 4.086 – 1.383x + 0.195x^2, R^2= 0.78; [3]$\hat{y}$=91.204 + 1.0671 – 0.0529x^2, R^2= 0.98; [4]$\hat{y}$= 7.262500 – 0.024617x, R^2= 0.63; [5]$\hat{y}$=60.685714 + 0.948571x – 0.0100476x^2, R^2= 0.86.

When exposing the silage to an aerobic environment, the development of harmful microorganisms involved in the spoilage of silage begins. In this way, residual carbohydrates and the fermentation product (lactic acid) are used as a substrate when the mass is exposed to oxygen (Pahlow *et al*., 2003). The increase in silage temperature is associated with the silage DM content, in which the heating capacity of silages with DM of 30 - 50% is higher when compared to contents of 15 - 30% due to the higher water activity in the material (Crawshaw and Woolford, 1979; McDonald *et al*., 1991). According to Wilkinson and Davies (2012), during the stability evaluation period, it is also possible to observe two temperature peaks, in which the first is associated with the activity of acetic acid aerobic bacteria and yeasts, and the second increase results from the development fungi. This effect was not observed in this study, considering that there was no change in the TITS of the silages.

The heating process of the silage is a reflection of the exothermic changes of the silage due to the diffusion of oxygen in the mass (Araújo *et al*., 2020a) promoting the loss of silage stability, thus the low stability is indicative of relatively high yeast counts (Wilkinson and Davies, 2012).

The main problem associated with legume silage is the high protein content and the low content of soluble carbohydrates. On the other hand, cactus pear silage, due to its high amount of sugars and low dry matter content, can result in excessive fermentation, which can result in nutrient losses and reduced aerobic stability due to excess sugars, and proliferation of yeast, resulting in alcoholic fermentation and, later, reduction of the aerobic stability of the silages. One of the ways to circumvent this problem would be to use mixed legume silage associated with cactus pear, allowing the buffering of the ensiled mass, reducing alcoholic fermentation by inhibiting yeasts (Brito et al., 2020). Silages of arboreal cotton and cactus pear showed AE results similar to those of corn silage with values between 91.68 and 112.08 hours (Severo *et al*., 2020). This improvement in stability may be associated with the presence of acetic acid and other substances with antimicrobial action (Silva *et al*., 2018).

The inclusion of cactus pear made it possible to decrease the pH during the exposure to oxygen when compared to the silage of arboreal cotton alone. This effect is associated with low activity of yeasts that metabolize lactic acid and promote an increase in pH, an effect that characterizes the increase in pH with spoilage of the silage (Zhang, Yu, and Na, 2017), reducing the time for the silage to show the maximum pH in aerobic medium.

The content of dry matter (DM), ether extract (EE), Organic matter (OM), and crude protein (CP) of the silages showed a decreasing effect ($P<0.05$) corresponding to a reduction of 1.84, 0.180, 0.271 and 0.327%, respectively, for each 1% inclusion of cactus pear. The use of cactus pear promoted an increasing linear effect for the levels of mineral matter (MM) ($P<0.001$), corresponding to an increase of 0.271%, for each 1% inclusion of cactus pear. Neutral detergent fiber corrected for ash and protein (NDFcp) ($P = 0.030$) and total carbohydrates (TC) ($P = 0.003$) showed an increasing linear effect with maximum values recorded for inclusion levels of 45 and 60% cactus pear, respectively. The use of cactus pear did not change ($P> 0.05$) the content of neutral detergent fiber (NDF), acid detergent fiber (ADF), non-fiber carbohydrates (NFC), hemicellulose (HEM), and total digestible nutrients (TDN) (Table 5).

Table 5. Chemical-bromatological composition of arboreal cotton silage with levels of addition of cactus pear.

Variables	Inclusion levels of cactus pear (%)					EPM	P-valor	
	0	15	30	45	60		L	Q
DM[1]	31.478	28.117	27.346	23.851	19.783	7.17	<0.001	0.144
MM[2]	5.925	6.076	6.120	6.306	7.169	1.84	<0.001	0.002
OM[3]	94.075	93.924	93.410	93.693	92.830	1.84	<0.001	0.002
EE[4]	2.038	1.549	1.521	1.44	0.738	1.86	<0.001	0.504
CP[5]	13.036	13.020	12.816	12.509	11.652	4.17	0.002	0.039
NDF	44.859	45.658	45.520	48.781	45.157	7.86	0.156	0.084
NDFcp[6]	37.124	37.709	37.916	37.910	37.925	6.76	0.030	0.082
ADF	41.886	33.863	36.009	35.697	34.656	19.36	0.057	0.133
TC[7]	78.080	78.130	78.160	79.743	80.144	4.45	0.003	0.401
NFC	34.140	31.941	34.555	30.962	35.282	8.86	0.648	0.057
HEM	4.241	11.795	9.511	13.083	10.500	21.63	0.062	0.095
TDN	74.695	74.152	74.245	72.029	74.493	5.34	0.156	0.084

SEM= Standard Error of the Mean; **L**= Linear; **Q** = Quadratic; Significance at 5% de probability; **DM**= dry matter (% NM); **MM**= Mineral matter (% DM); **OM**= Organic matter (% DM); **EE**= Ether extract (% DM); **CP**= Crude protein (% DM); **NDF**= Neutral detergent fiber (% DM); **NDFcp**= Neutral detergent fiber corrected for ash and protein (% DM); **ADF**= Acid detergent fiber (% DM); **TC**= Total carbohydrates (% DM); **NFC**= Non-fiber carbohydrates (% DM); **HEM**= Hemicellulose (% DM); **TDN**= Total digestible nutrients (% DM). Equations: [1]$\hat{y}$= 31.6469000 – 1.843800x, R^2= 0.96; [2]$\hat{y}$= 5.5038 + 0.2718x, R^2= 0.75; [3]$\hat{y}$= 94.401 – 0.2721x, R^2=0.76; [4]$\hat{y}$= 1.9992000 – 0.180550x, R^2= 0.84; [5]$\hat{y}$= 13.59 – 0,3279x, R^2= 0.81; [6]$\hat{y}$= 37.1692 + 0.18112x, R^2= 0.91; [7]$\hat{y}$= 77.1294 + 0.57381x, R^2= 0.81.

The content of DM and EE were reduced with the inclusion of cactus pear. This effect probably occurred because cactus pear had less content of these nutritional components, causing the decrease. The content of MM, OM, and CP showed a quadratic effect with the inclusion of cactus pear, while the NDFcp and TC showed an increasing linear effect due to the greater supply of minerals and carbohydrates from the inclusion of cactus pear, given that mixed silages have their nutritional profile altered according to the nutritional value of each forage (Brito *et al*., 2020).

Conclusion

The inclusion of cactus pear by up to 60% in arboreal cotton silages alters the fermentation profile with increased fermentation losses and nutritional reduction. Based on fermentation characteristics, chemical composition, and silage losses, all silages tested were suitable. However, considering the aerobic stability, it is recommended the addition of the forage cactus associated with tree cotton in the form of silage for animal feed with important quality and high nutritional value.

Acknowledgments

Universidade Federal do Agreste de Pernambuco (UFAPE), Garanhuns-PE, Brazil and National Council for Scientific and Technological development (CNPq), for the granting of the Corporate Post-doctorate scholarship (PDI; Process 316646/2020-2).

Ethics statement

Not applicable

Availability of supporting data

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable.

Author contributions

Conceptualization: F.S.C., A.L.R.M. and C.A.A.; **methodology**: F.S.C., C.A.A., C.J.P.C., D.A.S.M.; **resources:** J.M.C.S.R., D.S.C., M.K.N.S.; **data curation:** D.A.S.M., A.C.P.L., R.S.L.; **writing-original draft preparation**: C.A.A., F.S.C; **writing-review and editing:** A.L.R.M.; **visualization:** F.S.C., C.A.A.

References

Ali, N., Wang, S., Zhao, J., Dong, Z., Li, J., Nazar, M., and Shao, T. 2020. Microbial diversity and fermentation profile of red clover silage inoculated with reconstituted indigenous and exogenous epiphytic microbiota. Bioresource Technology, p. 123606.

Amaral, R. C. D., Bernardes, T. F., Siqueira, G. R., and Reis, R. A. 2007. Características fermentativas e químicas de silagens de capim-marandu produzidas com quatro pressões de compactação. *Revista Brasileira de Zootecnia.* 36(3): 532-539.

AOAC. 1995. Association of Official Analytical Chemists. Official Methods of Analysis of AOAC International. Official Methods of Analysis. 16.ed. Washington, D.C.: 1995. 1094p.

AOAC. 2016. Association of Official Analytical Chemists. Official Methods of Analysis of AOAC International. 20th. Latimer Jr., G.W. Washington (D.C.); p. 3100.

Araújo, C. A., santos, A. P. M., Monteiro, C. C. F., Lima, D. O., Torres, A. M., Santos, C. V. S., and Silva, J. J. 2020a. Efeito do Tempo de Ensilagem sobre a composição química, perfil

Fermentativo e Estabilidade Aeróbia de Silagens de Milho (*Zea mays*). *Diversitas Journal.* 5(1): 547-561.

Araújo, J. A. S., Almeida, J. C. C., Reis, R. A., Carvalho, C. A. B., and Barbero, R. P. 2020b. Harvest period and baking industry residue inclusion on production efficiency and chemical composition of tropical grass silage. *Journal of Cleaner Production*. 121953. https://doi.org/10.1016/j.jclepro.2020.121953.

Beltrão, N. E. M., Vale, I. S., Marques, I. F., Cardoso, G. D., and Araújo, W. 2010. Ocultivo do algodão orgânico no semi-árido brasileiro. *Revista Verde de Agroecologia e Desenvolvimento Sustentável. 5*(5): 08-13.

Bolsen, K. K., Lin, C., Brent, B. E., Feyerherm, A. M., Urban, J. E., and Aimutis, W. R. 1992. Effects of silage additives on the microbial succession and fermentation process of alfafa and corn silages. *Journal of Dairy Science. 75*: 3066-3083. https://doi.org/10.3168/jds.S0022-0302(92)78070-9.

Borges, I. D. A., Júnior, V. R. R., Monção, F. P., Soares, C., Ruas, J. R. M., Silva, F. V., and Rabelo, W. O. 2019. Nutritional and productive parameters of Holstein/Zebu cows fed diets containing cactus pear. *Asian-Australasian Journal of Animal Sciences. 32*(9): 1373. https://doi.org/10.5713/ajas.18.0584.

Brito, G. S. M. S., Santos, E. M., de araújo, G. G. L., de oliveira, J. S., de moura zanine, A., Perazzo, A. F., Campos, F. S., Lima, A. G. V., and Cavalcanti, H. S. 2020. Mixed silages of cactus pear and gliricidia: chemical composition, fermentation characteristics, microbial population and aerobic stability. *Scientific Reports. 10*(1): 1-13. https://doi.org/10.1038/s41598-020-63905-9.

Calixto-Junior, M., Jobim, C. C., Osmari, M. P., and Tres, T. T. 2017. Nutritional additives in high moisture corn silage. *Revista Brasileira de Ciências Agrárias. 12*(1): 105-111.

Corrales-García, J., Valdívia, C. B. P., Razo-Martínes, Y., and Sánchez-Hernández, M. 2004. Acidity changes and pH-buffering capacity of nopalitos (*Opuntia spp*.). *Postharvest Biology and Technology. 32*(2): 169–174. https://doi.org/10.1016/j.postharvbio.2003.11.008.

Crawshaw, R. and Woolford, M. K. 1979. Aerobic deterioration of silage in and out of the silo. *ADAS Quarterly Review.* 34: 151–178.

Dubeux-Junior, J. C. B. 2016. Cactus: a crop for the dry áreas. *University of Florida*. 28.

Dubeux-Júnior, J. C. B., Araújo-Filho, J. T., Santos, M. V. F., Lira, M. A., Santos, D. C., and Pessoa, R. A. S. 2013. Potential of cactus pear in South America. *Cactusnet Newsletter*. 13: 29-40.

Felkai-Haddache, I., Remini, H., Dulong, V., Mamou-Belhabib, K., Picton, I., Madani, K., and Rihouey, C. 2016. Conventional and microwave-assisted extraction of mucilage from *Opuntia ficus-indica* Cladodes: Physico-chemical and rheological properties. *Food and Bioprocess Technology. 9*(3): 481-492. https://doi.org/10.1007/s11947-015-1640-7

Grant, R. J., and Adesogan, A. T. 2018. Journal of Dairy Science Silage Special Issue: Introduction. *Journal of Dairy Science. 101*(5): 3935-3936. https://doi.org/10.3168/jds.2018-14630.

Gusha, J., Katsande, S., Zvinorova, P. I., and Ncube, S. 2013. The nutritional composition and acceptability of cacti (*Opuntia ficus indica*)-legume mixed silage. *Journal of Animal and Feed Research. 3*(2): 116-120.

Hall, M. B., 2001. Recentes avanços em carboidratos não-fibrosos na nutrição de vacas leiteiras. *SIMLEITE. Anais Lavras*. *2*: 149-159.

Jobim, C. C., Nussio, L. G., Reis, R. A., and Schmidt, P. 2007. Avanços metodológicos na avaliação da qualidade da forragem conservada. *Revista Brasileira de Zootecnia. 36*: 101-119.

Kalegowda, P., Chauhan, A. S., and Urs, S. M. N. 2017. *Opuntia dillenii* (Ker-Gawl) Haw cladode mucilage: Physico-chemical, rheological and functional behavior. *Carbohydrate Polymers. 157*: 1057-1064. https://doi.org/10.1016/j.carbpol.2016.10.070.

Kung-Junior, L. 2000. Microbial and chemical additives for silage: effect on fermentation and animal response. In: Workshop Sobre Milho para Silagem, 2. 2000, Piracicaba. Anais… Piracicaba: FEALQ, p.1-53.

Manhivi, V. E., Venter, S., Amonsou, E. O., and Kudanga, T. 2018. Composition, thermal and rheological properties of polysaccharides from amadumbe (*Colocasia esculenta*) and cactus (*Opuntia spp*.). *Carbohydrate Polymers*. *195*: 163-169. https://doi.org/10.1016/j.carbpol.2018.04.062.

Matias, A. G. S., Araujo, G. G. L., Campos, F. S., Moraes, S. A., Gois, G. C., Silva, T. S., Emerenciano-Neto, J. V. and Voltolini, T. V. Fermentation profile and nutritional quality of silages composed of cactus pear and maniçoba for goat feeding. *Journal of Agricultural Science*. *158*: 304-312. https://doi.org/10.1017/S0021859620000581.

Mcdonald, P., Henderson, A. R. and Heron, S. J. E. 1991. The biochemistry of Silage, 2nd ed. Marlow, UK: Chalcombe Publications.

Mciteka, H. 2008. Fermentation characteristics and nutritional value of *Opuntia ficus-indica* var. Fusicaulis cladode silage. 113 f. Dissertation (Cientiae Agriculturae). University of the Free State, Bloemfontein.

Mizubuti, I. Y., Pinto, A. P., Pereira, E. S., and Ramos, B. M. O. 2009. Métodos laboratoriais de avaliação de alimentos para animais. Londrina: Eduel, 1.

Monteiro, C. C. F., Ferreira, M. A., Véras, A. S. C., Guido, S. I., Almeida, M. P., Silva, R. C., and Inácio, J. G. 2019. A new cactus variety for dairy cows in areas infested with *Dactylopius opuntiae*. *Animal Production Science. 59*(3): 479-485. https://doi.org/10.1071/AN17256.

Monteiro, C. C. F., Melo, A. A. S., Ferreira, M. A., Campos, J. M. S., Souza, J. S. R., Silva, E. T. S., and Silva, E. C. 2014. Replacement of wheat bran with spineless cactus (*Opuntia ficus indica* Mill cv Gigante) and urea in the diets of Holstein x Gyr heifers. *Tropical Animal Health and Production.* 46(7): 1149-1154. https://doi.org/10.1007/s11250-014-0619-0.

Moura, M. D. S. C., Guim, A., Batista, Â. M. V., do Vale Maciel, M., Cardoso, D. B., de Lima-Júnior, D. M., and Carvalho, F. F. R. 2020. The inclusion of spineless cactus in the diet of lambs increases fattening of the carcass. *Meat Science*. *160*: 107975. https://doi.org/10.1016/j.meatsci.2019.107975.

Nobre, I. S., Araújo, G. G. L., Santos, E. M., De Carvalho, G. G. P., De Souza, B. B., Ribeiro, O. L., and Albuquerque, I. R. R. 2018. Ingestive behavior and thermoregulation in sheep fed forage cactus silage undergoing intermittent water supply. *Semina: Ciências Agrárias. 39*(4): 1683-1694.

Pahlow, G., Muck, R. E., Driehuis, F., Oude Elferink, S. J. W. H., and Spoelstra, S. F. 2003. Microbiology of ensiling. In: Buxton, D.R.; Muck, R.E.; Harrison, J.H. (Eds.) Silage science and technology. Wisconsin: ASA; CSSA; SSSA. p.31-93.

Pereira, G. A., Santos, E. M., Araújo, G. G. L., Oliveira, J. S., Pinho, R. M. A., Zanine, A. D. M., and Nascimento, T. V. C. 2019. Isolation and identification of lactic acid bacteria in fresh plants and in silage from *Opuntia* and their effects on the fermentation and aerobic stability of silage. *Journal of Agricultural Science*. *157*(9-10): 684-692. https://doi.org/10.1017/S0021859620000143.

Pirhofer-Walzl, K., Søegaard, K., Høgh-Jensen, H., Eriksen, J., Sanderson, M. A., Rasmussen, J., and Rasmussen, J. 2011. Forage herbs improve mineral composition of grassland herbage. *Grass and Forage Science. 66*(3): 415-423. https://doi.org/10.1111/j.1365-2494.2011.00799.x.

Santos, A. P. M. 2014. Silagens de sorgo BRS Ponta Negra aditivadas com ureia. Dissertação (Mestrado em Zootecnia) - UFPB/CCA, Areia – PB.

Santos, K. C., Carvalho, F. F. R., Magalhães, A. L. R., Silva, F. J. S., Cardoso, D. B., Sousa, D. R., and Batista, Â. M. V. 2020. An urea associated with alternative carbohydrate sources replace conventional concentrate for lambs? *Livestock Science*.104172. https://doi.org/10.1016/j.livsci.2020.104172.

SAS University Edition. 2015. SAS/STAT®14.1 User’s Guide: High-performance procedures. Cary, NC: SAS Institute Inc.

Senger, C. C. D., Kozloski, G. V., Sanchez, L. M. B., Mesquita, F. R., Alves, T. P., and Castagnino, D. S. 2008. Evaluation of autoclave procedures for fibre analysis in forage and concentrate feedstuffs. *Animal Feed Science and Technology*. *146*(1-2): 169-174. https://doi.org/10.1016/j.anifeedsci.2007.12.008.

Severo, I. K., Müller, S. S., Missio, R. L., Elejalde, D. A. G., Rieger, R. D., and Moraes, G. K. 2020. Silagem de milho colhida com diferentes alturas e adição de inoculante microbiano e enzimático. *Amazonian Journal of Agricultural and Environmental Sciences*. 63.

Silva-Elias, O. F. A., Leite, M. L. D. M. V., Azevedo, J. M., Souza, J. P. S., Nascimento, G. F., and Simplicio, J. B. 2017. Características agronômicas de cultivares de sorgo em sistema de plantio direto no semiárido de Pernambuco. *Revista Ciência Agrícola. 14*(1): 29-36.

Silva, D. J., Queiroz, A. C. 2002. Análise de alimentos: métodos químicos e biológicos. Viçosa, MG: Editora UFV. 235p.

Silva, F. A., Freitas, F. C. L., Rocha, P. R. R., Cunha, J. L. X. L., Dombroski, J. L. D., Coelho, M. E. H., and Lima, M. F. P. 2015. Milho para ensilagem cultivado nos sistemas de plantio direto e convencional sob efeito de veranico. *Ciências Agrárias* 36(1): 327-340.

Silva, L. D., Pereira, O. G., Silva, T. C., Leandro, E. S., Paula, R. A., Santos, S. A., and Valadares-Filho, S. C. 2018. Effects of *Lactobacillus buchneri* isolated from tropical maize silage on fermentation and aerobic stability of maize and sugarcane silages. *Grass and Forage Science* 73(3): 660-670.

Silva Santos, R. S., Emerenciano Neto, J. V., Bonfim, B. R. S., Santos, U. L. F., Rodrigues, A. C., Nunes Lista, F. N., Santos Difante, G. S., and Bezerra, J. D. V. 2020. Fermentation losses of cactus silages with elephant grass. *Journal of the Professional Association for Cactus Development*. *22*: 72-78. https://doi.org/10.56890/jpacd.v22i.345.

Sniffen, C. J., O'connor, J. D., Van-Soest, P. J., Fox, D. G., and Russell, J. B. 1992. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. *Journal of Animal Science.* 70(12): 3562-3577. https://doi.org/10.2527/1992.70113562x.

Van-Soest, P. J. 1991. Nutritional Ecology of the Ruminant. 2th. ed. Ithaca: Cornell University Press; p. 476.

Wang, H., Ning, T., Hao, W., Zheng, M., and Xu, C. 2016. Dynamics associated with prolonged ensiling and aerobic deterioration of total mixed ration silage containing whole crop corn. *Asian-Australasian Journal of Animal Science*. 29: 62–72. https://doi.org/10.5713/ajas.15.0319.

Wanjura, J. D., Barnes, E. M., Kelley, M. S., Holt, G. A., and Pelletier, M. G. 2014. Quantification and characterization of cotton crop biomass residue. *Industrial crops and products*. 56: 94-104. https://doi.org/10.1016/j.indcrop.2014.02.019.

Wilkinson, J. M., and Davies, D. R. 2012. The aerobic stability of silage: key findings and recent developments. *Grass and Forage Science*. 68(1): 1-19. https://doi.org/10.1111/j.1365-2494.2012.00891.x.

Zanine, A. D. M.; Santos, E. M.; Dórea, J. R. R.; Dantas, P. A. D. S.; Silva, T. C. D.; Pereira, O. G. 2010. Evaluation of elephant grass with addition of cassava scrapings. *Revista Brasileira de Zootecnia. 39*(12): 2611-2616.

Zhang, Q., Yu, Z., and Na, R. S. 2017. Effects of different additives on fermentation quality and aerobic stability of *Leymus chinensis* silage. *Grass and Forage Science. 73*(2): 413-419. https://doi.org/10.1111/gfs.12301.

Zhang, Y. X., Ke, W. C., Bai, J., Li, F. H., Xu, D. M., Ding, Z. T., and Guo, X. S. 2020. The effect of *Pediococcus acidilactici* J17 with high-antioxidant activity on antioxidant, α-tocopherol, β-carotene, fatty acids, and fermentation profiles of alfalfa silage ensiled at two different dry matter contents. *Animal Feed Science and Technology*. *268*: 114614. https://doi.org/10.1016/j.anifeedsci.2020.114614.

https://www.jpacd.org Electronic ISSN: 1938-6648