Tropical Animal Health and Production (2024) 56:72
https://doi.org/10.1007/s11250-024-03918-y

REGULAR ARTICLES

Forage cactus as an additive in corn without the cob silages of feedlot sheep diets

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Received: 8 March 2023 / Accepted: 30 January 2024 / Published online: 7 February 2024

Abstract
This study aimed to assess the impact of adding forage cactus as an additive to the production of corn silage without the cob on the performance of feedlot sheep and subsequent silage losses. The experimental design was completely randomized, consisting of three treatments: corn silage without cob; 0% = 100% corn plant without the cob; 10% = 90% corn plant without cob + 10% forage cactus; 20% = 80% corn plant without cob + 20% forage cactus. Significant effects were observed for dry matter intake ($P = 0.0201$), organic matter ($P = 0.0152$), ether extract ($P = 0.0001$), non-fiber carbohydrates ($P = 0.0007$). Notably, nutrient digestibility showed significant differences in organic matter ($P = 0.0187$), ether extract ($P = 0.0095$), neutral detergent fiber ($P = 0.0005$), non-fiber carbohydrates ($P = 0.0001$), and metabolizable energy ($P = 0.0001$). Performance variables, including total weight gain ($P = 0.0148$), average daily weight gain ($P = 0.0148$), feeding efficiency, and rumination efficiency of dry matter ($P = 0.0113$), also exhibited significant effects. Consequently, it is recommended to include 20% forage cactus in corn silage, which, based on natural matter, helps meet animals' water needs through feed. This inclusion is especially vital in semi-arid regions and aids in reducing silage losses during post-opening silo disposal.

Keywords Agribusiness by-products · Small ruminants · Semi-arid region · Zea mays

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Introduction

The utilization of agro-industrial residues in ruminant feeding is paramount from both environmental and socioeconomic standpoints. It not only prevents crop residues from being indiscriminately discarded into the environment but also supports the feasibility of intensive animal production (Artioli et al., 2015; Muhammad et al., 2016). Corn plants, after cob removal, represent a crucial by-product in animal feed due to their high production, cost-effectiveness, ease of harvest, and widespread availability, particularly in semi-arid regions (Li et al., 2014; Menardo et al., 2015; Artuzo et al., 2019).

The fermentable substrate found in corn grains within the ear is crucial for silage production, as lactic acid bacteria utilize it to produce organic acids that aid in preserving the corn plant as silage (Ferraretto et al., 2018). However, the absence of cobs in the silage of corn plants lessens the nutritional quality of the forage and directly impacts its preservation in the silo. Moreover, the harvesting period ideal for human consumption of corn is later than the suitable period for ensiling, resulting in a plant with high dry matter and neutral detergent fiber content. This impedes material compaction and prolongs oxygen presence in the silo, hindering the fermentation process (Ridwan et al., 2015).

A feasible strategy to enhance the nutritional value of cob less corn silage is by adding forage cactus during ensiling. Forage cactus boasts a high moisture and soluble carbohydrate content, effectively improving the fermentation process in the silo (Lopes et al., 2017). It can also serve as an excellent energy source, potentially replacing concentrated energy foods like corn grain, commonly used in ruminant diets (Lins et al., 2016). Additionally, forage cactus, when included in the silage, acts as an antifungal agent by producing a substantial amount of acetic acid, which effectively controls yeast activity. This ensures higher dry matter recovery and aerobic stability, and consequently, enhances the nutritional value of the silage (Pereira et al., 2020, 2022; Santos et al., 2020).

The hypothesis is that strategically including forage cactus in cob less corn silage can improve fermentation within the silo, ensuring the provision of higher-nutrient-quality forage to ruminants and potentially enhancing animal performance. Hence, the objective of this study was to assess the impact of adding forage cactus as an additive in the production of cob less corn silage on the performance of feedlot sheep and silage disposal after silo opening.

Materials and methods

Ethical principles of experimentation and experimental area

This study was conducted in strict compliance with the Brazilian legislation for research and experimentation with animals and was approved by the Committee of Ethics in the Use of Animals of the Federal University of Paraiba (Protocol n° 90461603/2021). The experiment was carried out on a private property located in the municipality of São José dos Cordeiros, state of Paraíba, located in the Borborema mesoregion and in the Western Cariri microregion, Brazil. The climate of the region of Cariri in the state of Paraíba is semi-arid, Bsh, according to the Köppen classification, with an average annual rainfall of around 551.7 mm, distributed between the months of February and June, and with an average annual temperature of 23.0 °C.

Animals and dietary treatments, experimental procedures

The experimental period lasted 64 days, with 14 days for adaptation to diets and facilities, and 50 days of confinement for evaluation and data collection. Experimental animals were thirty-six castrated male sheep, mixed breed, with an average initial weight of 20.57 ± 2.8 kg, housed in individual folds, provided with feeders and drinkers. Before the onset of the experiment, all animals were identified, weighed, and dewormed against endo and ectoparasites and vaccinated against clostridiosis.

Animals were distributed in a completely randomized design, with three treatments and 12 repetitions. The ingredients used were forage cactus, corn stover, corn meal, and soybean meal cotton cake (Table 1).

The treatments consisted of three experimental diets, formulated to be isoproteic to meet the requirements of growing lambs to gain of 200 g/animal/day (NRC 2007): (1) 0% = diet with 100% corn plant silage without the cob (control); (2) 10% = diet with 90% corn plant silage without cob + 10% forage cactus; and (3) diet with 0% = 80% corn plant silage without cob + 20% forage cactus (Table 2).

Table 1 Chemical composition of ingredients used in the composition of experimental diets, on a dry matter basis

Item, g/kg	Treatments			Forage cactus	Without the cob	Corn meal	Soybean meal	Cotton cake
	0%	10%	20%					
Dry matter	298	274	213	100	284	895	969	927
Organic matter	901	891	876	842	901	984	929	954
Crude protein	55.1	51.1	51.1	57.0	56.2	95.8	463	263
Ether extract	41.6	33.3	22.6	16.1	25.4	29.6	16.3	91.9
Ash	98.3	108	123	157	98.5	15.3	70.0	45.5
Total carbohydrates	805	807	802	769	819	859	450	599
Non-fiber carbohydrates	292	269	241	489	178	709	247	105
Neutral detergent fiber	512	537	564	280	640	140	175	494
Acid detergent fiber	265	281	300	98.7	292	37.7	94.1	334

0% = diet with 100% corn plant silage without the cob (control); 10% = diet with 90% corn plant silage without cob + 10% forage cactus; 30% = 80% corn plant silage without cob + 20% forage cactus

Ensiling process

Ensiling was carried out 100 days before the confinement of the animals. The cobless corn plant and forage cactus (*Opuntia stricta Haw*). Both cobless corn plant and forage cactus were harvested manually and chopped in a stationary forage machine (PP-35, Pinheiro Máquinas, Itapira, São Paulo, Brazil) to a particle size of approximately 2.0 cm. The material was packaged and compacted in laminated bags with dimensions of 120 × 50 cm and a capacity of 100 kg, properly sealed with the aid of rubber bands and stored in a place protected against rodents.

The average weight of the laminated bags was quantified, and the average values of each treatment were 60.11, 60.78, and 80.53 kg for the respective 0, 10, and 20% forage cactus inclusion. The amount of silage discarded due to the presence of mold or undesirable fermentation was determined. After opening each silo, material with the presence of mold or dark coloration resulting from butyric fermentation was weighed and discarded.

Table 2 Ingredient proportions and chemical composition of experimental diets for confined sheep-fed corn stover silage added with different levels of forage cactus, on a dry matter basis

Ingredients (g/kg DM)	Experimental diets		
	0%	10%	20%
Corn silage without the cob	456	0.00	0.00
Forage cactus	0.00	454	460
Corn meal	283	285	282
Soybean meal	74.7	74.8	74.0
Cotton cake	155	155	154
Urea	2.70	2.50	2.30
Mineral core*	13.6	13.6	13.5
Ammonium chloride	13.5	13.5	13.4
Ammonium sulfate	0.30	0.20	0.20
Chemical composition (g/kg DM)			
Dry matter	452	451	405
Crude protein	135	133	130
Ether extract	42.9	39.0	34.1
Ash	62.4	65.8	69.8
Neutral detergent fiber	368	379	393
Acid detergent fiber	190	198	207
Non-fiber carbohydrates	369	359	345

0% = diet with 100% corn plant silage without the cob (control); 10% = diet with 90% corn plant silage without cob + 10% forage cactus; 30% = 80% corn plant silage without cob + 20% forage cactus. *Mineral core = calcium (min.) 110.00 g/kg calcium (max.) 135.00 g/kg, phosphorus 87.00 g/kg, sulfur 8.00 g/kg, sodium 147.00 g/kg, cobalt 15.00 mg/kg, copper 590.00 mg/kg, chromium 20.00 mg/kg, iodine 50.00 mg/kg, manganese 2000.00 mg/kg, molybdenum 300.00 mg/kg, selenium 20.00 mg/kg, zinc 3800.00 mg/kg, fluorine (max.) 870.00 mg/kg

Intake and apparent digestibility

Diets were provided twice a day, at 8:00 a.m. and 2:00 p.m. offering 40% diet in the morning and 60% in the afternoon. Diets and water were provided ad libitum. The supply of the diets was adjusted by collecting and weighing leftovers daily before the first supply of the day, establishing up to 10% leftovers of the total offered. The intake of dry matter and nutrients was estimated by the difference between the amount present in the feed supplied daily and the leftovers of the following day.

To determine digestibility, samples of the food provided were taken, in addition to leftovers and feces during the 7 days that each animal remained in the individual folds. From the samples of feed, feces, and leftovers collected, the digestibility of nutrients and total digestible nutrients (TDN) were determined.

Fecal samples were taken directly from the rectal ampulla during the last 3 days of the collection period, being day 5 (06:00 a.m and 2:00 p.m), day 6 (08:00 a.m and 4:00 p.m), and day 7 (10:00 a.m and 6:00 p.m) following the methodology of Bispo et al. (2007).

Samples of feces, feed, and leftovers were identified and stored in a refrigerator at − 15 °C. At the end of the collection period, samples were homogenized to form one composite sample per animal and pre-dried in a forced circulation oven at 65 °C for 72 h. Samples of feces, feed, and leftovers were ground in a Wiley knife mill, with a 1.0 mm sieve, for chemical analysis and with a 2.0 mm sieve, for in situ determination of indigestible neutral detergent fiber (iNDF).

The amount of excreted fecal dry matter, used to determine the apparent digestibility of nutrients and the total digestible nutrient (TDN) content, was estimated by the concentration of iNDF, obtained after in situ incubation of feed, leftovers and feces, in triplicate, in non-woven fabric (TNT) bags (12.0 × 8.0 cm), containing approximately 1 g material per bag, with 2.0 mm particles, for a period of 288 h in a 7/8 Holstein cow fistulated in the rumen (License 52/2018), according to the methodology established by Casalli et al. (2008).

The remaining material from the incubation was submitted to digestion with neutral detergent, whose residue is considered iNDF, according to the INCT-CA F/011/1 method, and the methodology described by Detmann et al. (2012).

To determine fecal dry matter production (FDMP), the following formula was used:

- FDMP = indicator consumption (kg) /indicator concentration in feces (%)

The digestibility coefficients (DC) of DM, organic matter (OM), CP, EE, NDF, NFC, and TDN were calculated using the following equation: DC = [(amount ingested—amount excreted)/(amount ingested)] × 100 by Silva and Leão

(1979). The digestible energy (DE) was initially quantified as the product of the TDN content and the factor 4.409/100, considering an ME concentration of 82% of DE.

To estimate the total digestible nutrients (TDN) content, the equation proposed by Weiss (1999) was adopted, in which:

- TDN = CPd + EEd*2.25 + NFCd + NDFcpd, where CPd = (crude protein intake – excreted crude protein), EEd = (ether extract intake – excreted ether extract), NFCd = (non-fibrous carbohydrate intake – excreted non-fibrous carbohydrate) and NDFcpd = (neutral detergent insoluble fiber corrected for protein and ash intake – excreted neutral detergent insoluble fiber corrected for protein and ash)

Water intake

Water intake (WI) was evaluated daily. Water was supplied in plastic buckets (5 L) and weighed before being supplied, and again 24 h later. This variable was estimated using buckets randomly placed around the experimental shed, with the same amount of water available for each treatment, being determined by the weight difference over 24 h. Water lost by evaporation was also considered in the calculation of water intake, according to the methodology described by Souza et al. (2010).

Ingestive behavior evaluation

The ingestive behavior was carried out on the 25th day of the experimental period, during a period of 24 h, with sweeping observations every 10 min according to the methodology proposed by Martin and Bateson (1993), with the observed behavioral variables: feeding, rumination and idle, with the presence of four observers, one to collect the behavioral data of the animals in the three individual folds and one observer evaluating three animals per treatment in each collective fold, totaling four animals per treatment.

Chewing time was determined by the sum of the time spent for feeding and ruminating. The average daily duration of these activity periods was determined by dividing the total duration of each activity (feeding and ruminating in min/day) by its respective number of discrete periods. Nocturnal observation of the animals was performed with the aid of artificial lighting.

Two days before the ingestive behavior analysis, the shed was artificially lit during the night for the animals to adapt to the luminosity so as not to compromise the evaluation.

From the results referring to variables of ingestive behavior of feeding and rumination, the efficiency of feeding and rumination of DM and NDF, respectively, was determined. For this, the equations established by Bürger et al. (2000) were adopted.

Growth performance

To determine the performance, animals were weighed after fasting for 16 h on experimental days 1 and 50, to determine the initial body weight (BWI) and final body weight (BWF), and by difference, the total weight gain (TWG). The average daily weight gain (ADG) was obtained by dividing TWG by the experimental period (50 days). For the determination of the feed conversion (FC), the DMI divided by the ADG of the animals was considered.

Chemical analysis

For this purpose, values were determined according to the methodologies established by the Association of Official Analytical Chemists—AOAC (2000), being for dry matter (DM; method 934.01), mineral matter (MM; method 942.05), crude protein (CP; method 954.01), ether extract (EE; method 920.39). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined using the model proposed by Van Soest et al. (1991), using the fiber analyzer from ANKOM Fiber Analyzer – ANKON Technology Corporation, Fairport, New York, USA.

To estimate total carbohydrates (TC), the equation proposed by Sniffen et al. (1992), in which:

- TC = 100 – (%CP + %EE + %Ashes)

To estimate non-fiber carbohydrates (NFC), the equation recommended by Hall (2000) was used, in which:

- NFC = 100 – MM – EE – NDF – (CP – CPu + U), where CPu = CP content from urea (or mixture of urea and ammonium sulfate); U = urea content

Statistical analysis

The experimental design was completely randomized, using the animals' initial body weight as a covariate, according to the model below:

$$Y_{ij} = \mu + T_i + \beta(X_{ij} - X) + e_{ij}$$

where Y_{ij} = the observed dependent variable; μ = general mean; T_i = effect of forage cactus levels; $\beta(X_{ij} - X)$ = covariate effect (initial BW); and e_{ij} = experimental error.

The results were tested by analysis of variance (ANOVA) and the averages were compared by the Tukey's test, at the

Table 3 Water intake in sheep-fed corn stover silage added with different levels of forage cactus

Item (L/day)	Treatments			SEM	*P* Value
	0%	10%	20%		
Water intake through food	964b	895b	1280a	35.4	0.01
Water intake through water fountain	1388a	1398a	1064b	74.1	0.00
Total water intake	2353	2294	2344	80.6	0.85

0% = diet with 100% corn plant silage without the cob (control); 10% = diet with 90% corn plant silage without cob + 10% forage cactus; 30% = 80% corn plant silage without cob + 20% forage cactus. *SEM*, standard error of the mean; means followed by distinct letters are statistically different by Tukey's test at the 5% probability level

level of 5% significance using the statistical package Statistical Analysis System – SAS (2004), version 9.0.

Results

The type of silage had no significant effect on the total water intake ($P = 0.8537$), averaging at 2330.89 L/day. However, an observable statistical effect was noted regarding water intake through food ($P = 0.0001$), where animals consuming a diet consisting of 20% forage cactus exhibited the highest water intake. There was also a notable impact on water intake through the water fountain ($P = 0.0019$), with animals fed this diet showing a lower intake compared to others (Table 3).

The intake of dry matter (DM), organic matter (OM), non-fiber carbohydrates (NFC), and metabolizable energy (ME) displayed significant differences, with animals consuming the 20% forage cactus diet exhibiting higher values compared to those consuming 10% forage cactus (Table 4). Nevertheless, no differences were noted in the intake of these nutrients between animals fed the 0% and 20% diets. Notably, the intake of ether extract (EE) was higher in animals consuming corn plant without cob. Conversely, there were no significant effects observed in the intake of neutral detergent fiber (NDF, $P = 0.1215$) and crude protein (CP, $P = 0.0527$).

Among the nutrient digestibility results, only DM ($P = 0.1984$) and CP ($P = 0.0601$) exhibited no significant differences, recording mean values of 688.61 g/kg and 860.90 g/kg, respectively (Table 5). Notably, the diet containing 20% forage cactus displayed the lowest digestibility levels for OM and NFC, although it exhibited the highest digestibility values for EE and NDF.

Sheep fed the diet containing 20% forage cactus exhibited the highest total weight gain (TWG, $P = 0.0148$), average daily gain (ADG, $P = 0.0148$), and the most efficient feed utilization (FE, $P = 0.0137$), as detailed in Table 6.

Table 4 Intake of nutrients in sheep-fed corn stover silage added with different levels of forage cactus

Item (g/day)	Treatments			SEM	*P* value
	0%	10%	20%		
Dry matter	794ab	752b	839a	21.8	0.02
Organic matter	748ab	677b	774a	24.1	0.01
Crude protein	112	101	113	3.70	0.05
Ether extract	36.4a	29.2b	29.4b	1.02	0.00
Non-fiber carbohydrates	272ab	244b	303a	10.7	0.07
Neutral detergent fiber	327	302	327	9.85	0.12
Metabolizable energy (Mcal)	3.19ab	2.87b	3.23a	0.11	0.02

0% = diet with 100% corn plant silage without the cob (control); 10% = diet with 90% corn plant silage without cob + 10% forage cactus; 30% = 80% corn plant silage without cob + 20% forage cactus. *SEM*, standard error of the mean; means followed by distinct letters are statistically different by Tukey's test at the 5% probability level

Table 5 Digestibility of nutrients in sheep-fed corn stover silage added with different levels of forage cactus

Item (g/kg day)	Treatments			SEM	*P* Value
	0%	10%	20%		
Dry matter	687	696	681	6.37	0.19
Organic matter	732a	740ab	710b	7.65	0.01
Crude protein	872	849	861	6.70	0.06
Ether extract	810b	814b	844a	8.60	0.0095
Neutral detergent fiber	486b	529a	545a	10.8	0.0005
Non-fiber carbohydrates	913a	869b	875b	6.58	0.0001
Metabolizable energy (Mcal)	3.83a	3.75a	3.61b	0.03	0.0001

0% = diet with 100% corn plant silage without the cob (control); 10% = diet with 90% corn plant silage without cob + 10% forage cactus; 30% = 80% corn plant silage without cob + 20% forage cactus. *SEM*, standard error of the mean; means followed by distinct letters are statistically different by Tukey's test at the 5% probability level

There were no significant differences in the time spent feeding ($P = 0.1863$) and idling ($P = 0.2462$), with mean durations of 386.67 and 570.00 min per day, respectively (Table 7). However, animals consuming a diet with 20%

Table 6 Performance of confined sheep-fed corn stover silage added with different levels of forage cactus

Item	Treatments			SEM	*P* Value
	0%	10%	20%		
Total weight gain (kg)	9.08b	8.96b	10.8a	0.47	0.01
Average daily gain (g/day)	0.18b	0.19b	0.21a	0.01	0.01
Feeding efficiency*	0.22b	0.25ab	0.28a	0.01	0.01

0% = diet with 100% corn plant silage without the cob (control); 10% = diet with 90% corn plant silage without cob + 10% forage cactus; 30% = 80% corn plant silage without cob + 20% forage cactus. *(kg of ADG/kg MS); *SEM*, standard error of the mean; means followed by distinct letters are statistically different by Tukey's test at the 5% probability level

Table 7 Ingestive behavior, feeding, and rumination efficiencies and total chewing time of confined sheep-fed corn stover silage added with different levels of forage cactus

Item	Treatments			SEM	*P* value
	0%	10%	20%		
Daily spent time (min/day)					
Feeding	360	407	392	16.8	0.18
Rumination	483b	456b	530a	11.1	0.01
Idling	580	617	512	41.0	0.24
Feeding and rumination efficiency (g/hour)					
Feeding efficiency					
Dry matter	2.01	1.93	2.39	0.17	0.19
Neutral detergent fiber	0.69	0.67	0.88	0.06	0.05
Rumination efficiency (g/hour)					
Dry matter	1.40b	1.96a	1.83a	0.10	0.001
Neutral detergent fiber	0.48b	0.67a	0.67a	0.03	0.001
Total chewing time					
min/day	872	817	905	43.5	0.39

0% = diet with 100% corn plant silage without the cob (control); 10% = diet with 90% corn plant silage without cob + 10% forage cactus; 30% = 80% corn plant silage without cob + 20% forage cactus. *SEM*, standard error of the mean; means followed by distinct letters are statistically different by Tukey's test at the 5% probability level

forage cactus spent more time on rumination ($P = 0.0143$) compared to those fed other silages. There were no statistical differences in feeding efficiency for DM ($P = 0.1947$) and NDF ($P = 0.0590$), with mean rates of 2.11 and 0.75 g/h, respectively. However, a significant effect was observed for the rumination efficiency of DM ($P = 0.0111$) and NDF ($P = 0.0013$) in animals fed the 20% forage cactus diet.

There was a notable impact on silage loss after opening the silo ($P = 0.001$) (Fig. 1). The diet containing 20% of forage cactus resulted in reduced silage wastage upon silo opening compared to diets containing 0% and 10% of forage cactus.

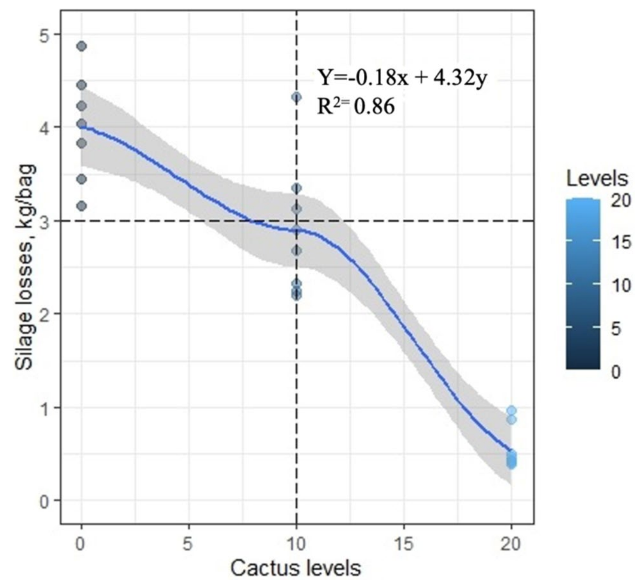

Fig. 1 Reduced silage wastage in corn without the cob silage enriched with varied forage cactus levels

Discussion

The decrease in water intake through the water fountain was observed in several studies involving forage cactus either combined with other forages or used exclusively as silage or fresh (Neto et al., 2016; Cordova-Torres et al., 2017; Miranda-Romero et al., 2018; Silva et al., 2021). Gusha et al. (2015) highlighted that the combination of forage cactus with other forages not only acts as a water reserve but is also crucial for herd survival in semi-arid regions where water scarcity directly impacts animal production. Reducing water intake without affecting animal performance is highly important, particularly in semi-arid regions. Al-Dawood (2017) emphasizes that a stable or positive water balance is crucial for adequate animal production since water participates in various physiological body functions.

Observed dry matter intake values were below those recommended by NRC (2007), which advocates an average daily intake of 1000 g/animal for animals with a 200 g/day gain. This is possibly linked to the increased fiber content of diets, as supported by the consumed NDF levels. Moreover, there was a reduction in NDF digestion, impacting ruminal absorption characteristics. This study confirms the general hypothesis that low NDF digestibility results in decreased passage rates (Pinho et al., 2018).

Similarly, Mertens (2001) suggests that NDF intake greater than 1.2% of body weight results in rumen filling, limiting intake. In this study, the average NDF intake for treatments was 1.55% or 15.51 g NDF/kg body weight, higher than the recommended level. The findings on EE intake were expected considering the diet's composition, where lower values were due to the nutrient's dilution with increased levels of forage cactus inclusion in the silage of corn plants without cobs since cactus has low concentrations of this nutrient (Frota et al., 2015). Matias et al. (2020) similarly noted reduced EE intake with increasing levels of forage cactus inclusion in maniçoba silage for goat diets.

The rise in nutrient intake may be related to higher concentrations in the 20% forage cactus treatment, such as higher NFC and TDN levels present in forage cactus. This categorizes forage cactus as a readily available energy-rich food compared to corn grains. According to Cordova-Torres et al. (2017), forage cactus can substitute energy concentrates widely, and in the absence of corn cobs in silage, its inclusion becomes an alternative to increase the silage's energy value.

Animals consuming the 20% forage cactus diet exhibited improved performance, likely due to the increased energy density from higher forage cactus levels and relatively higher DM intake compared to other animals. It is essential to note that dry matter intake greatly affects animal performance, constituting 60–90%, while diet digestibility only comprises 10–40% (Karimizadeh et al., 2017).

The variation in NDF intake might result from the higher forage cactus inclusion allowing more significant aggregation of both forage and concentrate particles, reducing selection. This aggregation did not occur in treatments without forage cactus inclusion or with 10%, causing animals to prefer the concentrate first. Improved fiber fraction digestibility in 10% and 20% forage cactus treatments could be due to the better ruminal environment created by the readily fermentable substrate from the forage cactus inclusion, favoring cellulolytic bacteria action and increasing NDF digestibility (Tauqir, 2010).

In certain scenarios where forage cactus inclusion is high in ruminant diets, metabolic disturbances might affect animal performance. This is associated with low levels of forage cactus fiber leading to a high passage rate. However, these effects were not observed in the present study, where forage cactus inclusion only influenced the fermentation profile and silage quality, not affecting animal performance. Regarding nutrient digestibility, OM, NFC, and ME superiority could result from higher animals' selectivity due to forage cactus inclusion, reducing concentrate components and their presence in the experimental diets. Treatments with 0% and 10% forage cactus demonstrated greater nutrient digestibility due to increased grain selectivity, which might result in greater digestibility of these nutrients.

Ingestive behavior assessment in diets with forage cactus is a vital tool for understanding potential issues related to reduced intake and diet acceptance by animals. Fiber content is directly associated with food consumption and rumination action (Schultz et al., 2019). NDF content's association with chewing and rumination activity suggests that lower DM and NDF content leads to a higher passage rate and a lower number of ruminations (Pinho et al., 2018). Anticipated higher rumination activity for diets without forage cactus inclusion was not observed, likely linked to the animal's feeding selection preference for concentrated feed, potentially resulting in fewer ruminations. Similar effects were observed in a study by Silva et al. (2021), where sheep consuming forage cactus silage exhibited fewer ruminations than those fed buffel grass.

Silva et al. (2021) also reported no significant difference for the evaluated diets, which might be related to the diets' similar fiber content. In general, the findings align with the concept proposed by Van Soest (1994), where confined animals spend more than 6 h per day feeding. The discrepancy in rumination efficiency for DM and NDF aligns with the data on ingestive behavior, indicating that greater forage cactus inclusion allowed less food particle selection. Animals fed diets with 0% and 10% forage cactus chose to consume the concentrate first, influencing rumination activity.

The reduction in silage losses due to forage cactus inclusion in corn silage without cobs might be linked to the heterofermentative pattern occurring with forage cactus inclusion, driven by Weissella bacteria's action, with higher potential for acetic acid production, thereby inhibiting mold and yeast growth (Pereira et al., 2020). Santos et al. (2020) mentioned that although silage production aims for greater lactic acid production, considerable levels of acetic acid can be beneficial, inhibiting mold and yeast proliferation and reducing silage deterioration by these microorganisms. Several studies highlight the advantageous effects of forage cactus in improving fermentation patterns, increasing LAB populations, lactic and acetic acid concentrations, reducing molds and yeasts, negatively impacting nutritional and fermentation quality, and ensuring silage stability after silo opening (Macêdo et al., 2018; Pereira et al., 2020, 2022; Santos et al., 2020).

This heterolactic fermentation pattern in forage cactus might be due to buffering substances in its mucilage, such as oxalic, malic, citric, malonic, succinic, and tartaric acids, resulting from Crassulacean acid metabolism (Petera et al., 2015; Isaac, 2016). These substances help maintain silage pH in the intermediate range, conducive to heterofermentative LAB growth and inhibiting secondary fermentation.

Therefore, the results reveal that the inclusion of forage cactus in corn silage without cobs significantly influenced the intake, digestibility, and performance of feedlot sheep, reflecting alterations in fermentation and silage quality. The study also highlights the importance of preserving corn silage without cobs through the strategic inclusion of forage cactus, a practice that can reduce losses during silo opening and enhance the nutritional efficiency of diets offered to sheep.

Conclusion

The inclusion of forage cactus in silages of corn plant without the cob resulted in a greater performance of finishing sheep, reducing losses due to silage disposal after opening the silo and ensuring water supply through food, essential in semi-arid regions. Thus, it is recommended the inclusion of 20% forage cactus, on a natural matter basis, as an additive when ensiling corn plants without the cob.

Acknowledgements The authors thank the Federal University of Paraiba for all technical support, facilities, and infrastructure.

Author contribution J.S.O., E.M.S.: conceptualization, methodology, funding acquisition, project administration; G.C. S., J.S. O., G.G.L.A., E.J.O.S.: original draft; G.C.S, D.S.V., G.M.L, L.P.S., P.G.B.G., P.C.T.Júnior, M.A.C.S.: data collected; G.C.S., G.R.M., D.F.O.C.: data analysis. F.N.S.S: writing and editing, data curation, and final review; N.B.V.: data collected.

Funding The research was supported by Paraiba State Research Foundation (Call PROPESQ/UFPB 03/2020) Grant number: PIN1 3354/2020.

Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval The study was approved by the Ethics Committee of the Federal University of Paraíba, Brazil (Protocol number 90461603/2021).

Conflict of interest The authors declare no competing interests.

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