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Intake, digestibility, nitrogen balance and performance in lamb fed spineless cactus silage associated with forages adapted to the semiarid environment Spineless cactus silages in diets for lambs

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HIGHLIGHTS

- Spineless cactus silage provide benefit inherent to the maintenance of water content.
- The use of spineless cactus silage must be associated with a source of fiber.
- Performance of sheep fed spineless cactus silage associated with tropical forages was investigated.
- Roughage based on spineless cactus allowed gains above 200 g/day.

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ABSTRACT

The study aimed to evaluate the intake, apparent digestibility, nitrogen balance and productive performance in lamb fed spineless cactus silage associated with forages adapted to the semiarid environment. Forty intact crossbred lambs, with an average body weight of 22.65 ± 1.01 kg, were distributed in a completely randomised design with five treatments (diets based on: spineless cactus silage (SCS), spineless cactus + buffelgrass silage (SCBS), spineless cactus + gliricidia silage (SCGS), spineless cactus + pornunça silage (SCPS) and corn silage (CS; witness) and eight animals per treatment. Intake, apparent nutrient digestibility, nitrogen balance, and performance of animals were evaluated. The SCGS diet showed higher intake of dry matter and organic matter ($P<0.05$). The SCGS and SCPS diets showed the highest crude protein intake ($P = 0.005$). Lower intake of ether extract was found in animals receiving diets containing SCS and SCBS ($P = 0.001$). SCBS and SCGS provided a higher intake of neutral detergent fiber ($P = 0.015$). SCS and SCGS diets displayed a higher intake of non-fiber carbohydrates ($P = 0.003$). SCGS diets displayed the highest total digestible nutrients intake ($P = 0.001$). SCPS diet showed lower digestibility of dry matter, organic matter, and crude protein ($P<0.05$). SCGS diet showed a lower digestibility coefficient for ether extract ($P = 0.009$). SCPS diet showed lower digestibility coefficients for neutral detergent fiber ($P = 0.022$). SCS and SCPS diets showed lower digestibility coefficients for non-fiber carbohydrates ($P = 0.011$). The CS promoted lower results for intake ($P = 0.003$), absorbed ($P = 0.003$) and balance ($P = 0.012$) for nitrogen. SCPS diet promoted higher excretion of nitrogen via faeces ($P = 0.001$) and less excretion of nitrogen via urine ($P = 0.033$). SCGS diet provided a higher final weight ($P = 0.006$). SCS and SCGS diets provided more significant body weight gain ($P = 0.001$). Combining spineless cactus with a roughage base

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allowed weight gains over 200 g/day, proving to be efficient in diets for feedlot lamb and gains similar or superior to corn-based diets.

1. Introduction

In semiarid regions, the dry season is a significant obstacle to animal production due to food shortages and the reduced nutritional value of available pastures. An alternative and abundant food found in these regions is the spineless cactus because of its adaptation to the region's soil and climatic conditions, high water content, the potential for biomass production (241.75 t/ha green matter and 12.46 t/ha dry matter) and nutritional value (as a source of energy, non-fiber carbohydrates) compared to traditional forage sources (Borges et al., 2019).

Spineless cactus is used in large proportions in diets for small ruminants in dryland regions as an almost sole roughage source. However, its exclusive use is not recommended due to the low fiber and crude protein content and the high water and mineral content, leading to metabolic disorders, low dry matter intake and weight loss (Pereira et al., 2021). The use of mixed silage of spineless cactus associated with forage plants (legumes or grasses) seeks to overcome the deficits of dry matter, fiber and crude protein aiming to improve the nutritional quality of diets that will be offered to ruminants (Silva et al., 2019).

Forages plants adapted to the semiarid environment, such as Buffelgrass (*Cenchrus ciliaris* L.), Gliricidia (*Gliricidia sepium*) and Pornunça (*Manihot* sp.), are amongst the possible combinations with spineless cactus in mixed silages composition that it can improve silages protein and fiber content (Carvalho et al., 2017; Macêdo et al., 2018; Brito et al., 2020). Gusha et al. (2015) observed that the use of spineless cactus silage in combination with some legumes might be important in feeding herds in regions prone to drought: their dry matter content between 37 and 43%, indicating that spineless cactus can be offered as silage for ruminants, promoting an adequate intake without laxative effects.

The present study aimed to evaluate intake, apparent digestibility, nitrogen balance and productive performance in lamb fed spineless cactus silage associated with forages adapted to the semiarid environment. We hypothesised that roughage based on spineless cactus could be efficient in diets for feedlot sheep with weight gains similar or superior to corn-based diets.

2. Material and methods

2.1. Study site

The experiment was conducted at the Embrapa Semiárido, located in Petrolina, State of Pernambuco, Brazil. The municipality has an average elevation of 376 m, at the geographical coordinates of 9º23′35'' South latitude and 40º30′27'' West longitude. The climate is BSwh' semiarid, with summer rainfall (Köppen and Geiger 1928). The rainy season starts in November and ends in April, with an annual average rainfall of 433 mm, relative humidity of 36.7% and average annual temperatures of 29.5 °C. This study was approved and certified by the Ethics Committee on the Use of Animals (CEUA) of the Embrapa Semiárido (Opinion no. 0004/2016).

2.2. Animals, treatments and experimental diets

Forty intact crossbred lamb (7 months old and 22.65 ± 1.01 kg of body weight) were distributed in individual stalls (1.00 × 2.00 m) equipped with feeding, drinking troughs and salt blocks. The experiment lasted 50 days, preceded by 16 days of animal adaptation to the experimental diets. At the beginning of the adaptation period, the animals were identified, weighed, treated against endo- and ectoparasites, and randomly allocated to the stalls previously identified according to the treatment. The experimental design was a completely randomised design, with five treatments (diets) and eight animals per treatment.

The experimental diets consisted of five silages: spineless cactus silage (SCS), spineless cactus + buffelgrass silage (SCBS), spineless cactus + gliricidia silage (SCGS), spineless cactus + pornunça silage (SCPS) and corn silage (CS; witness), plus concentrate based on soybean meal, corn meal, wheat bran and mineral supplements (Table 1). Spineless cactus Mexican Elephant Ear (*Opuntia stricta* Haw), was harvested at 24 months after regrowth. The buffelgrass (*Cenchrus ciliaris* L.; variety Biloela) was harvested at 120 days after regrowth. Gliricidia (*Gliricidia sepium*) and Pornunça (*Manihot* sp.), plants with an average height of 1.5 m were selected, and the upper third of the plants with young leaves and more tender stems, was harvested. All material was processed through a stationary forage chopper (PP-35, Pinheiro máquinas, Itapira, São Paulo, Brazil) to an average particle size of approximately 2.0 cm. Material samples were collected for chemical analysis (Table 2). The silages were made in 200 L plastic-drum silos with a removable lid sealed with a metal ring.

Diets were formulated following the National Research Council (NRC National Research Council, 2007) recommendations for gains of 200 g/day. Spineless cactus + buffelgrass silage (SCBS), spineless cactus + gliricidia silage (SCGS), and spineless cactus + pornunça silage (SCPS) were elaborated in a ratio of 70% spineless cactus: 30% forage plant. In all diets, a roughage: concentrate ratio of 60:40 was adopted. However, to increase the fiber content of the spineless cactus silage (SCS), based on McDonald et al. (1991), who recommends a minimum of 200 g/kg fiber, we used a 38:62 forage: concentrate ratio, with wheat bran as a fiber source (Silva et al., 2022). Ammonium chloride was added to all experimental diets, seeking to acidify the urine to prevent urolithiasis in the animals (Navarro et al., 2021) (Table 3).

2.3. Intake and apparent digestibility

Food was provided at 0830 hour and 1530 h, and water *ad libitum*. The amount of food offered was calculated according to the intake of the previous day, not allowing leftovers higher than 20% of the offered quantity. Weekly samples of foods offered and leftovers were collected for chemical analyses. The daily dry-matter intake (DMI) was obtained by the difference between the total DM of the consumed diet and the total DM present in the leftovers. Nutrient intake was determined as the difference between the total nutrients present in the consumed diet and the total nutrients present in the leftovers, on a total-DM basis.

A digestibility trial was performed across 10 days after 35 days of experimental feeding: five days for adaptation followed by five days for collection. The animals were kept in metabolism cages equipped with feeding and drinking troughs. Faeces were sampled using collection bags fixed to the animals, attached to the animals before the sampling period. The bags were weighed and emptied twice daily. A subsample of 10% of the total faeces amount was collected for further analysis. Samples were stored in a freezer at −20 °C.

2.4. Nitrogen balance

Urine was collected once a day in plastic buckets containing 100 mL 20% hydrochloric acid (HCl) so as to avoid nitrogen volatilization, and sampled (10% aliquot of the total urine) for nitrogen content determination. The apparent nitrogen balance (NB) was calculated according to the methodology described by Silva and Leão (1979).

2.5. Chemical analyses

Samples of the ingredients, diets, leftovers and faeces were pre-dried in a forced-air oven at 55°C for 72-h and ground to 1-mm particles (Wiley Mill, Marconi, MA-580, Piracicaba, Brazil). Chemical analyses were performed using the procedures described by the Association of Analytical Chemists (AOAC Association of Analytical Chemists, 2016) for dry matter (DM), mineral matter (MM), crude protein (CP), ether extract (EE), and acid detergent fiber (ADF), using the protocols 967.03; 942.05; 981.10; 920.29; and 973.18, respectively. Neutral detergent fiber (NDF) was determined as described by Van Soest et al. (1991) and lignin was determined by Silva and Queiroz (2002).

To estimate total carbohydrates (TC), we used the equation proposed by Sniffen et al. (1992). The non-fiber carbohydrates content (NFC) in diets containing urea in their composition were calculated as proposed by Hall (2003). In urea-free diets, NFC were obtained according to Weiss (1993).

The apparent digestibility coefficient of nutrients was calculated as described by Silva and Leão (1979). Total digestible nutrients (TDN) were estimated on the basis of the data of apparent digestibility, and calculated according to Sniffen et al. (1992). TDN of diets was converted into metabolisable energy using the National Research Council's equations (NRC, 2001).

2.6. Productive performance

To determine the body weight gain (BWG), the animals were weighed at the experimental period beginning, and at the end of the experimental period, after a solid-food deprivation period of 1200 h (with water access). The feed conversion (FC) was calculated as the ratio between the dry matter intake (DMI) and the average daily weight gain of the animals in the entire experimental period.

2.7. Statistical analysis

The data were submitted to Shapiro-Wilk and Levene's tests to verify the normality of the residues and homogeneity of the variances, respectively; once the assumptions were met, they were submitted to ANOVA by using the Statistical Analysis System version (SAS University) software. For productive performance variables, the animals' initial body weight (BW) was used as a covariate. Significant probability values were those below 5% ($P < 0.05$) using Tukey's test.

3. Results

The animals that received SCGS diet displayed higher DM (1.64 kg/day; $P = 0.018$) and OM (1.51 kg/day; $P = 0.014$) intake than the animals that received CS diet, and the average values of DM and OM intake of CS group were similar to those of the animals that received SCS, SCBS and SCPS diets (Table 4). The animals that received SCGS diet displayed higher DM intake in g/kg $BW^{0.75}$ (360.13 g/kg $BW^{0.75}$) compared to other silages tested ($P = 0.010$; Table 4).

The diets containing SCGS and SCPS showed the highest CP intake than CS ($P = 0.005$; Table 4). Lower EE intake was found in animals receiving diets containing SCS and CPBS than the other silages tested ($P = 0.001$; Table 4).

SCBS and SCGS provided higher of NDF intake in relation to the animals that received SCS ($P = 0.015$; Table 4). SCGS and SCPS showed higher NDF intake in g/kg $BW^{0.75}$ compared to other silages tested ($P = 0.01$; Table 4). Animals that received diets containing SCS and SCGS displayed the highest NFC intake ($P = 0.003$; Table 4). Higher TDN intake was found for animals that received diets containing SCGS than those that received SCBS, SCPS, and CS ($P = 0.001$; Table 4) group.

Diets containing SCPS showed lower DM ($P = 0.001$), OM ($P = 0.001$), and CP ($P = 0.001$) digestibility than those diets containing CP, SCBS, SCGS (Table 4). Diets containing SCGS showed a lower EE digestibility compared to other silages tested ($P = 0.009$; Table 4). Diets containing SCPS displayed lower NDF digestibility than those in SCS and SCGS ($P = 0.022$; Table 4). Diets containing SCS and SCPS showed lower NFC digestibility than those in SCBS, SCGS and CS ($P = 0.011$; Table 4) group.

Ingested N ($P = 0.003$), absorbed N ($P = 0.003$), and NB ($P = 0.012$) were lower in the control diet (CS) than in the other tested silages. Animals in SCPS group displayed higher N excretion via faeces ($P =$

Table 2
Chemical composition of ingredients (g/kg dry matter) before making the silages.

Item	Corn	Spineless cactus	Buffelgrass	Gliricidia	Pornunça
Dry matter[a]	262.5	107.5	623.0	247.5	300.1
Mineral matter	32.4	164.0	101.0	82.0	89.7
Neutral detergente fiber	552.5	304.0	683.0	465.9	500.2
Acid detergente fiber	280.5	159.7	479.0	333.9	312.9
Crude protein	62.0	49.5	60.5	179.2	145.0
Ether extract	20.6	14.3	17.4	23.7	47.4
Lignin	46.6	21.8	201.0	80.8	103.3
Soluble carbohydrates	152.1	110.0	40.0	304.8	127.7

[a] in g/kg natural matter.

Table 1
Chemical composition of ingredients (g/kg dry matter) offered in the experimental diets.

	Silages					Concentrate		
Item	CS	SCS	SCBS	SCGS	SCPS	Soybean meal	Corn meal	Wheat bran
Dry matter[a]	304.8	175.9	447.2	215.2	237.6	892.5	891.5	876.5
Mineral matter	70.8	95.6	85.2	88.9	118.9	66.5	19.2	52.3
Crude protein	85.0	50.0	72.2	133.8	130.2	471.8	101.6	160.6
Ether extract	31.6	19.3	15.0	30.0	30.0	17.1	36.6	35.0
Neutral detergent fiber	619.3	224.1	686.9	642.4	556.6	175.8	175.1	443.0
Acid detergent fiber	249.1	208.3	315.2	415.8	363.3	98.5	77.6	141.7
Lignin	59.4	63.7	60.1	49.0	68.4	13.2	12.8	57.4
Total carbohydrates	812.6	835.1	827.6	747.2	720.9	444.6	842.6	752.1
Non-fibrous carbohydrates	193.3	611.0	170.7	104.8	164.3	268.8	667.5	309.1
pH	3.5	4.9	3.9	3.9	4.4			
Ammonia nitrogen (g/kg N)	43.9	47.5	10.0	24.7	20.5			
Acetic acid	28.5	6.0	37.0	1.9	11.6			
Propionic acid	0.7	4.8	3.2	0.2	5.1			
Butiric acid	0.4	9.1	1.5	0.01	19.3			
Aerobic stability (h)	62.0	26.67	>96	57.7	96.0			

CS - corn silage; SCS - spineless cactus silage; SCBS - spineless cactus + buffelgrass silage; SCGS - spineless cactus + gliricidia silage; SCPS - spineless cactus + pornunça silage.

[a] in g/kg natural matter.

Table 3
Ingredient proportion and chemical composition (% dry matter) of the experimental diets.

Ingredients	Experimental diets CS	SCS	SCBS	SCGS	SCPS
Silage	59.6	37.8	59.5	59.6	59.7
Soybean meal	5.7	5.9	10.7	5.9	6.6
Corn meal	31.5	9.6	26.4	31.7	31.1
Wheat bran	0.0	43.5	0.0	0.0	0.0
Urea	0.2	0.5	0.7	0.0	0.0
Mineral core[a]	1.5	1.4	1.5	1.5	1.5
Ammonium chloride	1.2	1.2	1.2	1.2	1.2
Ammonium sulfate	0.02	0.05	0.07	0.00	0.00
	Chemical composition				
Dry matter[b]	42.2	32.8	50.9	28.9	30.0
Mineral matter	14.6	14.4	14.6	14.6	14.6
Crude protein	16.1	15.9	15.9	16.0	16.0
Ether extract	4.1	3.0	2.8	3.9	3.9
Neutral detergent fiber	43.5	30.4	44.7	44.9	39.8
Acid detergent fiber	26.2	23.1	35.6	21.3	32.0
Lignin	2.9	5.1	6.5	5.4	7.3
Total carbohydrates	65.2	66.6	66.6	65.4	65.4
Non-fibrous carbohydrates	29.3	41.4	28.7	36.0	28.2
Total digestible nutrients	70.6	69.3	67.4	70.5	70.1
Metabolizable energy (Mcal/day)	2.5	2.5	2.2	2.5	2.5

CS - corn silage; SCS - spineless cactus silage; SCBS - spineless cactus + buffelgrass silage; SCGS - spineless cactus + gliricidia silage; SCPS - spineless cactus + pornunça silage.

[a] Guaranteed levels provided by the manufacturer: (per kg in active elements): calcium – 120 g (min.); phosphorus – 87 g (min.); sodium – 147 g (min.); sulfur – 18 g (min.); copper – 590 mg (min.); cobalt – 40 mg (min.); chromium – 20 mg (min.); iron – 1800 mg (min.); iodine – 80 mg (min.); manganese – 1300 mg (min.); selenium – 15 mg (min.); zinc – 3800 mg (min.); molybdenum – 10 mg (min.); fluorine – 870 mg (max.); phosphorus (P) solubility in 2% citric acid – 95% (min.).

[b] in% natural matter.

0.001) and less N excretion via urine ($P = 0.033$) (Table 5).

Animals in SCGS group had higher final weight ($P = 0.006$; Table 6). Diets containing SCS and SCGS had higher BWG ($P = 0.001$; Table 6). SCBS-fed animals displayed the worst feed conversion ($P = 0.001$; Table 6).

4. Discussion

Evaluating the potential use of spineless cactus silage and the combination of spineless cactus with forage plants in mixed silages in diets for lambs is necessary to validate its nutritional capacity, so that is might be considered a viable food alternative for ruminants. The production of a diet constituted by mixed silages based on spineless cactus in combination with buffelgrass, pornunça and gliricidia, allows the simultaneous use of these forage resources, reducing labour costs improving the potential yield of dry matter. The homogeneous mixture of silage as a complete diet reduces the selection of components by the animals, benefiting their performance and decreasing costs compared to the conventional diet, given the more efficient intake (Macêdo et al., 2018).

The higher DMI provided by the diets indicate that studied silages showed desirable fermentation, which may influence their acceptability by the animals. The DMI directly affects the animals' productive performance (Mertens 1994). Thus, the diets resulted in average weight gain of 0.268 kg/day, with greater body weight gain for the animals receiving SCS (15.2 kg, approximately 0.293 kg/day) and SCGS diets (15.1 kg, approximately 0.303 kg/day), due to the higher DMI that these diets provided. The values found are above that established by the NRC National Research Council, 2007 (200 g/day). Bendaou and Omar (2013) used spineless cactus silage as feed to evaluate lamb's

Table 5
Nitrogen balance in lamb fed diets containing spineless cactus silage associated with forages adapted to the semiarid environment.

Itens	Experimental diets CS	SCS	SCBS	SCGS	SCPS	MSE	P Value
	g/day						
Nitrogen intake	31.7b	38.2ab	38.4ab	43.3a	42.8a	1.09	0.003
Nitrogen faeces	7.4b	8.4b	5.5b	8.3b	12.6a	0.58	0.001
Nitrogen urine	5.8ab	4.8ab	7.2a	4.9ab	3.0b	0.46	0.033
Absorbed nitrogen	24.3b	29.8ab	32.9a	35.1a	30.3ab	1.02	0.003
Nitrogen balance	18.5b	24.9ab	25.7ab	30.2a	27.2ab	1.14	0.012

CS - corn silage; SCS - spineless cactus silage; SCBS - spineless cactus + buffelgrass silage; SCGS - spineless cactus + gliricidia silage; SCPS - spineless cactus + pornunça silage; MSE - Mean standard error; P - Probability value; Means followed by distinct letters differ statistically by the Tukey test at the 5% probability level.

Table 4
Daily intake of nutritional components and apparent digestibility of nutrients in lamb fed diets containing spineless cactus silage associated with forages adapted to the semiarid environment.

	Items	Experimental diets					MSE	P Value
CS		SCS	SCBS	SCGS	SCPS			
	Intake (kg/day)							
Dry matter	1.20b	1.48ab	1.40ab	1.64a	1.46ab	0.04	0.018	
Organic matter	1.12b	1.36ab	1.28ab	1.51a	1.28ab	0.03	0.014	
Crude protein	0.20b	0.24ab	0.24ab	0.27a	0.25a	0.01	0.005	
Ether extract	0.06a	0.04b	0.04b	0.07a	0.06a	0.02	0.001	
Neutral detergent fiber	0.52ab	0.45b	0.63a	0.74a	0.58ab	0.03	0.015	
Non-fibrous carbohydrates	0.38b	0.66a	0.45b	0.64a	0.45b	0.02	0.003	
Total digestible nutrients	0.77c	0.97ab	0.82bc	1.12a	0.87bc	0.03	0.001	
	Intake g/kg $BW^{0,75}$							
Dry matter	202.6c	193.4c	191.6c	360.1a	286.3b	11.66	0.010	
Neutral detergent fiber	8.6bc	7.6c	9.7b	12.3a	11.7a	0.32	0.010	
	Digestibility (g/kg)							
Dry matter	747.5ab	777.4a	780.1a	809.9a	667.0b	12.61	0.001	
Organic matter	756.2ab	791.9a	789.1a	818.6a	675.7b	11.87	0.001	
Crude protein	747.7ab	793.9a	836.0a	797.6a	667.6b	13.92	0.001	
Ether extract	901.1a	806.1ab	876.9a	744.1b	846.2a	16.64	0.009	
Neutral detergent fiber	646.9ab	757.2a	676.5ab	708.59a	551.4b	11.85	0.022	
Non-fibrous carbohydrates	873.9a	810.2b	892.3a	874.9a	836.8b	8.67	0.011	

CS - corn silage; SCS - spineless cactus silage; SCBS - spineless cactus + buffelgrass silage; SCGS - spineless cactus + gliricidia silage; SCPS - spineless cactus + pornunça silage; MSE - Mean standard error; P - Probability value; Means followed by distinct letters differ statistically by the Tukey test at the 5% probability level.

Table 6
Productive performance in lamb fed diets containing spineless cactus silage associated with forages adapted to the semiarid environment.

Itens	Experimental diets					MSE	P
	CS	SCS	SCBS	SCGS	SCPS		Value
Initial body weight (kg)	22.4	21.7	22.1	24.2	23.3	0.24	0.230
Final body weight (kg)	34.1b	36.9ab	33.2b	39.4a	37.2ab	0.61	0.006
Body weight gain (kg)	11.7b	15.2a	11.1b	15.1a	13.9ab	0.43	0.001
Feed conversion	5.1a	5.0a	6.0b	5.4a	5.2a	0.15	0.001

CS - corn silage; SCS - spineless cactus silage; SCBS - spineless cactus + buffelgrass silage; SCGS - spineless cactus + gliricidia silage; SCPS - spineless cactus + pornunça silage; MSE - Mean standard error; P - Probability value; Means followed by distinct letters differ statistically by the Tukey test at the 5% probability level.

performance and reported weight gain of 195 g/day for animals fed spineless cactus silage and 255 g/day for a conventional diet.

The higher intake of dry matter provided by the SCGS may be related to the high digestibility of NDF in this group. Diets based on spineless cactus provide reduced NDF and ADF contents, which provides rapid ruminal emptying, since the spineless cactus does not have enough fiber to limit intake through physical filling, which favoured the results obtained, without interference with the animal performance (Macêdo et al., 2018). The combination of gliricidia with spineless cactus in the silage composition is interesting, given that, despite the high nutritional value that gliricidia has, it has a reduced acceptability by animals when used *in natura* form, due to the characteristic odour of green leaves, as a function of the release of volatile compounds (Sá et al., 2021). Thus, the complementation of these forage plants can provide the small ruminants with a silage with high nutritional value.

SCGS and SCPS diets provided EE intake similar to CS diet. Likewise, SCGS and SCPS diets provided higher CP and N intake than CS diet. This can be attributed to the higher content of EE and CP that gliricidia and pornunça present in their composition (Table 2). According to the NRC National Research Council, 2007, adequate levels of protein and energy intake for young lamb are necessary so that the animals can develop and fulfil their potential, and the maintenance requirement of these animals is made with less intake when compared to animals with greater weight and when if greater gains are sought, it is essential to balance the feed and meet the nutrients offered to animals' quality and quantity (McGrath et al., 2018).

The results observed for SCGS and SCPS are promising. Although there are recommendations for the cultivation of corn for the semiarid environment, its production has been highly affected by climate change in the region. In addition, since corn is a commodity, small ruminant farmers are looking for alternative ingredients to compose the diet of animals in confinement, with the aim of reducing costs without affecting productivity (Muscat et al., 2020).

The association of spineless cactus with forages adapted to the semiarid, such as gliricidia and pornunça, in the silage form is an alternative to replace the use of corn silages, reducing production costs and offering the animals feed with the energy and protein needed to improve the productive performance (Gusha et al., 2015). This is positive, as rumen microorganisms depend on fermentable sources of energy and nitrogen for their metabolic activity, strongly influencing rumen digestibility and nutrient flow. Thus, synchronization between energy and protein is essential to maximize microbial efficiency, promoting an improvement in dry matter digestibility (Barros e Silva et al. 2022).

The CP intake values found in the diets are above (117 g/animal/day, for 20 kg lambs with daily gains of 200 g) the NRC National Research Council, 2007 recommendation. The higher CP intake in SCGS and SCPS compared to the other silages tested is due to the higher CP in gliricidia and pornunça leaves used in making silage with spineless cactus. This result confirms the potential of using these species as a CP source in feeding ruminants, especially in combination with spineless cactus (Gusha et al., 2015).

The lower CP and NDF digestibility and the high N excretion in faeces found observed for lamb that received diets containing SCPS was lower than those observed for SCS, SCBS and SCGS. This fact is related to the higher lignin content that pornunça presents in its composition (Table 2), in relation to the other ingredients used in the making of the silages. As protein can bind lignin and lignin has low or no digestibility, it may have exerted a direct influence on CP thus being considered the main limiting factor of forage digestibility (NRC National Research Council, 2016). Thulin et al. (2014) mention that lignin is negatively correlated with CP and NDF digestibility, since it prevents the digestion of hydrolytic enzymes, limiting the attack of rumen microorganisms and, thus, reducing the action of microorganisms in the digestion process.

All diets tested provided TDN intakes higher than the 0.55 kg TDN/animal/day established by the NRC National Research Council, 2007, for animals of this category to obtain 200 g/animal/day. The NDF intake within the recommended standards did not limit the TDN intake, meeting the animals' requirements in this study. It is observed that CS diet provided lower TDN intake (0.77 kg/day) compared to SCS diet in its composition (0.82 – 1.12 kg/day). Similar to our findings, Costa et al. (2012), when testing spineless cactus levels to replace corn in diets for lamb, observed that diets containing 100% corn provided lower TDN intake (0.81 kg/day) compared to diets containing spineless cactus in its composition (0.84 – 0.90 kg/day).

The highest NFC intake for SCS and SCGS is due to the high NFC concentration in spineless cactus. Moura et al. (2020) also reported that lamb increased NFC intake with increased spineless cactus in diets containing maniçoba. Spineless cactus has low concentrations of DM, NDF and CP, requiring its association with fiber and protein sources to be used in the small ruminants feeding to maintain the proper conditions of ruminal functionality (Rodrigues et al., 2016). Thus, the complementation of spineless cactus silage with gliricidia is a way to supply the nutritional characteristics which spineless cactus presents in small amounts.

Although the highest N intake was observed for lambs that received SCGS and SCPS, all silages tested provided N intake above (31.7–43.3 g/day) of the NRC National Research Council, 2007 recommendation, which is 19.7 g /animal/day for lambs weighing 20 kg and gains of 200 g/day. The nitrogen intake above the requirements promotes greater nitrogen losses via faeces and urine, showing that the animal's excess nitrogen is eliminated (Van Soest 1994), as highlighted in the present study. According to Pereira et al. (2021), when N intake is greater than N excretion through faeces, it is indicative of adequate diet balance.

The nitrogen excreted in the urine is related to the protein degraded in rumen, resulting from the excess of ammonia produced from the rapid ruminal degradation and hydrolysis of urea (Hristov et al., 2019), justifying the higher concentration of N in the urine of SCBS, due to the highest urea concentration in the diet (Table 2). All treatments showed positive NB, demonstrating that the animals did not need to displace their body reserves to meet their nutritional requirements and that the diet was sufficient to meet the nutritional demand.

5. Conclusion

Combining spineless cactus with a roughage base, in a 70:30 ratio, associated with a concentrate source in a roughage:concentrate ratio of 60:40, allowed weight gains over 200 g/day, proving to be efficient in diets for feedlot sheep and gains similar or superior to corn silage based diets.

Data availability statement

The data that support this study will be shared upon reasonable request to the corresponding author.

CRediT authorship contribution statement

Tiago Santos Silva: Data curation, Formal analysis, Investigation, Methodology. **Gherman Garcia Leal de Araújo:** Conceptualization, Supervision, Funding acquisition. **Edson Mauro Santos:** Conceptualization, Supervision, Funding acquisition. **Juliana Silva de Oliveira:** Conceptualization, Supervision, Funding acquisition. **Paulo Fernando Andrade Godoi:** Data curation, Formal analysis, Investigation, Methodology. **Glayciane Costa Gois:** Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Alexandre Fernandes Perazzo:** Conceptualization, Supervision, Funding acquisition. **Ossival Lolato Ribeiro:** Conceptualization, Supervision, Funding acquisition. **Silvia Helena Nogueira Turco:** Conceptualization, Supervision, Funding acquisition. **Fleming Sena Campos:** Data curation, Formal analysis, Investigation, Methodology.

Conflicts of interest

The authors declare no conflicts of interest.

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