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Cactus Pear Silage to Mitigate the Effects of an Intermittent Water Supply for Feedlot Lambs: Intake, Digestibility, Water Balance and Growth Performance

Ismael de Sousa Nobre [1], Gherman Garcia Leal de Araújo [2], Edson Mauro Santos [1], Gleidson Giordano Pinto de Carvalho [3], Italo Reneu Rosas de Albuquerque [3], Juliana Silva de Oliveira [1], Ossival Lolato Ribeiro [4], Silvia Helena Nogueira Turco [5], Glayciane Costa Gois [5], Thieres George Freire da Silva [6], Alexandre Fernandes Perazzo [7], Anderson de Moura Zanine [8], Daniele de Jesus Ferreira [8], Francisco Naysson de Sousa Santos [8] and Fleming Sena Campos [8,*]

1 Department of Animal Science, Federal University of Paraíba, Areia 58051-900, Brazil
2 Brazilian Agricultural Research Corporation, Petrolina 56302-970, Brazil
3 Department of Animal Science, Federal University of Bahia, Salvador 40170-110, Brazil
4 Department of Animal Science, Federal University of the Reconcavo of Bahia, Cruz das Almas 44380-000, Brazil
5 Department of Animal Science, Federal University of São Francisco Vale, Petrolina 56304-917, Brazil
6 Postgraduate Program in Plant Production, Academic Unit of Serra Talhada, Federal Rural University of Pernambuco, Serra Talhada 56909-535, Brazil
7 Department of Animal Science, Federal University of Piauí, Teresina 64049-550, Brazil
8 Department of Animal Science, Federal University of Maranhão, Chapadinha 65080-805, Brazil
* Correspondence: flemingcte@yahoo.com.br

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Abstract: The aim of this study was to evaluate the intake, digestibility, water balance and growth performance of lambs receiving diets containing cactus silage under an intermittent water supply. Thirty-six male, uncastrated Santa Inês lambs with an initial weight of 19.8 ± 2.1 kg and age of 6 months were distributed in a 3 × 3 factorial arrangement, with three proportions of cactus pear in the diets (0 (control diet containing Tifton hay), 21% and 42% of dry matter) and three periods of intermittent water supply (0, 24 and 48 h), with four repetitions. Lambs that received diets non-isonitrogenous with cactus silage showed higher intakes of dry matter ($p < 0.001$), total digestible nutrients ($p < 0.001$), water excretion via faeces ($p < 0.001$) and water balance ($p < 0.001$). Lambs that received diets with cactus silage showed higher digestibility of total carbohydrates, non-fibre carbohydrates ($p = 0.005$), water intake via food ($p < 0.001$), total water intake ($p < 0.001$), water excretion via urine ($p < 0.001$) and water balance ($p < 0.05$), when compared to the control diet. Lambs that received diets with cactus silage promoted growth performance ($p = 0.001$). When using 42% forage cactus silage in place of Tifton hay and water offered at 48 h intervals, intake, digestibility, and performance of feedlot lambs were improved.

Keywords: animal production; succulent feed; water restriction

1. Introduction

The semi-arid region of the Brazilian northeast is one of the world's most densely populated dryland regions [1]. Its outstanding characteristics are high temperatures (annual average of 28 °C [2]), low rainfall (annual average of less than 800 mm [3]), relative air humidity around 55% [2], evaporative demand greater than 2000 mm/year, Thornthwaite aridity index ≤ 0.50, annual water deficit ≥ 60% and periodic droughts, which result in a water deficit for most of the year [3]. These factors directly influence the vegetation, its economy, and the feeding of animals and humans [4].

Due to food limitations and the lower nutritional value of available pastures, the dry season poses a serious challenge to animal production in semi-arid regions. Due to its adaptation to the region's soil and climatic conditions, high water content, potential for biomass production (241.75 t/ha green matter and 12.46 t/ha dry matter [DM]) and nutritional value (as a source of energy, non-fibre carbohydrate), the spineless cactus is a substitute compared to traditional forage sources and common food found in these areas [5,6].

It has excellent palatability, high metabolizable energy (11.38 MJ/kg DM; [7]), high digestibility (690–780 g/kg) [8], and a high water content (109 g/kg DM [9]), contributing to the supply of dietary water for the animal. However, the low content of DM (109 g/kg DM [9]), crude protein (44.6 g/kg DM [9]), neutral detergent fibre (260.3 g/kg DM [10]) and acid detergent fibre (146 g/kg DM [9]) impair its supply as the sole source of water to animals.

According to [6], in a study on the performance of lambs fed spineless cactus silage associated with forages adapted to the semi-arid environment, the diets resulted in an average weight gain of 0.268 kg/day, with greater body weight gain for the animals receiving spineless cactus silage (15.2 kg, approximately 0.293 kg/day) and spineless cactus + gliricidia silage (15.1 kg, approximately 0.303 kg/day) diets, due to the higher DM intake that these diets provided. The values found are above that established by [11] (200 g/day). When using forage palm silage as a ratio to evaluate the performance of lambs, Bendaou et al. [12] observed that animals fed with silage gained 195 g per day of weight, in comparison with those fed with a conventional diet with a weight gain of 255 g per day.

In addition, water supports the maintenance of homeostasis and is connected to all metabolic activities. IBGE [13] estimates that there are 13.5 million sheep in the semi-arid area of Brazil alone. These animals would need 41.1 million litres of water per day if they drank about 3 L per animal each day [14]. This number may be considerably higher if we consider the water content of the feed that these animals consume, the water used to produce the feed, and the water necessary to clean the cages and other equipment. So, the amount of water needed for animal husbandry is significant and should be used intelligently in order to maximize the efficiency of its abstraction and usage, which will have a positive impact on the environment.

A scarcity of water for animal consumption has the consequences of reducing growth, well-being and health, and increasing stress, generating negative impacts on productive and economic factors. According to [14], in sheep, water restriction can lead to skin retraction, dry eyes, weight loss, low food intake, dry faeces and reduced urine excretion.

This is important because during the dry season, the lack of water severely limits livestock production, and herds frequently need to travel several kilometres to reach a water source. In such cases, an intermittent water supply can be used as a strategy to mitigate the effects of water scarcity [15].

Studies evaluating the effects of forage-cactus-based silages on intake, digestibility, water balance and performance have already been reported in different parts of the world, such as Zimbabwe, per [16]. However, this information with small ruminants is still incipient in the semi-arid region of Brazil; it is limited and generally considers the use of cactus pear silage to mitigate the effects of an intermittent water supply [15,17,18]. We hypothesized that cactus pear silage reduces water intake by lambs, meeting the water demand of the animals without affecting live weight gain.

The aim of this study was to evaluate the intake, digestibility, water balance and growth performance of lambs growing receiving diets containing cactus silage under an intermittent water supply.

2. Materials and Methods

2.1. Description of the Study Site

The experiment was conducted at the experimental Caatinga biome field of the Animal Metabolism Unit, Embrapa Semi-arid, located in Petrolina, state of Pernambuco, Brazil. The municipality is at 376 m altitude, at the geographical coordinates of 9°23′35″ S latitude and 40°30′27″ W longitude. The climate is BSwh′ semi-arid, with summer rainfall [19]. The mean annual rainfall is 570 mm, relative humidity is 36.73% and average annual maximum and minimum temperatures are 32.22 °C and 20.90 °C, respectively.

The present study was submitted and approved by the Ethics Committee on the Use of Animals (CEUA) of the Federal University of Bahia (Opinion no. 0005/2016).

2.2. Animals, Experimental Design and Diets

Thirty-six crossbred, growing, intact male Santa Inês lambs from the same herd and from a single delivery (6 months of age and 19.8 ± 2.1 kg body weight) were housed in individual pens (1.2 × 1.0 m) equipped with feeding and drinking fountains for the diet and water supply. The experiment lasted 84 days, including 10 days of adaptation. At the beginning of the adaptation period, animals were identified, weighed, treated against endo- and ectoparasites through the application of an oral solution (200 µg/kg body weight; Ivomec, Merial, Campinas, Brazil) and randomly assigned to the pens previously identified according to the treatment.

Treatments were arranged in a 3 × 3 factorial design comprising three levels of cactus silage replacing Tifton hay in the diet (0, 21% and 42% on DM basis) and three intervals for supplying water (0, 24, and 48 h), with four replications. The effect of variables isolated was evaluated when the interaction was not significant. Water was supplied intermittently according to the respective treatments: T1 = no water restriction (daily water supply), T2 = 24 h of restriction and then water supply for 24 h and T3 = 48 h of restriction and then water supply for 24 h. On the water supply days, fresh water was provided ad libitum in the morning (at 09:00 h).

Experimental diets consisted of forage cactus silage, Tifton hay and concentrate based on corn meal, soybean meal, wheat bran and mineral supplements (Table 1).

Table 1. Chemical composition and fermentative characteristics of the ingredients used in experimental diets.

Items (in g/kg Dry Matter)	Ground Corn	Soybean Meal	Wheat Bran	Tifton Hay	Cactus Silage
Dry matter [a]	872	886	867	887	74
Organic matter	980	929	949	937	831
Ether extract	48	27	25	16	26
Crude protein	104	529	198	56	83
NDFap	388	213	420	614	428
Acid detergent fibre	345	128	125	404	279
Total carbohydrates	827	395	726	865	721
Non-fibre carbohydrates	439	182	307	251	293
Cellulose	25	124	85	340	224
Hemicellulose	354	85	294	210	149
Acid detergente lignin	09	04	40	63	55
Total digestible nutrients	937.5	832.4	742.8	604.9	659.91
pH	-	-	-	-	4.95
Water-soluble carbohydrates	-	-	-	-	15.06
N-NH3 (%NM)	-	-	-	-	2.72
Buffer capacity	-	-	-	-	14.23

[a] in g/kg fresh matter; NDFap—neutral detergent fibre corrected to ash and protein.

Silage comprised Mexican Elephant Ear cactus (*Opuntia stricta* Haw) forage harvested at 24 months after regrowth. The material was chopped with a stationary forage harvester (PP-35, Pinheiro máquinas, Itapira, São Paulo, Brazil) to an average particle size of approximately 2.0 cm and stored in 200 L plastic-drum silos (89 cm × 59 cm × 59 cm) with a removable lid sealed with a metal ring. The silage was used after a minimum period of 60 d after its confection. The diets were formulated as non-isonitrogenous, so the crude protein contents were not similar; however, they were formulated according to the recommendations of [11] for estimated weight gains of 150 g/day. The roughage: concentrate ratio was 60:40, and cactus silage was used to replace three proportions of hay in the diet (0, 21% and 42% DM) (Table 2).

Table 2. Chemical composition of the experimental diets.

Items (% Dry Matter)	Forage Cactus Silage Levels		
	0%	21%	42%
Ground corn	28	23	18
Soybean meal	8	10	12
Wheat bran	3	6	9
Tifton hay	60	39	18
Forage cactus silage	-	21	42
Mineral supplement [a]	1	1	1
	Chemical composition (in g/kg DM)		
Dry matter [b]	858	697	537
Organic matter	936	916	895
Crude protein	118	130	143
Ether extract	29	28	27
NDFap	491	445	399
Acid detergent fibre	259	237	214
Total carbohydrates	788	756	724
Non-fibre carbohydrates	297	311	325
Cellulose	220	198	176
Hemicellulose	231	208	185
Acid detergent lignin	39	39	37
Total digestible nutrients	660	661	663

[a] on a fresh matter basis; NDFap—neutral detergent fibre corrected to ash and protein. [b] Guaranteed levels provided by the manufacturer (per kg in active elements): calcium—120 g (min.); phosphorus—87 g (min.); sodium—147 g (min.); sulphur—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.).

Diets were provided twice a day, at 09:00 h and 15:00 h. The amount of feed offered was calculated according to the intake on the previous day. Amounts of feed offered and refused were weighed daily to calculate and adjust intake, allowing at least 10% leftovers in the trough. Weekly, samples of the offered food and refusals were individually collected per animal and stored at −20 °C for later laboratory analysis.

2.3. Intake and Digestibility of Nutrients

Daily DM intake was obtained from the difference between the total DM of the distributed feed and the total DM present in the refusals. Nutrient intake was determined as the difference between the total nutrients present in the ingested feed and the total nutrients present in the leftovers, on a total-DM basis.

A digestibility test was performed across 15 days in the final third of the experimental period: 10 days for adaptation followed by 5 days for data collection. For this, animals were distributed in metabolic crates provided with feeding arranged in a covered area. The faeces of each animal were collected using collection bags, which were fixed to the animals two days before the sampling period. Bags were weighed and emptied twice daily, and a sub-sample of 10% of the total amount was collected to form a composite sample for each treatment, which was stored at −20 °C. Urine was collected and weighed once daily in plastic buckets. The urine was then filtered, and 10 mL aliquots were collected and immediately diluted in 40 mL 0.03 N sulfuric acid [20].

2.4. Assessment of 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. Water balance was evaluated according to [21]. The production of metabolic water (faeces and urine) was estimated from the chemical analysis of the diets and calculated by multiplying the consumption of carbohydrates, protein and digestible ether extract by the factors 0.60, 0.42 and 1.10, respectively.

Water balance (WB) was evaluated using the following equations [20]:

$$\text{Total water intake (TWI; kg/day)} = \text{water intake (corrected for evaporation)} + \text{water from the diet} \quad (1)$$

$$\text{Total water excretion (kg/day)} = \text{water excreted via urine (WEU)} + \text{water excreted via faeces (WEF)} \quad (2)$$

$$\text{Water balance} = \text{total water intake} - \text{total water excretion} \quad (3)$$

2.5. Growth Performance

Animals were weighed at the beginning and end of experimental period and after a 12 h period of solid food deprivation (with access to water) to obtain the initial body weight (IBW), final body weight (FBW), total weight gain (TWG), average daily gain (ADG) and feed conversion (FC). The following equations were used:

$$\text{TWG (kg)} = \text{FBW} - \text{IBW} \quad (4)$$

$$\text{ADG (g/day)} = \text{TWG/confinement days} \quad (5)$$

$$\text{FC} = \text{dry matter intake/ADG} \quad (6)$$

2.6. Laboratory Analysis

Samples of ingredients, diets, refusals and faeces were pre-dried in a forced-air oven at 55 °C for 72 h and ground to 1 mm particles in a knife mill (Wiley Mill, Marconi, MA-580, Piracicaba, Brazil). All chemical analyses were performed using the procedures described by [22] for DM (DM; Method 967.03), mineral matter (MM; Method 942.05), crude protein (CP; Method 981.10) and ether extract (EE; Method 920.29). Neutral detergent fibre corrected for ash and protein (using heat-stable alpha-amylase without sodium sulphite) NDFap [23,24] and acid detergent fibre (ADF) were determined as described by [25] and lignin was determined by treating the ADF residue with 72% sulfuric acid [26]. Hemicellulose (HEM) was calculated by the following equation:

$$\text{HEM} = \text{NDF} - \text{ADF} \quad (7)$$

Total carbohydrates (TC) were estimated according to the equation proposed by [27], as follows:

$$\text{TC (g/kg)} = 1000 - (\text{CP} + \text{EE} + \text{MM}) \quad (8)$$

where

CP = crude protein;

EE = ether extract;

MM = mineral matter.

Non-fibre carbohydrate (NFC) contents were calculated as proposed by [28]:

$$\text{NFC (g/kg)} = \text{TC} - \text{NDFap} \quad (9)$$

The apparent digestibility coefficient of nutrients was calculated as described by [29]:

$$\text{ADC} = \{[\text{Nutrients ingested (kg)} - \text{nutrients excreted in the faeces (kg)}]/\text{nutrients ingested (kg)}\} \times 100 \quad (10)$$

Total digestible nutrients (TDN) were estimated on the basis of the data on apparent digestibility and calculated according to [27]:

$$\text{TDN} = \text{DP} + \text{DNDF} + (\text{DEE} \times 2.25) + \text{DNFC} \quad (11)$$

where

DP = digestible protein;

DNDF = digestible neutral detergent fibre;

DEE = digestible ether extract;

DNFC = digestible non-fibre carbohydrates.

2.7. Statistical Analysis

Treatments were arranged in a distributed 3 × 3 factorial arrangement, with three proportions of cactus pear in the diets (0 (control diet containing Tifton hay), 21% and 42% of dry matter) and three periods of intermittent water supply (0, 24 and 48 h), with four repetitions. The effect of variables isolated was evaluated when the interaction was not significant.

Data were tested by Shapiro–Wilk and Levene's tests to check the normality of the residuals and homogeneity of the variances, respectively; once the assumptions were met, they were tested by ANOVA, and means were compared by Tukey's test, as well as the interactions between them, with a statistical probability of up to 5% ($p < 0.05$) considered as significant using the Statistical Analysis System version 9.4 (SAS Institute, Inc. Cary, NC, USA) software.

The following mathematical model was used:

$$\text{Yijk} = \mu + \alpha\text{i} + \beta\text{j} + (\alpha\beta)\text{ij} + \text{k} + \text{eijk} \quad (12)$$

where Y is the observed value of variable ijk that refers to the k-th repetition of the combination of the i-th level of factor A with the j-th level of factor B; μ is the mean of all experimental units for the variable; αi is the effect of the levels of forage cactus silage (i = 0, 21% and 42%) at the observed value Yijk; βj is the effect of the intermittent water supply (j = 0, 24 h and 48 h) at the observed value Yijk; αβij is the effect of the interaction between the levels of forage cactus silage and intermittent water supply; k is the block effect on the observation Yijk; and eijk is the error associated with the observation of Yijk.

3. Results

There was no significant effect of an intermittent water supply (drinking fountain), nor was there a significant effect of the interaction between water supply and cactus silage on the DM and nutritional fraction intake ($p > 0.05$; Table 3). The lambs that received diets with 21% and 42% cactus silage showed higher intakes of DM, MO, CP, NDFap, TC, NFC and TDN ($p < 0.05$) when compared to the lambs that received the control diet (Table 3). Lambs that received the diet with 21% cactus silage showed the highest EE intake ($p < 0.001$; Table 3).

Table 3. Daily intake of nutritional components and apparent digestibility of nutrients in lambs fed forage cactus silage under an intermittent water supply.

Itens	Cactus Silage (%)			Intermittent Water Supply (h)			SEM	*p* Value		
	0	21	42	0	24	48		CS	IW	CS × IW
				Intake (g/day)						
Dry matter	712.8 b	967.4 a	996.1 a	894.7	888.1	893.5	28.70	<0.001	0.991	0.954
Organic matter	617.9 c	1813.8 b	2339.9 a	1635	1485	1640	4.48	<0.001	0.493	0.963
Crude protein	94.9 b	145.0 a	153.3 a	129.2	131.0	132.9	5.49	<0.001	0.915	0.828
Ether extract	24.4 b	32.6 a	25.9 b	29.1	25.9	27.9	1.00	<0.001	0.333	0.749
NDFap	331.9 b	394.9 a	390.5 a	371.5	375.2	370.6	9.38	0.020	0.977	0.976
Total carbohydrate	546.9 b	703.3 a	712.0 a	657.1	652.9	652.3	18.90	<0.001	0.991	0.970
Non-fibre carbohydrates	234.3 b	325.5 a	314.6 a	298.1	282.4	293.9	9.77	<0.001	0.694	0.862
Total digestible nutrientes	470.4 b	642.7 a	635.3 a	596.9	577.7	573.8	21.21	<0.001	0.835	0.954
				Digestibility (g/kg)						
Dry matter	632.5	666.5	681.6	674.0	658.7	646.8	1.25	0.139	0.563	0.282
Organic matter	649.9	682.6	698.7	690.5	674.7	666.2	1.20	0.128	0.582	0.282
Crude protein	711.7	698.2	728.3	708.7	723.2	706.4	1.04	0.383	0.696	0.102
NDFap	598.0	613.7	621.5	627.1	609.3	596.8	8.50	0.730	0.602	0.245
Total carbohydrate	629.6 b	673.7 a	695.2 a	682.1	660.2	656.2	7.80	0.049	0.556	0.359
Non-fibre carbohydrates	704.5 b	761.7 a	779.7 a	765.2	735.5	745.2	1.14	0.005	0.389	0.737

Means followed by different letters differ by Tukey's test at the 5% probability level for the following effects: CS—cactus silage; IW—intermittent water supply; CS × IW—interaction effect for cactus silage and intermittent water supply; NDFap—neutral detergent fibre corrected to ash and protein; SEM—standard error of the mean; *p*-value—probability value.

There was no significant effect of an intermittent water supply, nor was there a significant effect of the interaction between water supply and cactus silage on the apparent digestibility of nutrients ($p > 0.05$; Table 3). Lambs that received diets with 21% and 42% cactus silage showed higher digestibility of TC ($p = 0.049$) and NFC ($p = 0.005$) in relation to the lambs that received the control diet (Table 3).

There was neither an effect of an intermittent water supply nor an effect of the interaction between water supply and cactus silage on water intake, water excretion and water balance ($p > 0.05$; Table 4). The control diet promoted higher water intake via drinker ($p < 0.001$; Table 4). Lambs that received the diet with 42% cactus silage showed higher total water intake and WEU ($p < 0.001$) in relation to the animals fed diets with 21% cactus silage and the control diet (Table 4). Diets with 21% and 42% cactus silage promoted higher WIF, WEF and WB ($p < 0.001$) when compared to the control diet (Table 4).

Table 4. Water balance of lambs fed forage cactus silage under an intermittent water supply.

Itens (g/Day)	Cactus Silage (%)			Intermittent Water Supply (h)			SEM	*p* Value		
	0	21	42	0	24	48		CS	IW	CS × IW
				Intake (g/day)						
Water intake via drinker	1403.7 a	711.0 b	156.0 c	837.1	857.8	530.3	109.71	<0.001	0.065	0.716
Water intake via food	120.2 b	2273.5 a	3432.8 a	2062.8	1903.2	2009.2	239.49	<0.001	0.145	0.586
Total water intake	1523.9 c	2984.5 b	3588.8 a	2899.9	2760.9	2539.5	173.12	<0.001	0.305	0.462
Water excretion via faeces	331.4 b	687.2 a	646.3 a	588.8	545.9	548.1	36.90	<0.001	0.733	0.358
Water excretion via urine	255.5 c	630.8 b	1090.3 a	787.1	551.6	661.6	72.43	<0.001	0.066	0.736
Water balance	937.0 b	1666.5 a	1852.1 a	1523.9	1663.5	1328.8	96.33	<0.001	0.224	0.767

Means followed by different letters differ by Tukey's test at the 5% probability level for the following effects: CS—forage cactus silage; IW—intermittent water supply; CS × IW—interaction effect for cactus silage and intermittent water supply; SEM—standard error of the mean; *p*-value—probability value.

Animals fed a diet with 42% cactus silage showed higher FBW in relation to the animals receiving the control diet ($p = 0.002$). A higher proportion of cactus silage in the diets promoted higher TWG ($p = 0.001$) and ADG ($p = 0.001$). Animals that received the control diet presented higher FC ($p = 0.028$) than animals fed diets with 42% cactus silage (Table 5). Animals that were given water every 48 h presented higher TWG ($p = 0.032$) and ADG ($p = 0.032$). Lower FC was found for animals that received drinking water every 48 h ($p = 0.007$) (Table 5).

Table 5. Growth performance of lambs fed cactus silage under an intermittent water supply.

Itens (g/Day)	Cactus Silage (%)			Intermittent Water Supply (h)			SEM	*p* Value		
	0	21	42	0	24	48		CS	IW	CS × IW
				Intake (g/day)						
Initial body weight (kg)	19.3	20.5	19.8	19.9	20.2	19.3	1.26	0.143	0.326	0.373
Final body weight (kg)	29.8 b	34.1 ab	35.1 a	32.8	32.0	34.2	2.57	0.0018	0.306	0.979
Total weight gain (kg)	10.5 b	13.6 a	15.4 a	12.8 ab	11.8 b	14.8 a	1.83	0.001	0.032	0.609
Average daily gain (g)	142.0 b	184.0 a	208.0 a	173.4 ab	159.1 b	200.8 a	24.75	0.001	0.032	0.609
Feed conversion (kg DMI/kg ADG)	5.0 a	4.4 b	4.1 b	4.7 a	4.9 a	3.9 b	0.49	0.028	0.007	0.081

Means followed by different letters differ by Tukey's test at the 5% probability level for the following effects: CS—cactus silage; IW—intermittent water supply; CS × IW—interaction effect for cactus silage and intermittent water supply; DMI—dry matter intake; ADG—average daily gain; SEM—standard error of the mean; *p*-value—probability value.

4. Discussion

4.1. Intake, Digestibility and Growth Performance

The use of forage cactus silage reduces water intake by lambs, meeting the animals' water demands without affecting growth performance. Thus, the use of forage cactus silage meets the demand for water in periods of water scarcity, attenuating the reduction in feed intake that would culminate in weight reduction due to the loss of body mass and water [30,31].

The average DMI observed was higher than the requirement recommended by the NRC [11], which is 780 g/animal/day for lambs at the age and weight range used in the present study, with gains of 150 g/day. The results of DMI observed for treatments with inclusion levels of forage cactus silage (21% and 42%) were also higher (967.4 and 894.7 g/kg DM, respectively) than the requirement recommended by the NRC [11]. Forage cactus silage, compared to diets containing Tifton hay, may provide higher DMI due to the high rate of DM degradability due to high concentrations of non-fibre carbohydrates, which may explain the results obtained in this study.

Cordova-Torres et al. [32] evaluated the effect of water deprivation (without water and ad libitum) and increasing levels of forage cactus (30%, 50% and 70% in replacement of Tifton hay) in the diets of growing lambs on DMI and obtained values lower than those of the present study when lambs were subjected to water stress (804 g/kg DM) and increasing levels of forage cactus (803 g/kg DM).

Thus, it is evident that there were no limitations on DMI, indicating that the use of cactus silages in place of Tifton hay in diets for small ruminants showed desirable fermentation properties and high acceptability by the animals, which favoured the increase in ADG and feed conversion (Table 5), in addition to providing water supply via food (Table 4), allowing animals to not reduce food intake when receiving water in amounts below their requirements.

The use of cactus silage to replace Tifton hay may have been one of the factors responsible for the highest intake of CP in animals fed 21% or 42% cactus silage in the diets, since the cactus silage presented in its composition a higher content of CP (8.3% DM) than Tifton hay (5.6% DM) (Table 2), which provided the animals with a crude protein intake above that recommended by the NRC [11], which is 117 g/day for animals in this category. Forage cactus, when well managed and fertilized, can provide a greater supply of nitrogen, as well as other bulky foods, which explains the high CP percentages in its composition. It should also be taken into account the fact that the diets are not isonitrogenous, having different levels of crude protein, which possibly increased the consumption of this ingredient.

Ether extract intake was higher in animals fed a diet with a composition of 21% cactus silage than in the other two levels tested, with higher consumption values than those reported by the NRC [11] (30 g/kg DM). Adequate energy intake levels for young lambs are necessary for animals to develop and fulfil their potential [33]. This fact may explain the highest final weight values of the animals in the treatment with 21% forage cactus silage.

The decreasing levels of NDFap in the diets, as well as the decrease in the percentages of Tifton hay (Table 2), allowed higher intake of NDFap and NFC by lambs fed diets containing cactus silage. Forage cactus has a low content of NDFap, which is associated with a high content of soluble carbohydrates that increase the intake of NFC by lambs [17], corroborating the findings of the present study. According to [34], forage cactus can be considered a good source of non-fibre carbohydrates. Because of their rapid degradation, these nutrients improve the digestive flow through the gastrointestinal tract, increasing the intake of nutrients.

The absence of significant differences in DMI and nutrient digestibility in lambs under intermittent water supply in the present study can be seen as a positive fact, as it suggests that an intermittent water supply within 48 h can be used for lambs in feedlot, as a way to save water, without influencing the intake of DM and nutrient digestibility in these animals. These results can be evidenced by research carried out by [17] and [31] using an intermittent water supply (ad libitum and 24 and 48 h water restrictions) for lambs and goats, respectively. In a study evaluating the effect of water restriction on the growth performance of lambs fed replacement levels (30%, 50% and 70%) of Tifton hay for forage cactus under water restriction, [32] also did not observe an effect on animal performance. However, research carried out by [15] observed a reduction in DM consumption in lambs subjected to water restrictions of 24, 48 and 72 h.

With the use of forage cactus as silage, there was a change in the composition of the diet, mainly with regard to the proportions of non-fibre carbohydrates. These results may be related to low concentrations of ADF and ADL (Table 2) and a higher concentration of NFC in cactus silage in relation to Tifton hay, which probably increased ruminal degradation and nutrient digestion.

The increase in the proportion of non-fibre carbohydrates possibly provided better conditions in the rumen, since non-fibre carbohydrates are easily degraded, increasing the energy supply and improving the energy: protein ratio, which favours microbial growth and, therefore, digestion [35,36]. Thus, the reduced NFC digestibility for Tifton hay is related to the high content of non-fibre carbohydrates present in forage cactus, which after rapid fermentation in the rumen, promote a sharp decline in rumen pH, an increase in the rate of passage and, consequently, reduction in cellulolytic activity [37].

4.2. Water Balance

Animals that were given diets containing cactus silage had less need to seek water from the drinking fountain, as they ingested more water via food. This is due to the low DM content present in cactus silage (73.90 g/kg fresh matter; Table 1) and, consequently, the high moisture content in its composition, which demonstrates the efficiency of this forage in supplying water and its ability to significantly assist in animal watering in arid and semi-arid regions, where water can be a limiting factor in animal production.

Since the highest water intake was found in animals fed cactus silage, it was to be expected that there would also be greater excretion of water via faeces and urine in these animals, which in fact occurred. Water excretion via the faeces of animals that received cactus silage was more than twice that observed in animals that did not receive this food. This is justified by the highest water content of diets containing cactus silage. According to [11], the amount of water contained in ruminant faeces can be influenced by the water content of the diet; more humid diets and those with a higher mineral content generally result in a higher faecal water content.

As with the excretion of water via faeces, the excretion of water via urine increased with the use of cactus silage in the diet, showing an increasing behaviour as the proportion of cactus silage in the diet increased. Lambs fed diets containing 42% cactus silage excreted the largest amount of water, on average 1090.30 g/day. The authors of [38] reported that small ruminants fed diets containing forage cactus lowered their water intake via the drinking fountain and excreted large volumes of urine, as compensatory mechanisms in the regulation of the total volume of water circulating in the body.

For animals to have good productive performance, it is necessary that the water balance in these animals is positive and stable, thus guaranteeing a water balance between their body fluids [30]. Lambs fed diets containing 21% and 42% cactus silage showed an average water balance of 1759.3 g/day water. The greater values of water balance for animals that ingested cactus silage in their diet emphasize the efficiency in the use of drinking fountain water and water contained in their food by small ruminants. Thus, it can be inferred that the water balance observed for both the cactus silage and the intermittent water supply was suitable.

5. Conclusions

Lambs' productive performance is improved when cactus silage substitutes up to 42% of DM of Tifton hay in non-isonitrogenous diets. On the other hand, an intermittent supply of water in periods of up to 48 h does not impair the performance of lambs under feedlot conditions.

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