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ANIMAL SCIENCE

Effect of spineless cactus [*Nopalea cochenillifera* (L.) Salm Dyck] on nutrient intake, ingestive behaviour, and performance of lambs

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Abstract: The objective of this study was to evaluate the effect of increasing levels of spineless cactus (SC) [*Nopalea cochenillifera* (L.) Salm Dyck] on nutrient intake, ingestive behaviour, and performance of lambs in a feedlot. Thirty-two male (non-castrated) Santa Inês lambs with a mean initial body weight (BW) of 20.4 ± 2.60 kg were distributed across four levels of spineless cactus: zero, 24, 52, and 75% of total diet dry matter (DM). Over 56 days, the animals had their intake and performance monitored. The inclusion of SC influenced ($p<0.05$) in a quadratic way the dry matter intake and total digestible nutrients, but linearly decreased ($p<0.05$) the neutral detergent fiber intake. Drinking water intake decreased linearly ($p<0.05$) with the inclusion of SC in the diet. The inclusion of SC influenced ($p<0.05$) in a quadratic way the digestibility of organic matter in the diet. The increase in the level of SC in the diet increased linearly ($p<0.05$) the feeding and rumination efficiencies of the lambs. The maximum daily gain of 0.237 kg/day was achieved with 44% SC in the diet. It is recommended to include up to 40% of spineless cactus in the diet of lambs.

Key words: cactus pear, forage cactus, *Nopalea cochenillifera*, water intake.

INTRODUCTION

The world's largest sheep herds are found in arid and semi-arid areas of Asia, Africa, and America (FAO 2019). In these regions, the periodic droughts damage the main feed source of livestock, the natural rangelands. With climate change and the expansion of arid areas around the world, the frequency of climatic anomalies, such as droughts, is increasing (Huang et al. 2016). Therefore, the use of drought-tolerant plants, such as spineless cactus, to feed the herd can reduce the seasonality of the feed supply and improve animal production in arid and semi-arid areas.

The spineless cactus (*Nopalea* ssp. and *Opuntia* ssp.) is a succulent forage, with a great concentration (522 ± 70 g/kg) non-fibrous carbohydrates (NFC), low concentration (261 ± 70 g/kg) of neutral detergent insoluble fiber (NDIF), and great ruminal digestibility of dry matter (DM) (Conceição et al. 2016, Siqueira et al. 2017, Barros et al. 2018). In addition to these nutritional characteristics, the genus *Nopalea* has the advantage of being resistant to carmine Cochineal (*Dactylopius* sp), an agricultural pest that has been decimating spineless cactus crops in Brazil. Another advantage of forage cactus is that it's chemical composition changes little in relation to the time of harvest, and the producer can choose to harvest it at two or four years, i.e. at times of greatest need.

When evaluating the carmine-resistant spineless cactus [*Nopalea cochenillifera* (L.) Salm Dyck], Cardoso et al. (2019) indicated that the inclusion of 45% of spineless cactus in the diet linearly increased the performance of growing lambs, suggesting the inclusion of greater levels of Cactaceae in diets of lambs. Therefore, we aimed to evaluate the effect of increasing the levels of inclusion of spineless cactus on the performance of lambs in the feedlot.

MATERIALS AND METHODS

All procedures were conducted in accordance with the guidelines set by the Conselho Nacional de Controle de Experimentação Animal and approved by the Comitê de Ética no Uso de Animais (CEUA) of the Universidade Federal Rural de Pernambuco (license 23082.012176/2014-51).

The experiment was carried out in Recife, PE, Brazil. The city presents an average temperature of 25.8 ± 2.8°C and rainfall of 1800 mm/year. Thirty-two male (non-castrated) Santa Inês lambs (*Ovis aries*) with a mean initial body weight of 20.4 ± 2.60 kg were allocated to individual stalls provided with feeders and drinking fountains, with water ad libitum. Initially, the animals were submitted to a 14-day period for adaptation to the experimental diets, facilities, and management. During adaptation, the animals were treated against endo and ectoparasites and identified. After the adaptation, the animals were weighed and distributed across four treatment rations (levels of zero, 24, 52, and 75% of spineless cactus in the diet on a dry matter basis) in a randomized block design and confined for 56 days.

The experimental feed (Table I and II) was formulated as recommended by the NRC (2007) to achieve a 200 g daily gain for growing lambs. The rations were composed of spineless cactus (*Nopalea cochenillifera* Salm Dyck), grass Tifton hay (*Cynodon* spp), soybean meal, ground corn grain, mineral mix, and urea. The spineless cactus was chopped in a proprietary disintegrating machine (Trapp JK-700, Laboremus) and the Tifton 85 hay was ground in a forage machine with a 13-mm sieve. The rations were provided as a complete mixture twice daily, with 60% being offered in the morning and 40% in the afternoon. During the experiment growing lambs were fed for ad libitum intake with 15% leftover feed daily.

Table I. Chemical composition of the diets ingredients.

Item	Tifton hay	Spineless cactus	Ground corn	Soybean meal
Dry matter*	918.17	100.00	881.69	890.69
Organic matter#	962.60	812.70	919.40	925.60
Ash#	17.40	187.30	80.60	74.20
Ether extract#	17.10	16.90	41.60	13.80
Crude protein#	76.00	58.60	90.90	526.80
Neutral detergent fiber#	745.10	259.70	98.50	143.80
Acid detergent fiber#	356.40	150.80	76.80	25.00
Non-fibrous carbohydrates#	144.40	477.50	688.40	241.40

***g/kg on as-fed basis; #g/kg on DM basis.**

Samples of the experimental diet, rations offered were collected weekly and generated an individual composite samples that was weighed, identified, predried in an oven at 55°C for 72 hours, and ground in a mill (need specified here brand of the mill) with 1-mm granulometry. After this procedure, dry matter (DM, method, 934.01), ash (method, 105 942.05), crude protein (CP, method, 968.06), and ether extract (EE, method, 920.39) were analyzed according the methodologies described by AOAC (2000).

The determination of neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according the methodology described by Van Soest et al. (1991). The protein corrections followed the methodology described by Licitra et al. (1996). For the quantification of total carbohydrates (TC), was used the following equation: 100 - (%CP + %EE + %ash) according to Sniffen et al. (1992), and for the non-fibrous carbohydrate content, only for the diet, NFC =100% DM - (CP% 112 - CP% derived from urea + %urea) + NDF% + EE% +MM% (Hall 2000).

The water intake was measured over 26 days during the experimental trial. The daily water intake in g/day was measured by subtracting the weight of the water offered minus leftover and also the losses by evaporation (Araújo et al. 2019), always at the same time (09:00 am).

To obtain the total digestible nutrients (TDN), an apparent digestibility assay was performed by estimating faecal dry matter production using the external marker Enriched and Purified Lignin (LIPE®). The intake of a

Table II. Proportion of ingredients and chemical composition of the experimental diets with increasing levels of spineless cactus.

Ingredients (g kg/DM)	Inclusion of spineless cactus (%)			
	0	24	52	75
Tifton hay	774	530	253	0
Spineless cactus	0	241	519	753
Ground corn	89.2	67.6	44.9	24.3
Soybean meal	121.6	146	167.8	206.2
Mineral mix[1]	5.1	5.1	5.1	5.5
Urea[2]	10.1	10.3	10.2	11.0
Chemical composition (g kg/DM)				
Dry matter*	911.5	308.3	174.7	128.1
Organic matter#	939.6	903.3	861.9	825.1
Crude protein#	159.2	166.4	170.6	185.7
Ether extract#	18.6	17.9	17.2	16.5
Neutral detergent fiber#	602.9	484.8	351.8	227.5
Acid detergent fiber#	285.7	233.9	176.0	120.5
Non-fibrous carbohydrates#	202.5	273.5	355.8	426.0
Total digestible nutrients#	721.1	753.6	731.8	670.
Metabolizable energy (Mcal/kg DM)	2.6	2.7	22.6	2.4

[1]Assurance levels provided by the manufacturer: calcium=140 g, phosphorus=70 g, magnesium=1320 mg, iron=2200 mg, cobalt=140 mg, manganese=3690 mg, zinc=4700 mg, iodine=61 mg, selenium=45 mg, sulphur=12 g, sodium=148 g, and fluorine=700 mg.; [2]Urea: protein equivalent 280 g/kg of crude protein in DM. *g/kg on as-fed basis; #g/kg on DM basis.

250-mg capsule of LIPE® was applied for seven consecutive days, two days for adaptation, and five days rectally obtained feces once daily at different times, as recommended by Ferreira et al. (2009). During the digestibility assay, rations offered, leftovers and feces samples were collected and placed in a forced ventilation oven at 55°C for 72 hours, and ground in a mill (Tecnal© R-TE-650/1) with 2-mm granulometry and submitted to laboratory analysis. Then, the apparent digestibility of the different nutrients was calculated using the formula: [(ingested nutrient – excreted nutrient)/ingested nutrient] *100. The total digestible nutrient intake (TDN) was calculated according to Weiss (1999).

The ingestive behavior of the animals was analyzed by trained people on the 40th day of the experimental period, using the scan sampling method proposed by Martin & Bateson (2007), adapted for 10-minute intervals, for 24 hours. In the intervals of 43 observations, the following behavioral variables were determined: feeding, rumination, and idle times. The feeding efficiencies were calculated as a function of the dry matter (DM, kg DM/h) and neutral detergent fiber (NDF, kg NDF/h), obtained as the DM intake quotient (kg/day) or NDF (kg/day) and feeding time (h/day) (DM intake/feeding time and NDF/feeding time); the rumination efficiency as a function of the DM and NDF intakes (DM, kg DM/h and NDF, kg NDF/h) calculated as the ratio between the DM intake and NDF intake as a function of rumination time (h/day); the total chewing time (h/day) as the sum of the feeding and rumination times; and the idle times were considered the times when the animal was not feeding or ruminating (Bürger et al. 2000).

After 56 experimental days, the animals were fasted for 16 hours and weighed to obtain the final body weight (FBW). The total weight gain (TWB) was calculated as the difference between the final body weight (FBW) and initial body weight (IBW); the estimate of average daily gain (ADW) was calculated by the relationship between the TWG and total days of the performance period (56 days): ADG = (TWG/56). The feed conversion (FC) was calculated by the relationship between dry matter (DM) intake and DWG.

The experiment was a completely randomized block design. The mathematical model used was $Yijk = \mu + Ti + \beta j + eij$, where Yijk=the observed variable, μ = the overall mean, Ti=the effect of treatment, βj = the effect of block, and eijk=the random error associated with each observation. Data were submitted to analysis of variance and regression with the procedures GLM and REG of SAS version 9.1 (SAS Inst. Inc., Cary, NC). The criteria used to choose the model were the significance of the regression coefficients and biological behavior.

RESULTS

The inclusion of different levels of spineless cactus in the diet had a quadratic effect ($p < 0.05$) on the dry matter (DM), organic matter (OM), crude protein (CP), and total digestible nutrients (TDN) intake, with maximum level of 1322.0 g/d; 1199.0 g/d, 217 g/d, and 991 g/d obtained with a spineless cactus inclusion level of 42%, 38%, 37%, and 39%, respectively (Table III). The neutral detergent fiber (NDF) intake decreased linearly ($p < 0.05$), whereas the non-fibrous carbohydrate (NFC) intake showed a positive linear increase ($p < 0.05$) in response to increasing levels of spineless cactus in the diet.

There was a quadratic behavior ($p < 0.05$) of the dry matter (DM), organic matter (OM), crude protein (CP), and neutral detergent fiber (NDF) digestibility, with a maximum level of 798 g/kg, 838 g/kg, 843 g/kg, and 739 g/kg obtained with inclusion levels of spineless cactus of 47%, 63%, 35%, and 36%, respectively. Increasing levels of spineless cactus increased linearly ($p < 0.05$) the

Table III. Nutrient intake and digestibility of lambs fed with increasing levels of spineless cactus inclusion in the diet. Body weight (BW).

Item	Inclusion of spineless cactus (%)				SEM	*P*-value	
	0	24	52	75		L	Q
Intake (g/day)							
Dry matter	891.5	1258.3	1291.9	1075.1	168.25	0.0375	<.0001[1]
Dry matter (%BW)	3.74	4.75	4.72	4.50	0.469	0.0052	0.0009[2]
Organic matter	871.1	1165.1	1147.1	902.0	152.17	0.7582	<.0001[3]
Neutral detergent fiber	508.9	469.5	432.1	239.7	65.591	<.0001[4]	0.0027
Neutral detergent fiber (%BW)	2.13	1.77	1.57	0.98	0.154	<.0001[5]	0.0494
Crude protein	160.2	221.5	206.9	178.1	27.984	0.3904	<.0001[6]
Ether extract	17.4	22.1	23.6	18.0	3.385	0.5227	0.0002[7]
Non-fibrous carbohydrates (g/d)	199.3	371.5	449.3	463.8	0.630	<.0001[8]	0.0015
Total digestible nutrients (g/d)	647.4	952.4	952.0	724.3	15.725	0.3624	<.0001[9]
Digestibility (g/kg)							
Dry matter	687	778	782	743	4.036	0.0117	<.0001[10]
Organic matter	712	802	808	813	47.808	0.0003	0.0179[11]
Crude protein	793	846	834	796	35.141	0.9713	0.0009[12]
Ether extract	358	605	667	579	97.748	<.0001	<.0001[13]
Neutral detergent fiber	675	728	716	637	63.388	0.2236	0.0061[14]
Non-fibrous carbohydrates (g/d)	794	817	853	882	28.441	<.0001[15]	0.7719

L - Linear; Q - Quadratic; SEM = standard error of the mean; [1]$y = 896.2 + 2.0222x – 0.0024x2$, $R^2 = 0.9963$; [2]$y = 3.7878 + 0.0047x -0.000006x^2$, $R^2 = 0.9403$; [3]$y = 875.09 + 1.6886x - 0.0022x^2$, $R^2 = 0.9962$; [4]$y = 537.34 - 0.3299x$, $R^2 = 0.8195$; [5]$y = 2.153 – 0.0014x$; $R^2 = 0.9473$; [6]$y = 163.46 + 0.2926x - 0.0004x^2$, $R^2 = 0.9195$; [7]$y = 184.17 + 0.033x - 0.0005x^2$, $R^2 = 0.9707$; [8]$y = 241,03 + 0.3435x$; $R^2 = 0.8597$; [9]$y = 651.3 + 1.7289x - 0.0022x^2$, [10]$y = 689.49 + 0.4667x - 0.0005x^2$, $R^2 = 0.9814$; [11]$y = 716.87 + 0,381x - 0,0003x^2$; $R^2 = 0,9404$; [12]$y = 794.97 + 0.2791x - 0.0004x^2$, $R^2 = 0.9686$; [13]$y = 360.69 + 1.311x - 0.0014x^2$, $R^2 = 0.9977$; [14]$y = 674.51 + 0.3578x - 0.0005x2$, $R^2 = 0.9992$; [15]$y = 791.74+ 0.1183x$, $R^2 = 0.9962$.

digestibility of the non-fibrous carbohydrates in the diet. The digestible organic matter (DOM) intake had a quadratic ($\hat{Y} = 627.42 + 1.6913x - 0.0021x^2$; $R^2 = 0.98$) with a maximum level of 967 g/d with the inclusion of 40% of spineless cactus in the diet.

The addition of spineless cactus to the diet decreased linearly ($p < 0.05$) the intake of drinking water, but increased linearly ($p < 0.05$) the intake of water from feed (Figure 1).

Increasing levels of spineless cactus in the diet resulted in a linear decrease ($p < 0.05$) in feeding time, but a linear increase ($p < 0.05$) in idle time. The rumination time presented a quadratic behavior ($p < 0.05$) as a function of the levels of spineless cactus, with a maximum of 8.13 h with 47% of spineless cactus in the diet. The feed efficiency and rumination of DM increased linearly ($p < 0.05$) with the increasing inclusion of spineless cactus (Table IV).

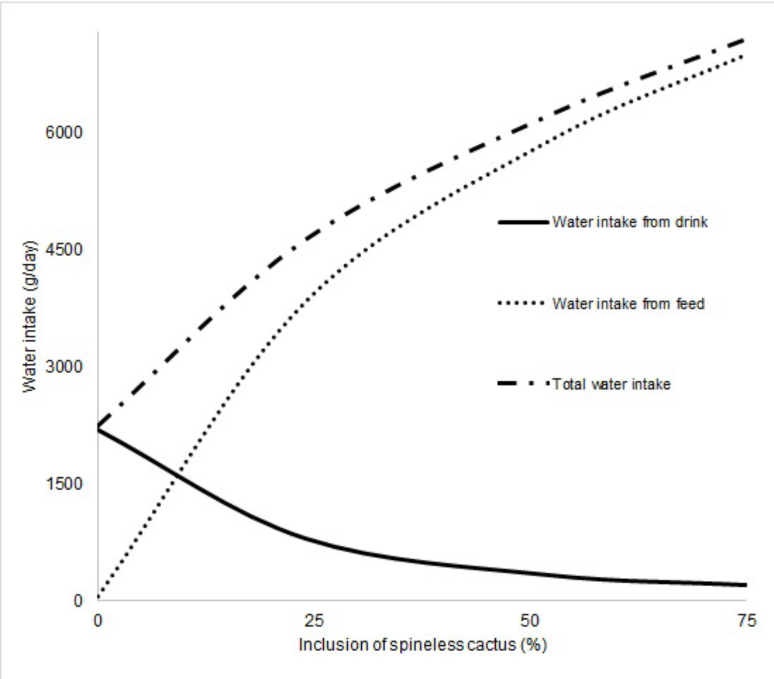

Figure 1. **Water intake by lambs fed with increasing levels of spineless cactus inclusion in the diet. Water intake from drink ($^1\hat{Y} = 1847.53 - 2.57262x$, $R^2 = 0.9353$, $p < 0.0001$); Water intake from feed ($^2\hat{Y} = 763.77 + 9.15872x$, $R^2 = 0.8319$, $p < 0.0001$); Total water intake ($^3\hat{Y} = 2611.30 + 6.5810x$, $R^2 = 0.9653$, $p < 0.0001$).**

There was a quadratic behavior ($p < 0.05$) of the final weight (FW) and average daily gain (ADG) of the lambs, with a maximum of 32.65 kg and 0.237 kg/d at the spineless cactus inclusion levels of 33% and 44%, respectively. The best feed conversion was obtained with a level of 36% of spineless cactus in the diet of lambs.

DISCUSSION

The DM, DOM, and TDN intakes indicated that up to approximately 40% of spineless cactus inclusion in the diet of lambs, there is an increase in the intake of these nutrients by the animals. However, higher levels of spineless cactus appear to reduce the consumption of digestible nutrients by sheep. This cactus is rapidly and extensively fermented in the rumen (Batista et al. 2009), generating a large number of organic acids (Santos et al. 2010) and a consistent ruminal pH (Lima et al. 2018). In this scenario, it is possible that high levels of spineless cactus above 40% inhibit nutrient intake mainly through the increased flow of metabolites and their effects on animal satiation (Miller et al. 2008). In a recent meta-analysis, Knupp et al. (2019) observed effects of the spineless cactus on the DM intake by sheep and found that with diets including more than 50% of spineless cactus, a reduction in DM intake occurs.

With the addition of spineless cactus (zero to 75% DM) there was a 110% increase in the NFC concentration and a 62% decrease in the NDF concentration of the experimental diets. This occurred since the spineless cactus had a lower NDF concentration (259 g/kg vs 754 g/kg) and higher NFC concentration (477 g/kg vs 144 g/kg) than Tifton 85 hay. These modifications help to explain the linear increase in the intake of NFC and the decrease in NDF intake by lambs fed with increasing levels of spineless cactus. The NDF:NFC ratio consumed in total carbohydrates increased from 72:28 with zero of spineless cactus to 34:66 with 75% of inclusion, that is, there was an inversion of the type of carbohydrate predominant in the diet consumed by the animals. This might be associated with

Table IV. Ingestive behavior of lambs fed with increasing levels of forage palm inclusion in the diet.

Item	Inclusion of spineless cactus (%)				SEM	*P*-value	
	0	24	52	75		L	Q
Feeding time (h/day)	4.3	3.7	3.9	2.7	0.904	0.0033[1]	0.3179
Rumination time (h/day)	7.1	7.1	7.2	4.6	1.200	0.0006	0.0071[2]
Idle time (h/day)	12.4	13.0	13.1	16.5	1.339	<.0001[3]	0.0052
Chewing time (h/day)	11.5	10.9	11.1	7.4	1.313	<.0001	0.0022[4]
Feeding efficiency (kgDM/h)	0.23	0.34	0.31	0.40	0.120	0.0161[5]	0.7484
Feeding efficiency (kgNDF/h)	0.13	0.13	0.10	0.09	0.046	0.7223	0.6059
Rumination efficiency (kgDM/h)	0.12	0.17	0.16	0.25	0.068	0.0027[6]	0.3609
Rumination efficiency (kgNDF/h)	0.07	0.06	0.05	0.05	0.019	0.0468[7]	0.4619

L - Linear; Q - Quadratic; SEM = standard error of the mean; [1]$y = 4.376 – 0,0018x$, $R^2=0.74$; [2]$y = 7.0258 + 0.0047x – 0.005x^2$, $R^2=0.8992$; [3]$y = 11,986 + 0.0048x$, $R^2=0.707$; [4]$y = 11.238 + 0.005x – 0.05x^2$, $R^2=0.872$; [5]$y = 0.2525 + 0.0002x$, $R^2=0.7177$; [6]$y = 0.1269 + 0.0001x$, $R^2=0.7318$; [7]$y = 0.0716 – 0.005x$, $R^2=0,82$.

an increase in the intake rate and the observed effects on nutrient digestibility.

In relation to digestibility, the spineless cactus is rich in carbohydrates that are rapidly fermented in the rumen (Santos et al. 2018) and the replacement of a forage rich in NDF—Tifton 85 hay—by spineless cactus increased the dry matter digestibility, but only up to the inclusion level of 47%. Above this level, we propose that the increase in the rate of passage of the intake, mainly from the rumen-reticulum to the small intestine, caused a reduction in the intestinal digestion of the nutrients and impacted the total digestibility of the diet. Siqueira et al. (2017) observed that increasing spineless cactus inclusion increased the passage rate and reduced the intestinal digestibility of dietary DM.

The inclusion level of spineless cactus affected in a quadratic way the digestibility of the NDF, initially increasing the digestibility of the NDF to the level of 36% of spineless cactus in the diet. It was proposed that the increase in the soluble NDF fraction of the diet with the inclusion of the spineless cactus (Lins et al. 2016) might be associated with the initial improvement in the digestibility of dietary NDF. However, there was a decrease in NDF digestibility at levels above 36% of spineless cactus in the diet, probably due to the reduction in ruminal pH (Pinho et al. 2018) and the increase in the NDF passage rate (Conceição et al. 2016).

The increase in water intake from feed with increasing levels of spineless cactus occurred due to the great moisture concentration of this forage (900 g/kg of water). Vieira et al. (2008) also observed an increase in water intake from feed with the inclusion of spineless cactus in the diet of goats. Pordeus Neto et al. (2016) studied the water balance in sheep fed with a greater level of spineless cactus and found that electrolyte-free water reabsorption in sheep fed spineless cactus was higher than in those fed Tifton 85 hay. They justified this finding since water via feed was ingested in small quantities continuously, facilitating reabsorption in the large intestine of the animals. Thus, the ingestion of water from feed through the spineless cactus makes the animals more efficient in the use of this resource.

We propose that the increase in dietary moisture (88 g/kg to 872 g/kg, from zero to 75% of spineless cactus) was related to the decrease in the feeding time of the animals. However, the decrease in NDF concentration of feed (602 g/

Table V. **Performance of lambs fed with increasing levels of spineless cactus inclusion in the diet.**

Item	Inclusion of spineless cactus (%)				SEM	*P*-value	
	0	24	52	75		L	Q
Initial body weight (kg)	20.6	20.4	20.5	20.0	-	-	-
Final body weight (kg)	27.2	32.9	33.2	28.9	3.391	0.378	0.005[1]
Body weight at slaughter (kg)	6.6	12.6	12.1	9.0	1.652	0.018	<.0001[2]
Average daily gain (g/day)	118.2	220.2	211.4	157.2	29.16	0.028	<.0001[3]
Feed conversion	7.14	5.78	6.16	6.95	0.852	0.169	<.0001[4]

L - Linear; Q - Quadratic; SEM = standard error of the mean; [1]$y = 27.239 + 0.0329x – 0.00005x^2$, R^2=0.999; [2]$y = 6.8089 + 0.0306x – 0.00005x^2$, R^2=0.968; [3]$y = 121.69 + 0.5227x – 0.0006x^2$, R^2=0.9692; [4]$y = 7.0712 – 0,0067 + 6.10^{-10}x^2$, R^2=.

kg to 227 g/kg NDF, from zero and 75% spineless cactus) contributed to the reduction in feeding time and an increase in feeding efficiency (Bispo et al. 2010). Siqueira et al. (2018) also observed a reduction in feeding time and an increase in feeding efficiency in cattle fed with increasing levels of spineless cactus. The rumination time presented a quadratic behavior, with a reduction above the level of 47% of spineless cactus in the diet. We propose that the increase in the rate of passage and the reduction in the indigestible NDF consumed (Moraes et al. 2019) might be associated with the reduced rumination in animals fed high levels of spineless cactus. Maciel et al. (2019) also observed the decreasing linear behavior of the rumination time of sheep fed with increasing levels of spineless cactus.

The lambs gained more weight when fed with approximately 44% of spineless cactus in the diet, however, they were more efficient at converting food to weight gain with a level of 36% of spineless cactus in the diet. Oliveira et al. (2017) reported a maximum gain of 200 g/d at the level of 17% of spineless cactus in the diet of lambs fed with increasing levels of spineless cactus. More recently, Cardoso et al. (2019) also observed increasing weight gain and improved feed conversion with levels of up to 45% of spineless cactus in the diet of lambs.

CONCLUSIONS

It is recommended to include up to 40% of spineless cactus [*Nopalea cochenillifera* (L.) Salm Dyck] in the diet of lambs to optimize the performance of animals receiving diets with a 77:23 ratio of roughage:concentrate. The inclusion of spineless cactus also provides a supply of water to the animals, therefore, it is a strategic resource during the periodic droughts that devastate the arid zones.

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