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Effects of replacing corn with cactus pear (*Opuntia ficus indica* Mill) on the performance of Santa Inês lambs

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ABSTRACT

The objective of this study was to evaluate the performance and nutrient digestibility of feedlot Santa Inês sheep fed with increasing levels (0, 25, 50, 75, 100% dry matter basis) of cactus pear (*Opuntia ficus indica*, Mill) as a replacement for corn. Forty-five male (non-castrated) Santa Inês sheep, averaging 27.50 ± 0.48 kg body weight (BW) at the beginning of the study, were used in this trial. A completely randomized block design with nine replicates per treatment was used. The intakes of DM, OM, CP, EE, TC, NFC, TDN and ME were quadratic, while the intakes of mineral matter (MM) and NDF increased linearly with increased levels of cactus pear in the diet. The voluntary intake of water decreased with increased levels of cactus pear in the diet. Increased levels of cactus pear in the diet increased the apparent digestibility of DM, OM, CP, NDF, and TC linearly, but did not influence the digestibility of EE or NFC. Daily weight gain (DWG) and feed efficiency decreased linearly with increased levels of cactus pear in the diet. The replacement of corn by cactus pear does not affect the conversion of the feed. Overall, increased levels of cactus pear in the diet of these sheep favours a high digestibility of nutrients, improves the quality of forage, reduces the voluntary intake of water, and thus represents an important source of fodder and water reserves for use in semiarid regions.

1. Introduction

A strategy often used for improving the performance of small ruminants in semiarid regions of Brazil is adequate feed management, particularly during times of scarce forage and in intense production systems. Feedlot systems for sheep have been stimulated to meet consumer market requirements for better quality carcasses, as well as to maintain regularity of the availability of meat throughout the year, contributing to the increase of meat consumption (Medeiros et al., 2007). This system helps intensify the finishing of lambs for commercialization more rapidly, increasing the circulation of capital and diminishing performance loss due to more effective control of internal parasites (Reis et al., 2001). However, this practice can be limited by the high costs of feed, which necessitates studies aimed at quantifying animal performance in productive and economic terms.

The finishing of sheep is possible as long as there is a feed capable of supplying the nutritional requirements necessary for weight gain. Traditionally in this production system, it is necessary to use grains such as corn for concentrating energy during finishing. However, corn exhibits considerable price variation throughout the year in Brazil due to exportation and its substantial use in human, poultry and swine diets. Furthermore, in semiarid regions, corn production is a high-risk activity.

Cactus pear (*Opuntia ficus indica* Mill), as a result of its energetic value, high coefficient of dry-matter digestibility

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Table 1
Chemical composition of the ingredients of the feed based on dry matter (%).

Ingredients	DM	Ash	CP	EE	NDF	ADF	TC	NFC	TDN	ME
Cactus pear	10.8	11.8	3.9	1.6	31.2	21.7	82.6	53.0	60.8	2.2
Ground corn	88.5	1.5	8.8	3.6	11.4	4.2	86.1	78.1	85.6	3.1
Soybean meal	89.2	7.0	48.2	2.3	14.5	10.9	42.5	34.1	75.7	2.7
Wheat bran	87.9	5.7	16.1	3.5	45.4	13.4	74.6	32.1	64.4	2.3
Tifton hay	90.9	7.0	8.7	1.4	79.2	39.2	82.8	8.4	48.2	1.7

DM, dry matter; CP, crude protein; EE, ether extract; NDF, neutral detergent fibre; NDF, neutral detergent fibre corrected for crude protein; ADF, acid detergent fibre; TC, total carbohydrates; NFC, non-fibrous carbohydrates; TDN, total digestible nutrients; ME, metabolizable energy (Mcal/kg of DM).

and adaptability to soil and climatic conditions, has become the basis for ruminant feed in the Brazilian semiarid region with demonstrated potential as a substitute for corn in the finishing of sheep. Cactus pear is a very important feed in prolonged periods of drought, because in addition to furnishing nutrients, it supplies a large proportion of water requirements to the animals during this time of the year. This objective of this study was to evaluate the performance of Santa Inês lambs fed with variable proportions of cactus pear (*Opuntia ficus indica* Mill) replacing corn in their diets.

2. Materials and methods

Forty-five non-castrated male lambs of the Santa Inês breed, with an average live weight (LW) of 27.50 ± 0.48 kg were utilized for this study. Lambs were confined in individual stalls within the Small Ruminant Research Unit of the Federal University of Paraíba, in the city of de São João do Cariri in Paraiba, Brazil. This is a semiarid region, with an average annual temperature of 26 °C and a pluviometric index of 395 mm annually. Animals were weighed, identified, and removed of internal parasites at the beginning of the experiment.

Corn was replaced with cactus pear in the diet at 0, 25, 50, 75, and 100% of the base dry matter. The cactus pear was manually cut into slices of approximately 5 cm^2. Ground Tifton-85 (*Cynodon dactylon*) hay was used as forage, mixed with wheat bran, soybean meal, ground corn, mineral supplements and cactus pear. The diets were formulated according to the NRC (2007) guidelines for a weight gain of 250 g/animal/day, and animals were fed a total mixed ration *ad libitum*. The chemical composition of ingredients used in the diets and diet compositions are presented in Tables 1 and 2, respectively.

Each animal was weighed once every seven days over the 45-day experimental period; the first 10 days allowed animals to adapt to the diets and the final 35 days were used for the data collection. Food was offered to the animals twice a day; 50% was given at 7:00 am and 50% was given at 4:00 pm. The amount of food offered, and the leftovers, were weighed daily to calculate a voluntary intake and establish a 10% leftover criteria. Water was offered *ad libitum*.

The compositions of the feed were determined according to the methodology described by AOAC (1997). To measure the neutral detergent fibre (NDF) and acid detergent fibre (ADF), the methodology described by Van Soest et al. (1991) was used. The total digestible nutrient contents (TDN) were calculated according to the equation proposed by Weiss (1999), where TDN (%) = (%CPd + %NDFcpd + %NFCd + (%EEd × 2.25) − 7 (CPd, digestible crude protein; NDFcpd, digestible neutral detergent fibre corrected to protein; NFCd, digestible non-fibrous carbohydrate; EEd, digestible ether extract). The digestible energy (DE) was estimated as DE (Mcal/kg) = 0.04409 × TDN (%). The conversion of DE to ME was estimated as DE × 0.82.

Data from the experiment were analyzed by analysis of variance (ANOVA) using the General Linear Model (GLM) procedure in SAS (2002). Treatment averages were compared using Tukey's tests for pairwise comparisons. The data collected were subjected to ANOVA by using the following model: $Y_{ij} = \mu + \alpha_i + \beta_j + e_{ij}$, where μ is the overall average, α_i the ith treatment effect, β_j the jth block effect and e_{ij} is the random error associated with Y_{ij}. The criteria used in the choice of the regression equations were biological behaviour, determining coefficients (r^2) and the significance of the regression parameters obtained by the t-test at 1 and 5% probability.

3. Results and discussion

The DMI and OMI showed a quadratic relationship ($P < 0.05$) with increased levels of cactus pear in the diet ($P < 0.05$). The maximum DMI was approximately 54.0% of cactus pear in the diet, where the intake of DM reached 1.49 kg/day. It was noted that the animals selected their diets during meals. In both the morning and afternoon

Table 2
Ingredient and chemical composition of the experimental diets.

	Replacing levels (%)				
	0	25	50	75	100
Ingredients (%DM)					
Cactus pear	0.0	7.0	14.0	21.0	28.0
Ground corn	28.0	21.0	14.0	7.0	0.0
Soybean meal	17.6	17.6	17.6	17.6	17.6
Wheat bran	11.4	11.4	11.4	11.4	11.4
Tifton hay	40.0	40.0	40.0	40.0	40. 0
Mineral salt	1.5	1.5	1.5	1.5	1.5
Limestone	1.5	1.5	1.5	1.5	1.5
Composition (% in the DM)					
Dry matter	89.5	59.3	44.4	35.4	29.5
Organic matter	90.7	89.9	89.1	88.3	87.5
Ash	5.1	5.8	6.5	7.2	8.0
Crude protein	16.2	15.9	15.5	15.2	14.9
Ether extract	2.3	2.2	2.1	1.9	1.8
NDF	42.6	43.9	45.3	46.7	48.1
TDN	63.8	62.1	60.4	58.7	56.9
ME (Mcal/kg of DM)	2.3	2.2	2.2	2.1	2.1

NDF, neutral detergent fibre; TDN, total digestible nutrients; ME, metabolizable energy.

Table 3
Intake of ingredients by Santa Inês sheep fed with cactus pear (*Opuntia ficus indica* Mill) replacing corn.

Intake	Replacing levels (%)					*X*	SEM	Regression	
	0	25	50	75	100			L	Q
DM (kg/day)	1.3	1.4	1.5	1.4	1.3	1.4	0.03	ns	*
DM (%LW)	4.1	4.6	4.7	4.5	4.3	4.4	0.11	ns	ns
DM (g/LW$^{0.75}$)	96.5	109.1	111.4	106.9	102.1	105.2	2.66	ns	ns
OM (kg/day)	1.2	1.3	1.4	1.3	1.2	1.3	0.03	ns	*
Ash (g/day)	65.2c	84.7bc	98.4ab	104.4ab	108.5a	92.2	3.35	***	ns
CP (g/day)	207.1	230.9	232.4	218.3	201.8	218.4	5.69	***	*
EE (g/day)	30.3ab	32.6a	31.6ab	28.4ab	25.1 b	29.6	0.82	*	*
NDF (g/day)	543.3	638.3	680.5	670.1	652.4	636.9	17.52	*	ns
TC (kg/day)	0.87	1.1	1.1	1.1	1.0	1.1	0.02	ns	*
NFC (kg/day)	0.48	0.52	0.51	0.47	0.42	0.48	0.01	***	*
TDN (kg/day)	0.81	0.90	0.90	0.84	0.77	0.85	0.02	ns	*
ME (Mcal/day)	2.9	3.2	3.3	3.0	2.8	3.1	0.08	ns	*
VWI (kg/day)[1]	4.9 a	4.2 b	3.6c	2.9d	2.3e	3.6	0.14	***	ns

ns, not significant by Tukey's test. DM, dry matter; CP, crude protein; EE, ether extract; NDF, neutral detergent fibre; TC, total carbohydrates; NFC, non-fibrous carbohydrates; TDN, total digestible nutrients; ME, metabolizable energy (Mcal/kg of DM); VWI, voluntary water intake.
* $P<0.05$.
*** $P<0.001$.

feedings, they first ingested the cactus pear, followed by the concentrate and finally the Tifton hay (Table 3). Factors including low fibre content, high palatability, and high passage rate of the cactus pear may have contributed to their greater intake as cactus pear availability increased from 25 to 75%. These results corroborate those of Sirohi et al. (1997) and Nefzaoui and Salem (2001). The difference in intake of DM (% of LW) and DM (g/kg$^{0.75}$) among the diets was not significant ($P>0.05$), with averages of 4.43% and 105.21 g/kg$^{0.75}$, respectively. There was an increase in mineral intake with increasing levels of cactus pear in the diet ($P<0.05$), most likely due to the high content of minerals present in the cactus pear, and consequently in the sheep diets (5.11–8.0%).

The CPI (crude protein intake) also showed a quadratic relationship with increased cactus pear in the diet ($P<0.001$). Here, the maximum point was 45.9% of cactus pear in the diet, such that CP intake was approximately 232.6 g/day or 156.1 g/kg of dry matter ingested daily. This CPI per kg of DM represents 93.47% of the CP requirements suggested for sheep in feedlots by NRC (2007). Cactus pear forage has a low content of crude protein; however, this did not interfere with the availability of protein for the animals, as their diets had an average of 15.56% CP (2.49% of N × 6.25). It was estimated that the intake of N was 33.1, 36.9, 37.2, 34.9 and 32.3 g/day. This N-intake meets the minimum requirements in the rumen for microbial protein synthesis. Misra et al. (2006) confirmed that diets with cactus pear forage are advantageous when the availability of nitrogen is adequate.

The intake of NDF linearly increased with the proportion of cactus pear in the diet ($P<0.05$). Cactus pear has more NDF than corn, and thus there was an increase in the content of dietetic NDF, and consequently its intake, with increasing cactus pear in the diet. Valdés et al. (2000) reported that ruminal repletion can occur when the intake of NDF is between 10 and 12 g/kg LW/day. The animals in this study consumed an average of 20.1 g/day of NDF/kg of LW. This confirms the capacity for NDF intake from tropical forage by Santa Inês sheep. Similar NDF intake was observed on Morada Nova sheep (22.8 g/kg of LW/day) by Medeiros et al. (2007).

The intake of TDN and ME by sheep was quadratically related ($P<0.05$) to the proportion of cactus pear in the diet. Although the energy value of cactus pear is less than that of the corn, the digestibility coefficients of the OM, CP and NDF increased linearly with higher proportions of cactus pear in the diet; the intake of TDN did not vary (Table 4). The maximum points were estimated to be 43.33 and 43.52% of cactus pear in the diet when the intake of TDN and ME reached 0.904 kg/day and 2.71 Mcal/day, respectively.

Table 4
Nutrient digestibility of Santa Inês sheep fed with cactus pear (*Opuntia ficus indica* Mill) replacing corn.

Digestibility (%)	Replacing levels (%)					*X*	SEM	Regression	
	0	25	50	75	100			L	Q
Dry matter	70.2	71.9	76.2	76.4	80.9	75.1	1.3	*	ns
Organic matter	73.4b	74.9ab	79.6ab	78.5ab	83.2a	77.9	1.1	*	ns
Crude protein	74.5c	78.3bc	83.0ab	82.8ab	86.6a	81.0	1.1	***	ns
Ether extract	68.0	61.0	68.4	65.6	72.2	67.0	2.7	ns	ns
NDF	56.6b	59.5b	69.1ab	68.8ab	77.5a	66.3	2.0	***	ns
TC	72.4b	72.0b	77.3ab	73.0b	82.9a	75.6	1.1	*	ns
NFC	93.6	93.1	93.5	91.4	92.4	92.8	0.7	ns	ns

ns, not significant by Tukey's test. NDF, neutral detergent fibre; TC, total carbohydrates; NFC, non-fibrous carbohydrates.
* $P<0.05$.
*** $P<0.001$.

Table 5
Performance of Santa Inês sheep fed with cactus pear (*Opuntia ficus indica* Mill) replacing corn.

Variables	Replacing levels (%)					*X*	SEM	Regression	
	0	25	50	75	100			L	Q
Initial LW (kg)	26.6	27.3	28.0	27.7	27.9	27.5	0.2	–	–
Final weight (kg)	35.9	35.8	35.9	36.	35.2	35.7	0.2	ns	ns
Daily weight gain (kg/day)	0.255	0.236	0.218	0.231	0.210	0.230	0.06	*	ns
Feed efficiency (%)	18.6	17.7	16.9	16.0	15.2	16.9	0.6	*	ns

ns, not significant by Tukey's test.
* $P < 0.05$.

Voluntary water intake (VWI) of the sheep diminished ($P < 0.01$) by approximately 25.6 g/day for each percent of cactus pear in the diet. This intake declined from 4.9 to 2.31 kg of water/day when the proportion of cactus pear varied from 0 to 100%. This behaviour most likely resulted because cactus pear contains a considerable amount of water in its tissue, which led to a decrease of direct water intake at the water troughs (Tegegne et al., 2007; Costa et al., 2009). This result demonstrates the importance of the cactus pear as a source of water in semiarid regions.

The coefficients of digestibility of the DM, OM, CP, and NDF increased linearly with increasing levels of cactus pear in the diet; the coefficient of digestibility of the EE did not increase significantly (Table 4). Similar results were described by Oliveira et al. (2007) as they substituted corn and Tifton hay with cactus pear in the diets of lactating cows.

The digestibility of OM varied from 73.37 to 83.2%, and the intake of digestible organic matter was 0.851, 0.973, 1.067, 0.988 and 0.990 kg/day for each of the cactus pear treatments (0, 25, 50, 75 and 100%), respectively. The digestibility of CP varied similarly, from 74.53 to 86.62%, representing intakes of digestible protein of 154.3, 180.7, 192.8, 180.7 and 174.8 g/day for each of the treatments, respectively. Table 4 shows that there were no associative effects; the digestibility of nutrients increased with the inclusion of cactus pear forage in the diets.

Digestible organic matter is important for ruminal microbial protein synthesis as an energy source. From the digestible protein intake, it is estimated that the intakes of N were 24.7, 28.9, 30.8, 28.9, and 27.9 g/day for each of the treatments, respectively. N stimulated ruminal microbial growth, favouring cellulolytic activity. In response, ruminal microbiota makes more energy available in the form of fatty acids, and reduces the quantity of protein that escapes from ruminal degradation.

The digestibility of NDF increased linearly ($P < 0.001$) with increasing levels of cactus pear in the diet. The digestibility of NDF varied from 56.58 to 77.53% between the 0 and 100% cactus pear treatments, respectively. Cactus pear has a high content of soluble carbohydrates, such as pectin, which is rapidly fermented in the rumen. NDF in the diets varied from 426.0 to 481.2 g/kg DM between the 0 and 100% cactus pear treatments, respectively. Most of the NDF in the diet came from Tifton hay (316.7 g/kg DM). The combination of Tifton hay with cactus pear promoted the physical effectiveness of NDF in the diet. This fibre stimulated chewing and rumination, assuring a suitable ruminal environment for the development of microbial populations.

In this study, digestive disturbances causing reductions in DM intake and in the digestibility of nutrients were not observed. Likewise, there were no liquid faeces or increases in abdominal distension in the animals. It is assumed that ruminal pH was not altered by the inclusion of cactus pear forage in the diet. Misra et al. (2006) verified this by observing ruminal pH around 7.0 when cactus was in the diet of sheep. Ben Salem and Smith (2008) also reported that the high content of sugars in cactus pear did not affect ruminal fermentation in sheep. The effects of high carbohydrate solubility in cactus pear relative to the reductions of ruminal cellulolytic activity were not measured (Gebremariam et al., 2006).

The apparent digestibility of the TC increased with higher proportions of cactus pear in the diet ($P < 0.05$). There was no significant effect of the digestibility of the NFC ($P > 0.05$), which averaged 92.82%. Cactus pear contains high levels of carbohydrates easily fermentable by ruminal microbiota. These carbohydrates represent fraction A (sugars and organic acids of rapid degradability) and fraction B1 (starch, pectin and glucan), as classified by Sniffen et al. (1992).

The daily weight gain (DWG) linearly decreased ($P < 0.05$) with increases of cactus pear in the diet (Table 5). The decrease in the amount of energy intake in the diets with 75 and 100% cactus pear reduced the weight gain of the animals.

The DWG decreased from 255 to 210 g/day between the diets with 0 and 100% of cactus pear, respectively. The reduction of the metabolisable energy supply in the diet (2.30–2.05 Mcal of ME/kg DM) and the ME intake from the 75% cactus pear treatment led to a marginal reduction in the weight gain of the sheep. It can be inferred that for each additional percentage unit of this cactus, there was a reduction of approximately 0.378 g in the DWG. This difference of 45 g between the DWG of the sheep fed with diets containing 0 and 100% of cactus pear is considered to be relatively small. For the Brazilian semiarid region, where soil and climate conditions make the production of cereal grains such as corn difficult, the use of cactus pear forage as a substitute for this cereal in feedlot sheep is justifiable.There was a higher intake of dry matter per kg of weight gain, resulting in a lower feed efficiency and leading to a linear decrease ($P < 0.05$) with increasing levels of cactus pear in the diet.

4. Conclusions

The total substitution of cactus pear for corn, although it led to a reduction in weight gain, increased DM intake

and improved the sheep's ability to digest the nutrients. Cactus pear is thus recommended as part of the diet during the finishing of lambs in feedlot confinement in Brazilian semiarid regions.

Confined sheep, when furnished with cactus pear, diminished their voluntary water intake.

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