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Replacement of grain maize with spineless cactus in the diet of dairy goats

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Research Article

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Abstract

Spineless cactus (*Nopalea cochenillifera*) is widely used in animal feed in semi-arid regions, due to the adaptive characteristics to such conditions and for having high levels of soluble carbohydrates. This research article describes the effect of replacing grain maize with spineless cactus in the diet of dairy goats on dry matter intake, water intake, milk yield, milk physicochemical characteristics and diet production costs. Eight multiparous Anglo Nubian goats were fed diets in which grain maize was replaced with spineless cactus at four levels (0, 33, 66, and 100%) in a double 4 × 4 Latin square design. Milk yield was measured and samples collected in the last three days of each period for physicochemical analysis and for determining nutrient intake. Diet production costs were also determined. Replacing maize with spineless cactus did not influence dry matter intake. Water intake *via* the drinker decreased linearly in response to the increasing levels of spineless cactus in the diet. The replacement of maize with spineless cactus did not change milk yield or physicochemical parameters. Total feed cost and the percentage of revenue losses from feed decreased with the replacement. Therefore, spineless cactus can fully replace grain maize in the diet of dairy goats, as it does not change dry matter intake or milk yield, but rather reduces feed costs and the drinking-water intake of goats.

Livestock activity in semi-arid regions is directly affected by climatic conditions characterized by long periods of drought and rains poorly distributed in time and space (Ramalho, 2013), which ultimately reduce the availability of feed in most months of the year. These regions have the potential for small ruminant farming owing to the greater adaptive capacity of these animals to such conditions (Hermuche *et al.*, 2013). However, the lack of technologies and adequate dietary management compromises the viability of production systems, possibly rendering them unsustainable over time (Emerenciano Neto *et al.*, 2011).

Among the concentrate feedstuffs used in goat diets, maize predominates in the majority of production systems due to its high energy value. Nevertheless, it is a human food product as well as one of the main ingredients used in the composition of diets for non-ruminant animals. In addition, semiarid regions do not have favourable climatic conditions for maize production. For these reasons, maize has become a costly ingredient (Batista *et al.*, 2020). Thus, feedstuffs with elevated levels of highly digestible carbohydrates have been investigated as alternative sources of energy to replace starchy grains (Costa *et al.*, 2009; Batista *et al.*, 2020). Spineless cactus (*Nopalea cochenillifera*) is widely used in animal feed in semi-arid regions (Batista *et al.*, 2020; Brito *et al.*, 2020; Matias *et al.*, 2020) due to its adaptability to these environments. Another important aspect of spineless cactus is the high level of water-soluble carbohydrates in its composition, a great part of which are esterified sugars that include high concentrations of galactose, arabinose, xylose and fructose (Habibi *et al.*, 2004; Brito *et al.*, 2020). These characteristics make it an aqueous energy concentrate with the potential to replace ground maize in ruminant diets (Costa *et al.*, 2009; Cordova-Torres *et al.*, 2015; Silva *et al.*, 2015; Felix *et al.*, 2016).

Spineless cactus also has a high moisture content (87 to 90%). This is a further advantage, since the inclusion of the cactus in ruminant diets can reduce water intake and human-animal competition for water in regions where water resources are limited (Borges *et al.*, 2019). we hypothesized that replacing grain maize with spineless cactus in diets for dairy goats would not change their dry matter intake or milk yield, but might result in a reduction in the cost of the diet and in drinking-water intake. Therefore, this study was carried out to examine

the effect of replacing maize grain with spineless cactus in the diet of dairy goats on dry matter intake, water intake, milk yield, milk physicochemical characteristics and diet production costs.

Materials and methods

All procedures performed in this experiment complied with the guidelines of Normative Resolution no. 25, of September 29, 2015, of the National Council for the Control of Animal Experimentation.

Experiment site

The experiment was conducted on the farm at the Federal Institute of Education, Science and Technology of Rio Grande do Norte, Apodi campus, located in Apodi – RN, Brazil (5°37′38″S, 37° 49′55″W; 150 m altitude). The climate of the region is a BSh'W type, according to the Köppen classification, with the rainfall concentrated in short seasonal periods that usually last three to five months. Annual precipitation in the region is 150 to 1300 mm and temperatures are relatively high, averaging around 28°C, with a maximum of around 40°C (Ramalho, 2013). The average minimum and maximum temperatures recorded during the experimental period were 21.29 and 36.81°C, respectively.

Experimental design and development

The experiment was laid out in a simultaneous double Latin square (4 × 4) design. Treatments consisted of diets in which 0, 33, 66, or 100% of grain maize were replaced with spineless cactus. Eight multiparous lactating Anglo Nubian goats with an average live weight of 43.33 ± 1.12 kg were confined in individual stalls (3.0 × 4.0 m) with slatted floors, equipped with feeders and drinkers. The two groups of four animals were grouped as a blocking factor taking into account milk production and days in lactation. The experiment lasted 60 d, which consisted of four periods of 15 d, the first 12 of which were used for the animals to adapt to the experimental diets, followed by three days of data collection. The diets were changed every 15 d so that all animals would receive all diets.

Diets and feeding management

Food was provided in two daily meals, immediately after milking: at 06 : 00 and 15 : 00. The diet consisted of approximately 40% buffel grass hay (*Cenchrus ciliaris* (L)), and 17% soybean meal. The rest of the diet consisted of corn grain (*Zea mays* L.) (concentrate), which was gradually replaced by forage palm (online Supplementary Table S1). The diet was formulated according to NRC (2007) recommendations, to meet the nutritional requirements of lactating goats producing 1.5 kg/day of milk with 3.0% fat, with a daily weight gain of 0.080 kg. The animals were weighed at the beginning and at the end of each experimental period to adjust the experimental diets.

The diet ingredients were offered separately as hay, spineless cactus and concentrate, and there was no left-over concentrate or spineless cactus. The left-over hay was weighed and packed in plastic bags, which were then labelled with the respective treatments. At the end of each period, these were homogenized and a composite sample of approximately 250 g was taken for each treatment. Samples of supplied and left-over hay, concentrate and spineless cactus were ground for further chemical analysis according to the methodology of AOAC (2005), to determine the contents of dry matter (DM, method 2001.12), mineral matter (MM, method 942.05), crude protein (CP, method 984.13) and ether extract (EE, method 920.39). The levels of neutral detergent fibre (NDF, method 2002.04), acid detergent fibre (ADF, method 973.18) and lignin (method 973.18) were determined sequentially, using sulphite or thermostable amylase (AOAC, 2005). For the estimation of non-fibrous carbohydrates (NFC), the following equations proposed by Sniffen *et al.* (1992): NFC (%) = 100 − (NDF + CP + EE + MM) (online Supplementary Table S2).

Nutrient intake

Nutrient intake was estimated as the difference between the total amount of the nutrient contained in the feedstuffs supplied and the total amount of the nutrient present in the orts. The intakes of dry matter (DMI) and nutrients from hay were determined as the difference between the total hay/nutrients supplied and total orts, corresponding to the last three days of each experimental period. The intakes of concentrate, spineless cactus and nutrients were determined based on the quantity supplied, since there were no orts. Water intake from the drinker was quantified as the difference between the daily quantity supplied and the quantity left over in the drinkers. The amount of evaporated water was discounted, which was measured by recording the amount of evaporated water in an isolated stall of the animals.

Milk yield and composition

Milk yield was determined by weighing on a digital scale on the last three collection days of each experimental period. After milking, samples of milk were taken to evaluate the physicochemical parameters: fat (%), protein (%), total solids (%), lactose (%), density, pH and freezing point (°C), using an ultrasonic milk analyser (Ekomilk®).

Production cost

All amounts in Brazilian real (BRL) have been converted to American dollar (USD), considering the currency quotation on October 28, 2020. Because they are produced on the farm, the feed costs of hay and spineless cactus were considered production costs, which were USD 0.091 and USD 0.087 per kg of DM, respectively, calculated according to methodologies used by Resende *et al.* (2017) and Dantas *et al.* (2017).

The costs of soybean meal and grain maize, in turn, were calculated as the selling prices in the study region, i.e., USD 0.38 and USD 0.21 per kg of DM, respectively (CEPEA-USP, 2021). Total feed cost was calculated by adding the costs of all diet ingredients. The percentage participation of the feed cost in the revenue from the sale of milk was calculated as milk yield multiplied by the selling price of milk in the region (USD 0.35/kg) divided by the feed cost. All prices used in the calculations corresponded to the average of the last two years practiced in the western region of the state of Rio Grande do Norte – Brazil.

Statistical analysis

Data were subjected to analysis of variance and the effect of the treatments was checked by regression analysis, using the statistical software Sisvar, version 4.6 (Ferreira, 2014). The following statistical model was used:

$$Y_{ijkl} = \mu + T_i + P_j + A_k + L_s + \alpha_{ijkl},$$

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Table 1. Intakes of dry matter, water and dietary ingredients as well as nutrient intakes by lactating goats in response to the replacement of maize with spineless cactus

	Replacement of maize with cactus (%)							P-value	
Item	0	33	66	100	SEM	Equation	R^2	*L*	*Q*
DM (g/day)	1518.25	1483.50	1512.37	1496.62	32.27	$\hat{y} = 1502.69$	–	0.80	0.77
DM (%LW)	3.65	3.50	3.56	3.38	0.11	$\hat{y} = 3.52$	–	0.13	0.91
Hay (g/day)	522.87	486.37	507.37	511.50	30.47	$\hat{y} = 507.03$	–	0.54	0.71
Cactus (g/day)	0.00	231.00	462.75	683.00	5.79	$y = 3.60 + 6.85x$	99.96	<0.01	0.14
Conc. (g/day)	995.00	766.00	542.00	302.00	4.80	$y = 995.54–6.92x$	99.99	<0.01	0.68
H_2O^a (kg/day)	3.24	2.52	2.07	0.97	0.23	$y = 4.02–0.73x$	97.32	<0.01	0.45
H_2O^b (kg/day)	0.23	1.74	3.25	4.69	0.04	$y = 0.26 + 0.04x$	99.96	<0.01	0.16
H_2O^c (kg/day)	3.47	4.26	5.32	5.66	0.23	$y = 3.54 + 0.02x$	96.41	<0.01	0.31
Nutrient intakes									
MM (g/day)	84.13	104.13	129.88	152.25	3.17	$y = 83.214 + 0.6911x$	99.79	<0.01	0.22
MM (%LW)	0.20	0.25	0.31	0.34	0.01	$y = 0.2027 + 0.0014x$	99.09	<0.01	0.66
CP (g/day)	241.88	230.25	226.25	218.88	3.78	$y = 240.21–0.2191x$	96.10	<0.01	0.53
CP (%LW)	0.58	0.55	0.53	0.50	0.01	$y = 0.5796–0.0008x$	97.73	<0.01	0.90
NDF (g/day)	542.25	547.00	591.88	621.00	21.99	$y = 533.5 + 0.8448x$	92.97	<0.01	0.58
NDF(%LW)	1.30	1.28	1.40	1.40	0.06	$y = 1.2839 + 0.0012x$	73.01	0.04	0.91
ADF (g/day)	242.88	260.25	297.88	326.88	11.32	$y = 238.69 + 0.87x$	98.29	<0.01	0.62
ADF (%LW)	0.58	0.61	0.70	0.74	0.03	$y = 0.5754 + 0.0017x$	95.81	<0.01	0.93
Lignin (g/day)	40.13	44.63	53.00	59.75	2.15	$y = 39.331 + 0.2019x$	98.83	<0.01	0.62
Lignin (%LW)	0.10	0.11	0.13	0.13	0.01	$y = 0.1011 + 0.0003x$	89.23	<0.01	0.88
EE (g/day)	61.75	49.88	39.00	26.75	0.84	$y = 61.658–0.348x$	99.97	<0.01	0.98
EE (%LW)	0.15	0.12	0.09	0.06	0.01	$y = 0.1468–0.0009x$	99.96	<0.01	0.77
NFC (g/day)	588.38	552.63	525.63	477.75	6.12	$y = 589.75–1.0785x$	98.91	<0.01	0.35
NFC (%LW)	1.42	1.31	1.23	1.08	0.02	$y = 1.426–0.0033x$	98.36	<0.01	0.36

DM, dry matter; Conc, concentrate; H_2O, drinking water; MM, mineral matter; CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre; EE, ether extract; NFC, non-fibrous carbohydrates; SEM, Standard error of the mean; *L*, linear; *Q*, quadratic.
[a]Water from the drinking fountain.
[b]Food water.
[c]Total water.

where Y_{ijkl} = value observed in period j, animal k and Latin square s, for treatment j; μ = overall mean; T_i = effect of treatment i (0, 33, 66 and 100% replacement); P_j = effect of period j (1 to 4); A_k = effect of animal k (1 to 8); L_s = effect of Latin squares (1 and 2); α_{ijkl} = random-error component associated with treatment i, period j, animal k and Latin squares. The significance level was set at 5% for all statistical analyses.

Results

Replacing grain maize with spineless cactus did not influence ($P > 0.05$) DMI or hay intake (Table 1). The intakes of spineless cactus and concentrate showed positive and negative linear responses to the replacement of maize with spineless cactus, respectively. Water intake *via* the drinker decreased linearly in response to the growing levels of the cactus added to the diet fed to the dairy goats. With each increase in the level of maize replaced with spineless cactus, water intake was estimated to decrease by 0.73 kg/day. On the other hand, the consumption of water through food and total, increased linearly in response to the inclusion of spineless cactus in the diet (Table 1). The intakes of MM, NDF, ADF and lignin increased linearly in response to the replacement of maize with spineless cactus (Table 1), whereas the intakes of CP, EE and NFC decreased.

Replacing maize with spineless cactus in the diet did not change ($P > 0.05$) milk yield or any of the physicochemical parameters (Table 2). The hay cost did not differ according to the diets (Table 3), whereas the concentrate cost decreased and the spineless cactus cost increased with the replacement of maize. The total feed cost and the percentage of revenue loss from feed decreased as maize was replaced with spineless cactus.

Discussion

The decrease in DM intake following the inclusion of spineless cactus in the ruminant diet is attributed to the high moisture content of the feed (Araújo *et al.*, 2004; Oliveira *et al.*, 2007; Borges *et al.*, 2019). However, regardless of the level of replacement of

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Table 2. Yield and physicochemical parameters of milk from lactating goats in response to the replacement of maize with spineless cactus

	Replacement of maize with cactus (%)						*P*-value	
Item	0	33	66	100	Mean	SEM	*L*	*Q*
Yield (g/day)	929.00	966.00	1160.00	1024.00	997.00	74.58	0.27	0.30
Fat (%)	6.00	4.28	4.97	4.71	4.99	0.33	0.12	0.11
Protein (%)	3.17	3.04	3.15	3.30	3.17	0.10	0.34	0.27
Total solids (%)	9.08	8.81	9.06	9.21	9.04	0.37	0.72	0.60
Lactose (%)	5.23	5.10	5.23	5.32	5.22	0.20	0.69	0.63
Density	30.48	30.89	31.30	32.13	31.19	1.62	0.51	0.91
pH	6.51	6.53	6.89	6.51	6.57	0.24	0.76	0.46
Freezing point (°C)	52.81	52.11	53.30	52.71	52.66	2.92	0.95	0.98

SEM, Standard error of the mean; L, linear; Q, quadratic.

Table 3. Feeding cost for lactating goats in response to the replacement of maize with spineless cactus

	Replacement of maize with cactus (%)						*P*-value	
Cost	0	33	66	100	Equation	R^2	*L*	*Q*
Hay (USD/head/day)	0.05	0.04	0.04	0.05	$\hat{y} = 0.25$	–	0.98	0.55
Concentrate (USD/head/day)	0.25	0.20	0.16	0.12	$y = 1.42 - 0.007x$	99.93	<0.01	0.94
Cactus (USD/head/day)	0.00	0.02	0.04	0.06	$y = 0.001 + 0.003x$	99.98	<0.01	0.41
Total diet (USD/head/day)	0.30	0.26	0.24	0.22	$y = 1.68 - 0.004x$	99.54	<0.01	0.68
FC/RM ratio (%)	90.77	80.06	63.24	62.92	$y = 89.21 - 0.30x$	90.15	<0.01	0.07

FC, feed cost; RM, revenue from the sale of milk; L, linear; Q, quadratic.
All amounts in Brazilian real (BRL) have been converted to American dollar (USD), considering the currency quotation on October 28, 2020;

grain maize with spineless cactus, the maintenance of the same DMI levels in dairy goats can be explained by the high palatability and high rate of passage of the cactus (Costa *et al.*, 2009). With the increased participation of the cactus in the diet, there was also a reduction in energy levels caused by the replacement of maize, which has higher concentrations of TDN (online Supplementary Table S2). Additionally, DMI in ruminants is also controlled based on energy requirements (Alen, 2000).

The observed average DMI was 1650 kg/day, which is 16% higher than the 1386 g/day predicted by the NRC (2007) for an animal with 43.33 kg live weight, producing 1 kg of milk per day. In this condition, it is suggested that spineless cactus can replace maize in the diet up to 100%, without prejudice to DMI. Another relevant aspect was the reduction in water intake *via* the drinker following the inclusion of spineless cactus, which was due to the high moisture content of this ingredient. This shows the potential of this forage as a water reserve for animals in semi-arid regions, where long drought periods occur (Oliveira *et al.*, 2007; Borges *et al.*, 2019). The water requirement can be met through three different sources: voluntary water intake; water intake from the feed; and water from the metabolism of nutrients in the body. Larger supplies of water *via* the feed translate into a lower water intake from the drinker (Zanetti *et al.*, 2019), which in turn reduces human-animal competition for water and the water footprint of animal production (Thomassen *et al.*, 2014).

The replacement of maize with spineless cactus in the diet of dairy goats increased the intakes of MM, NDF and ADF by the animals (Table 1). This was because the levels of these nutrients in spineless cactus are higher than those found in maize. On the other hand, the lower concentrations of CP, EE and NFC in spineless cactus explain the reduction in the intake of these nutrients by the goats in response to the increased participation of the cactus in the diets. However, this variation in nutrient intake was not sufficient to change DMI and, consequently, the milk yield of the goats.

The similar milk yield and composition, irrespective of the level of maize replaced with spineless cactus, may be associated with the high ability of the goat species to adapt to quantitative and qualitative variations of diets or forages, without changing their performance (Ramos *et al.*, 2020). This was confirmed by Vicente *et al.* (2020), who also did not observe changes in the physicochemical parameters of goat milk, even with a 10% difference in the TDN content of the diets. Costa *et al.* (2009) observed that the milk yield of Saanen and Alpine goats was not affected by the use of spineless cactus replacing maize. These results demonstrate that spineless cactus has the potential to meet the energy requirement for milk production of goats.

Concentrate costs decreased due to the decreased intake of this component. Because it is the most expensive component, when only concentrate and hay were used, feed costs represented 90.77% of the revenue obtained from the sale of milk. This percentage is close to the 84.43% observed by Vicente *et al.* (2020), who used 60% concentrate in the diet of feedlot Saanen and Alpine goats. The authors also highlighted that the economic results of the diets were unsatisfactory. Moreover, other costs

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such as labour, milking utensils were not accounted for. The production of spineless cactus on the farm allows a reduction in the cost of this ingredient and, consequently, of the milk produced, when it is used (Table 3). The same is not true for maize, whose use is dependent on its purchase on the market, since its cultivation is considered risky in semi-arid regions. Therefore, a buffel grass hay-based diet associated with spineless cactus represents a lower cost, which may result in greater profitability.

In conclusion, spineless cactus can fully replace grain maize in the diet of dairy goats, as it does not change dry matter intake, milk yield or milk composition, but rather reduces their drinking-water intake and diet production costs. Thus, spineless cactus can be regarded as an important energy food for lactating goats in semi-arid and arid regions.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0022029921000352

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