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Native and introduced forage cacti in Saanen dairy goat diets

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ABSTRACT. This study aimed to assess the nutrient intake and milk production of dairy goats fed with total mixed rations with different species of forage cacti. Five pluriparous Saanen goats (50 ± 4 kg) at nine weeks of lactation were allocated in a Latin square (5×5) with five diets and five periods. Each period was composed of 10 days for adaptation and seven days for collection. The treatments were composed of 473.0 to 501.0 g kg⁻¹ of forage cacti: xiquexique (*Pilosocereus gounellei*), mandacaru (*Cereus jamacaru*), facheiro (*Pilosocereus chrysostele*), cactus cladodes cv. miúda (*Nopalea cochenillifera* Salm-Dyck) and cactus cladodes cv. orelha de elefante mexicana (*Opuntia stricta*); plus sabiá hay (*Mimosa caesalpinifolia*) (188.0 to 198.0 g kg⁻¹) and concentrate (311.0 to 329.0 g kg⁻¹). The intake of dry matter, organic matter, ether extract, neutral detergent fiber, total carbohydrates, and water intake through diet components were unaffected by experimental diets. For milk production and feed efficiency, no difference was observed among the diets. All diets containing different species of forage cacti can be used for dairy goats feed.

Keywords: Cactaceae; ruminant nutrition; semi-arid; water intake.

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Introduction

In the Brazilian semi-arid region, goats are among the most suitable species for ruminant livestock production systems, and Caatinga vegetation is used as the main food source for these animals. In this region, introduced and native forage cacti are used as strategic roughage feed for cattle, goats, and sheep in times of severe drought.

The introduced cacti, for instance, the clones of (*Nopalea cochenillifera*; *Opuntia stricta*), are a good option as strategic food reserves for the livestock at Brazilian semi-arid, with high biomass productivity, water reserve for the herds during drought periods, and its high value as an energy source with a high digestibility (Ben Salem, 2010; Ramos et al., 2020; Araújo, Voltolini, Chizzotti, Turco & Carvalho, 2010; Costa et al., 2009; Siqueira et al., 2017; Moraes et al., 2019).

The chemical composition of cacti can vary with climatic factors, plant age, time of year, irrigation, and techniques used for thorn removal (Silva, Lima, & Rêgo, 2013; Magalhães et al., 2018). Generally, cacti are recommended to be associated with foods rich in fiber and protein when used in ruminant feed, due to its high-water content and non-fibrous carbohydrates (NFC) in its composition (Ben Salem, 2010; Ramos et al., 2013; Catunda et al., 2016).

Studies in the semi-arid region of Brazil show the efficiency of the use of native cacti in animal feed (Silva et al., 2013), however little is known about the effects of this alternative feeding regarding nutrient intake and milk production of goats comparing different native and introduced cacti species.

In a study with dairy goats, Silva, Melo, Rêgo, Lima and Aguiar (2011) when evaluating *P. gounellei* or *C. jamacaru* combinations associated with 'flor de seda' (*Calotropis procera*) or *Mimosa caesalpinifolia* bush hays for Saanen goats, they reported milk production was not altered (1.3kg day⁻¹). Costa et al. (2009) studying complete diets constituted of Tifton hay (*Cynodon spp.*), and replacing ground corn by cactus cladodes (*Opuntia ficus indica*), reported milk production of (1.8 kg day⁻¹) for Saanen and Alpine Brown goats. The ability of animals to intake food in sufficient quantities to meet their maintenance and production requirements is one of the most important factors in feeding systems largely dependent on roughage feed (Sniffen et al., 1993; Van Soest, 1994).

The production and quality of goat milk may vary depending on several factors, such as the type and quality of the animals' diet, race, lactation period and climate, as well as the combined action of these factors with the environmental conditions of each country or region (Zambom et al., 2005, 2013; Lopes et al., 2017; El-Tarabany, Abdel-Hamid, Ahmed-Farid, & Al-Marakby, 2019).

This study aimed to evaluate nutrient intake, and production of milk in Saanen goats fed with total mixed rations with different species of forage cacti.

Material and methods

Ethics Committee on the Use of Animals (CEUA) of the Universidade Federal do Rio Grande do Norte (UFRN), under license number 058/2015.

The experiment was conducted at the Experimental Station of Cruzeta- RN, Brazil, belonging to the Agricultural Research Corporation of Rio Grande do Norte (EMPARN). Cruzeta city is located at the following geographical coordinates: 6° 26' south latitude and 36° 35' west longitude of Greenwich and 230 m average altitude. The climate, according to the Koppen classification, is the type BSs'h semi-arid. According to the National Institute of Meteorology (INMET, 2014), the mean temperature and relative humidity and total rainfall in the trial were 28.4°C; 54.75% e 99.2 mm, respectively.

Pluriparous Saanen goats at nine weeks of lactation and average live weight of 50 ± 4kg were used. The animals were distributed in a Latin square design (5 x 5) with five goats, five experimental diets, and five periods. The experiment was performed in pens with cement floor, consisting of five stalls, each measuring (1.0 x 3.0 m), with partitioned wooden fences and indoor areas covered with ceramic roof tiles. Feeders (plastic drum with a capacity of 50 kg) and a plastic bucket for drinking (9.0-liter capacity) were individual and located outside the stalls. The study lasted 85 days, with five consecutive experimental periods of 17 days, 10 days for adaptation, and seven days for each collection period. The animal weighing was performed at the beginning and end of the introduction period and every 17 days until the end of the trial.

The diets were formulated to meet the daily milk production requirements of 2.0 kg assuming 50kg goats as average weight according to the nutritional requirements of the National Research Council (NRC, 2007).

The treatments were defined based on dry matter, evaluating four varieties of cacti: xiquexique (*Pilocereus gounellei*), mandacaru (*Cereus jamacaru*), facheiro (*Pilosocereus chrysostele*), spineless cactus cv. Miúda (*Nopalea cochenillifera* Salm-Dyck) and spineless cactus cv. Orelha de elefante mexicana (*Opuntia strica* Haw) associated with "Sabiá" hay (*Mimosa caesalpiniiifolia*) and concentrate composed of ground corn, soybean meal, and mineral mix (recommended for lactating goats) (Tables 1 and 2).

Table 1. Chemical composition of the ingredients of the experimental diets.

Item	Ingredients							
	<i>P. gounellei</i>	<i>C. jamacaru</i>	<i>P. chrysosteles</i>	<i>Nopalea</i>	<i>Opuntia</i>	Sabiá hay	Ground corn	Soybean meal
DM ¹	150.0	208.8	152.6	128.3	103.4	837.7	903.9	907.0
OM ²	811.4	851.8	825.2	829.2	797.1	936.0	961.4	921.5
CP ²	74.1	82.0	54.1	79.2	49.4	130.3	94.5	470.0
EE ²	16.2	16.2	20.5	18.4	20.0	22.8	35.1	25.6
NDF ²	421.2	443.0	446.1	350.1	394.2	513.4	135.6	120.3
ADF ²	281.0	324.7	389.1	148.6	121.8	324.2	43.9	106.6
TC ²	721.1	753.7	750.5	731.5	727.7	802.7	831.8	425.9
NFC ²	342.8	345.9	301.9	474.5	380.7	161.1	746.2	335.5

¹g kg⁻¹ fresh matter (NM), ²g kg⁻¹ DM, DM = dry matter, OM = organic matter, CP = crude protein, EE = ether extract, NDF = neutral detergent fiber, ADF = acid detergent fiber, TC = total carbohydrates, NFC = non-fibrous carbohydrates.

The native cacti were harvested from Caatinga areas and transported weekly to the experiment. The thorns of *P. gounellei*, *C. jamacaru*, and *P. chrysostele* were removed on a daily basis with a butane gas flamethrower and subsequently ground in a forage machine. The introduced cacti (*Nopalea* and *Opuntia*) were harvested from cultivated and irrigated areas and after that they were hand-cut with a knife at feeding time. The Sabiá hay was prepared by the gathering of fresh leaves and stalks of tender plants, then ground in a forage machine and spread in 10cm layers in a solar dryer.

Table 2. Proportions of ingredients in the diet.

Item	Experimental diets				
	<i>P. gounellei</i>	<i>C. jamacaru</i>	<i>P. chrysosteles</i>	<i>Nopalea</i>	<i>Opuntia</i>
Forage cacti	498.9	478.5	501.2	473.3	486.0
Sabiá hay	189.0	196.8	187.8	197.9	195.0
Ground corn	189.6	197.1	188.8	200.7	193.7
Soybean meal	102.3	106.5	102.0	107.1	104.8
Mineral mix	20.2	19.1	20.2	21.1	20.6
Chemical composition (g kg ⁻¹)					
DM ¹	256.8	346.4	259.7	234.9	189.9
OM ²	858.3	879.4	864.9	869.3	852.7
CP ²	127.6	133.5	117.4	132.6	117.0
EE ²	21.7	21.9	23.8	23.0	23.6
NDF ²	346.6	352.4	348.1	305.4	328.6
ADF ²	325.5	306.6	327.3	188.5	142.0
TC ²	712.8	727.9	727.4	717.7	716.0
NFC ²	377.3	380.0	356.7	442.2	396.1

¹g kg⁻¹ fresh matter (NM). ²g kg⁻¹ DM, DM = dry matter, OM = organic matter, CP = crude protein, EE = ether extract, NDF = neutral detergent fiber, ADF = acid detergent fiber, TC = total carbohydrates, NFC = non-fibrous carbohydrates.

The feed was offered twice a day at 7:00 a.m. (500.0 g kg⁻¹) and at 4:00 p.m. (500.0 g kg⁻¹), consisting of a mixture of one of the cacti, Sabiá hay, ground corn, soybean meal, and minerals to form a total mixed ration. A 10% leftover of the total dry matter was allowed.

To obtain the nutrient intake and chemical analysis, the samples were collected weekly during the adaptation period and daily in the collection period. Samples consisted of the ingredients offered in diets, as well as the leftover food left by each animal, sampled daily to obtain a composite sample of the experimental period (weekly).

In the laboratory, the samples were pre-dried in a forced ventilation oven at 55°C, prepared to chemical analysis for chemical composition through the Association of Official Analytical Chemists [AOAC] (1997) methods, to determine dry matter (DM, method 934.01), ash (method 942.05), organic matter (OM, method 930.05), crude protein (CP, Kjeldahl N × 6.25, method 981.10), and ether extract (EE, method 920.39). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to Van Soest, Robertson and Lewis (1991).

The total carbohydrates (TC) were calculated according to Sniffen, O'Connor, Van Soest, Fox, and Russell (1992) where TC = 100 - (% CP + % EE + % Ash). Non-fibrous carbohydrates (NFC) were calculated according to the equation described by Hall, Hoover, Jennings, and Webster (1999) where NFC = % TC - % NDF.

The goats were hand milked at 6 a.m. and 3 p.m. Individual milk production was quantified with milk samples being collected twice a day, once per week in the adaptation period and at each of the seven days during the collection period. Milk production was evaluated by daily control and 4%-fat-corrected milk by the equation suggested by the National Research Council [NRC] (2001).

Data were submitted to analysis of variance and comparison of means by Tukey test, using the SAS program (Statistical Analysis System [SAS], 2002) version 9.0.

Results and discussion

There was an effect ($p < 0.05$) of the diets on the crude protein (CP) intake, a lower value observed for goats fed *Opuntia*. There were also differences ($p < 0.05$) between treatments for acid detergent fiber (ADF) intake, with lower intakes values for the animals fed with *Nopalea* and *Opuntia*. The non-fibrous carbohydrates (NDF) intake was higher ($p < 0.05$) for animals fed with *P. gounellei*, *C. jamacaru*, and *Nopalea* (Table 3).

Regarding the dry matter (DM) intake expressed in g day⁻¹, % of BW, and metabolic weight, values were very close to the recommended by NRC (2007) that is 2.25 g day⁻¹. The high DMI of the diets may be related to the low content of NDF and the high content of NFC (Table 2). All diets contained low levels of NDF (305.0 to 352.0 g kg⁻¹), but within the minimum limit of 250.0 g kg⁻¹ fiber in the diet necessary for animal production and health (Mertens, 1997).

There were no differences ($p < 0.05$) for dry matter (DM), organic matter (OM), neutral detergent fiber (NDF), ether extract (EE) and total carbohydrates (TC) intake on the experimental diets (Table 3). The absence of treatment effects may be related to the proximity of NDF concentrations in the experimental diets (305.4 to 352.4 g kg⁻¹) which justifies the lack of significance for NDF intake by the dairy goats. High concentrations of NDF limit intake due to the physical strain of the rumen reticulum, while the intake of diets with lower NDF levels would be limited in achieving the animal's energy requirement (Mertens, 1983).

Table 3. Nutrients intake of dairy goats fed with different forage cacti.

Item	Experimental diets					CV%
	<i>P. gounellei</i>	<i>C. jamacaru</i>	<i>P. chrysosteles</i>	<i>Nopalea</i>	<i>Opuntia</i>	
DM (g day ⁻¹)	2,602.46	2,382.70	1,967.58	2,241.38	2,065.07	18.25
DM (% BW)	5.11	5.10	3.84	4.31	3.96	18.76
DM (g day ^{-0.75})	136.78	133.15	102.75	115.62	106.25	18.39
OM (g day ⁻¹)	2,202.33	2,105.07	1,689.77	1,941.10	1,675.50	12.70
OM (% BW)	4.33	4.50	3.29	3.73	3.26	16.26
OM (g day ^{-0.75})	115.50	117.50	87.98	100.08	87.18	15.60
CP (g day ⁻¹)	352.83 a	340.70 a	261.31 ab	302.66ab	231.41 b	17.39
CP (% BW)	0.69 ab	0.73 a	0.51 bc	0.58abc	0.46c	18.41
CP (g kg ^{-0.75})	18.51a	19.08a	13.68ab	15.59ab	12.15b	17.39
NDF (g day ⁻¹)	787.32	761.95	652.47	653.75	640.25	21.82
NDF (% BW)	1.55	1.62	1.27	1.27	1.25	21.95
NDF(g kg ^{-0.75})	41.24	42.32	33.93	34.03	33.27	21.73
ADF (g day ⁻¹)	468.05a	518.92a	453.01a	307.71b	281.79b	17.43
EE (g day ⁻¹)	66.35	56.43	55.81	56.01	49.04	13.56
TC (g day ⁻¹)	1,798.14	1,718.52	1,380.31	1,592.00	1,393.92	15.24
NFC (g day ⁻¹)	1,022.95a	953.96ab	746.26b	1,020.07a	711.74b	14.66

DM = dry matter, OM = organic matter, CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, EE = ether extract, TC = total carbohydrates, NFC = non-fibrous carbohydrates, CV% = coefficient of variation. Means followed by different letters in the lines differ ($p < 0.05$) by Tukey's test, at 5% probability.

In this study, even though the average NDF intake was high (1.39% of live animal weight), it does not seem to have negatively influenced the DM intake of the experimental diets. Silva et al. (2011) in a study with Saanen goats using combinations of *P. gounellei* or *C. jamacaru* with *Calotropis procera* or *Mimosa caesalpinifolia* bush hay, and diets containing NDF levels of 439.9 to 358.9 g kg⁻¹, reported DMI values ranging from 1,139.16 g day⁻¹ to 1,867.35, which are lower than in the present study.

According to Mertens (1992) intake is responsible for the function of the animal, live weight, production level, variation of live weight, physiological state, and size. Also, to food, nutrient content, energy density, chewing need and filling capacity; and feeding conditions, food availability, space in the feeder, time of access to food, and frequency of feeding. The higher DM intake of the current research compared to the values obtained by Silva et al. (2011), may be associated with the live weight, production level, and age of the Saanen goats.

Costa et al. (2009) replacing 1,000.0 g kg⁻¹ of corn by forage cactus, representing 280.0 g kg⁻¹ DM in the total diet of dairy goats, reported DM intake values among the diets (1,950 to 2,365 g day⁻¹). Factors including low NDF, high palatability, and passage rate of the forage cactus may have contributed to their greater intake as spineless cactus availability increased. Pereira et al. (2013) and Zambom et al. (2013) replacing corn by mesquite pod meal and soybean hull, did not find any difference in the DM intake of Saanen goats (1.42 and 2.22 kg day⁻¹, respectively). Santos et al. (2014) evaluating (cottonseed cake, soybean meal, aerial cassava hay, and leucaena hay) in dairy goats' diet, reported that intake of DM was not affected by the experimental diets (2.08 kg day⁻¹). Pereira et al. (2013) and Santos et al. (2014) reported that the replacement of traditional foods by alternative sources without increasing the NDF levels that limit the intake and the fact that the diets were isonitrogenous do not affect DMI of animals.

The absence of a significant difference for OM intake can be partly explained by the similar behavior of DM intake (Table 3). Silva et al. (2011) reported differences ($p < 0.05$) for OM intake of cacti ranging from 997.97 to 1,659.04 g day⁻¹ for dairy goats, results lower than the observed in this study.

The lowest value observed for the intake of CP by animals fed the *Opuntia* diet compared with *P. gounellei* and *C. jamacaru* diets, which may be explained by the low level of CP (Table 2) in the diet composition with this specie (*Opuntia stricta*). All diets provided intakes of CP with values above the recommended by the NRC (2007) of 0.211 kg day⁻¹, showing that the experimental diets were able to meet the requirements of CP of the animals.

While, the lower ADF intakes were observed in diets containing *Nopalea* and *Opuntia*, which may be related to the lower ADF content of these cacti (Table 1), there was no difference ($p > 0.05$) between the experimental diets for the intake of TC and EE, with averages of 1,576.58 and 56.73 g day⁻¹, respectively. On the other hand, the diets differed ($p < 0.05$) in NFC intake, expressed in g day⁻¹, ranging from 711.74 (*Opuntia*) to 1,022.95 (*P.gounellei*). The intake of TC, EE, and NFC of this research were intermediaries to those reported by Silva et al. (2011) in a study with native cacti, hay, and Saanen goats.

The water intake through food (WIF) did not vary ($p > 0.05$) between the treatments, with an average value of 7,050.19 g day⁻¹, but there was a difference ($p < 0.05$) in supplied water intake (SWI) between the experimental diets. There was a difference ($p < 0.05$) for the total water intake (TWI) varying from 11,043.02 (*P. chrysostele*) to 15,930.97 g day⁻¹ (*Nopalea*) (Table 4). The TWI/DMI intake and SWI/DMI intake ratio were not influenced by the treatments.

Table 4. Water intake of dairy goats fed with different forage cacti.

Item	Experimental diets					CV%
	<i>P. gounellei</i>	<i>C. jamacaru</i>	<i>P. chrysosteles</i>	<i>Nopalea</i>	<i>Opuntia</i>	
WIF (g day ⁻¹)	8,435.88	4,806.14	6,469.82	8,346.97	7,193.15	26.17
SWI (g day ⁻¹)	5,278.80ab	6,390.40ab	4,573.20b	7,584.00a	4,311.20b	23.61
TWI (g day ⁻¹)	13,714.68ab	11,196.54b	11,043.02b	15,930.97a	11,504.35ab	18.35
SWI/DMI	2.04	2.66	2.30	3.35	2.43	31.48
TWI/DMI	5.27	4.72	5.72	7.26	6.01	20.81

DMI = dry matter intake, WIF = water intake from the feed, SWI = supplied water intake, TWI = total water intake. CV% = coefficient of variation, Means followed by different letters in the lines differ ($p < 0.05$) by Tukey's test, at 5% probability.

Regarding the absence of effects of diets on water intake, Silva et al. (2011) also reported differences in SWI for Saanen goats consuming native forage cacti ranging from 4,456.25 to 6,584.87 g day⁻¹. Costa et al. (2009) reported a lower TWI (9.26 kg day⁻¹) by lactating goats who received rations with higher forage cactus levels replacing ground corn grain.

According to Van Soest (1994), the relation of the water content in tropical forages for intake can be considered a function of the structural volume if the forage contains water in the structure of the cellular wall. Minson (1990) reported that conventionally water levels exceeding 780 g kg⁻¹ of fresh forage cause a decrease in voluntary animal intake. In this research, the high-water levels of forage cacti did not negatively influence the DMI among the experimental diets. The water intake results of this research confirm the high concentrations of water in the cellular contents of the cacti which is an important characteristic for semi-arid regions, where water availability is a limiting factor for animal production (Costa et al., 2009; Araújo et al., 2010; Ben Salem, 2010).

The fat-corrected milk at 4% (FCM) and fat production (FP) differed ($p < 0.05$) between the types of cacti with higher values observed for animals fed with *P. gounellei*, *C. jamacaru* and *Nopalea* (Table 5). For milk production and feed efficiency (FE), there was no difference ($p > 0.05$) between diets, with an average value of 1.90 kg day⁻¹ and 0.9 kg milk g DMI⁻¹, respectively (Table 5).

Table 5. Milk production of dairy goats fed with different forage cacti.

Item	Experimental diets					CV%
	<i>P. gounellei</i>	<i>C. jamacaru</i>	<i>P. chrysosteles</i>	<i>Nopalea</i>	<i>Opuntia</i>	
MP (kg day ⁻¹)	1.92	1.97	1.70	2.09	1.83	10.17
FCM (kg day ⁻¹)	1.70ab	1.73ab	1.49b	1.92a	1.54b	10.24
FP (g day ⁻¹)	62.41ab	62.67ab	54.39b	72.33a	54.05b	11.87
FE (kg milk g DMI ⁻¹)	0.74	0.83	0.87	0.96	1.00	19.91

MP = milk production, FCM = 4% fat-corrected milk, FP = fat production, FE = feed efficiency, CV% = coefficient of variation; Means followed by different letters in the lines differ ($p < 0.05$) by Tukey's test, at 5% probability.

This uniform response of milk production can be explained by the balance of NDF (from 305.4 to 352.4 g kg⁻¹), and NFC (356.7 to 442.2 g kg⁻¹) concentration of the diets. Branco et al. (2011) reported that the effect of the concentration and quality of fiber on dairy's goat milk production occurs in a direct manner. With increased NDF concentration of fodder, there is a reduction in DMI or a reduction in ruminal digestion rate directly affecting the nutrient partitioning for milk production.

In the present study the results of the milk production presented by Silva et al. (2010), Pereira et al. (2013), and Zambom et al. (2013) with Saanen goats, allow to highlight the possibility of alternative feeding management. The producer at the Brazilian semi-arid region can use five cacti species and a drought-tolerant forage legume participating with 70% of the animal diet, with a 40-60% reduction in water intake via food, less quantity concentrated feed, contributing to the viability of the animal production systems of the Caatinga.

Conclusion

All diets containing different species of cacti can be used for dairy goats feed, for providing enough nutrient intake to meet the animals' nutritional requirement, milk production, and feed efficiency.

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