Acta Scientiarum

http://periodicos.uem.br/ojs/acta
ISSN on-line: 1807-8672
Doi: 10.4025/actascianimsci.v45i1.58162

Intake, digestibility, and ingestive behavior of sheep fed with thornless Mandacaru, cactus pear genotypes Orelha de Elefante Mexicana and Miúda

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ABSTRACT. This study aimed to evaluate the intake, digestibility, and ingestive behavior of sheep fed with different species of forage cacti. Fifteen sheep (17.27kg ± 1 kg) were distributed in a completely randomized experimental design with three treatments and five replicates. The treatments were diets on a dry matter basis composed of 430.9 g kg^{-1} of thornless Mandacaru cactus (*Cereus hildmannianus*), 525.7 g kg^{-1} of cactus pear cv. Orelha de Elefante Mexicana (*Opuntia stricta*) and 492.1 g kg^{-1} of cactus pear cv. Miúda (*Nopalea cochenillifera*) in addition to Sabiá hay (*Mimosa caesalpiniaefolia*) (194.7 to 233.8 g kg^{-1}), plus concentrate feed. The intake of the dry matter, organic matter, ether extract, neutral detergent fiber, total carbohydrates, non-fiber carbohydrates, total digestible nutrients and voluntary water intake in g day^{-1} was not differ ($p > 0.05$) by experimental diets. There were no differences ($p > 0.05$) in digestibility coefficients of the dry matter, organic matter, neutral detergent fiber, total carbohydrates, non-fiber carbohydrates, and total digestible nutrients between the experimental diets. The feeding times differed ($p < 0.05$) between diets, with a higher value for *the Opuntia* diet, while the rumination times, feeding efficiency, and rumination efficiency did not differ ($p > 0.05$). The cactus *Cereus* and *Opuntia* and *Nopalea* have similar nutritional value in sheep's diet.

Keywords: *Cereus hildmannianus*; native cacti; digestibility; strategic forage.

Received on March 11, 2021.
Accepted on February 23 2022.

Introduction

Small ruminant production is the main source of income for farmers living in arid and semiarid regions. Sheep and goats raised in these areas often face severe nutritional deficiencies during food shortage periods, resulting in poor productive and reproductive performance (Ben Salem, 2010).

The vegetation in the Brazilian semiarid region is Caatinga, composed of shrubs and small trees which are usually thorny and deciduous, annual plants, cacti, bromeliads, and an herbaceous component composed of grasses and dicotyledons (Santos et al., 2010). Livestock in this region is a less risky activity about agriculture, as it allows the use of xerophilous plants (native or introduced), as well as adopting forage conservation practices (hay and silage) in animal feed (Santos, Silva, Dubeux Júnior, Lira, & Silva, 2013).

In certain areas of the semiarid where cactus pear (*Opuntia* and *Nopalea*) does not acclimatize or have low yields, mandacaru (*Cereus jamacaru*) and xiquexique (*Pilosocereus gounellei*) cacti are used during prolonged drought periods as strategic forage sources in the diets of ruminants (Silva, Lima, & Rego, 2013; Góes Neto et al., 2021).

Thornless Mandacaru is a columnar cactus with a height ranging from 3.5 to 5.3 m found in the states of Rio Grande do Norte, Paraíba, and Pernambuco (Cavalcanti & Resende, 2006). This species is used as an ornamental plant, but it has forage potential since it contains 12% crude protein (CP) based on a dry matter (DM) in its chemical composition.

Cactus pear, a cactus introduced to the northeastern semi-arid with high biomass productivity (Edvan et al., 2020), high palatability, non-fiber carbohydrate (NFC) concentration and DM digestibility (Costa et al., 2012), could be a fundamental strategic forage to use in various production systems in semiarid regions around the world (Rocha Filho et al., 2021), constituting a strategic forage option for sheep in this environment. On the other hand, due to the low concentration of neutral detergent fiber (NDF) and CP in DM of cacti species, the association of this cactus with foods rich in fiber and CP increases the concentration of effective fiber and CP in the diet (Ben Salem, 2010), and in turn animal performance by increasing digestibility of other nutrients (Andrade-Montemayor, Cordova-Torres, García-Gasca, & Kawas, 2011).

In a study carried out with lambs evaluating the combinations of mandacaru (*Cereus jamacaru*) or xiquexique (*Pilosocereus gounellei*) associated with silk flower hay (*Calotropis procera*) or Sabiá hay, Silva, Lima, Aguiar, Melo and Rêgo (2010) it was reported that there was no difference between the diets in the daily weight gain of the animals with an average of 86 g, or in the intake of DM, organic matter (OM) and total digestible nutrients (TDN), with means of 620.86 g day^{-1}, 571.34 g day^{-1} and 419.93 g day^{-1}, respectively. Studies evaluating different genotypes of spineless cactus in diets of lambs fed genotypes cv. Miúda (Cordova-Torres et al., 2017; Cardoso et al., 2019), Orelha de Elefante Mexicana (Lopes et al., 2020; Rocha Filho et al., 2021), and Gigante (Rocha Filho et al., 2021; Pereira et al., 2021) has obtained values of 2.88 to 4.06 % of BW for intake of DM and digestibility of DM with values between 648 to 832 g kg^{-1} as well as the 240 to 265 g day^{-1} of performance. However, few studies are evaluating the nutritional value of thornless mandacaru (*Cereus hildmannianus*) in the diet of lambs.

Thus, this study aimed to evaluate the intake of nutrients and water, digestibility, and ingestive behavior of sheep fed thornless mandacaru, cactus pear genotypes Orelha de Elefante Mexicana, and Miúda.

Material and Methods

The experiment was conducted at the Animal Nutrition Laboratory of the Jundiaí Agricultural School (EAJ), belonging to the Federal University of Rio Grande do Norte (UFRN), located in Macaíba/RN, with the geographic coordinates 05° 53' 35.12'' South latitude and 35° 21' 47.03'' West longitude. The climate of the region is dry sub-humid with water surplus from May to August. The average minimum, mean, and maximum temperature and the total rainfall during the experimental period were 26°C, 28.5°C, 31°C, and 70 mm, respectively. Ethics Committee on the Use of Animals (CEUA) of the Universidade Federal do Rio Grande do Norte (UFRN), under license number 008.011.2017.

Fifteen non-castrated male crossbred lambs (½ Soinga x ½ Santa Inês) of four months of age and initial weight of 17.27 kg ± 1.05 kg were distributed in a completely randomized design with three treatments and five replications. The lambs were kept in individual metabolism cages (1.2 m length x 0.8 m width) containing feeders and drinking water with coupled fecal collection trays. The cages were arranged side by side in the same direction and the center of the experimental shed. The experimental period lasted 21 days, with 14 days for the animals to adapt to treatment and metabolism cages, and the last seven days for data collection. The animals were weighed at the beginning and at the end of the experimental period.

The cactus cladodes variety Miúda was harvested from the existing plants at the Agricultural School, Macaíba, Rio Grande do Norte state, Brazil; the variety Orelha de Elefante Mexicana from the irrigated cultivation at the Experimental Station of Terras Secas of Agricultural Research Corporation of Rio Grande do Norte (EMPARN), located in the municipality of Pedro Avelino/RN; and the thornless mandacaru in the municipality of Parelhas, Rio Grande do Norte state, Brazil. The Sabiá hay used was composed of leaves and tender branches crushed in a forage machine, distributed in 10 cm layers for shade dehydration. The cacti offered were manually sliced using knives, with a particle size of approximately 3 cm. Only the forage material was used from the thornless mandacaru, separated from the woody stem.

Feeding was offered twice a day at 8 am (50%) and 4 pm (50%), and 10% of total dry matter was allowed. The diets were formulated to meet sheep requirements for the weight gain of 100 g day^{-1}, according to recommendations of the National Research Council (NRC, 2007). Each experimental diet was composed of one of the three thornless variety at a time. Mandacaru cactus (*Cereus hildmannianus*), cactus pear cv. Orelha de Elefante Mexicana (*Opuntia stricta*) or cactus pear cv. Miúda (*Nopalea cochenillifera*), added with Sabiá hay, corn, soybean, and mineral salt (Table 1) in various proportions (Table 2).

Food intake was measured daily by the difference between the amount of food offered and the amount of leftovers, based on a dry matter (DM). The water offered daily per animal was 4.000 g in individual buckets, weighing the daily supply and the leftover of the previous day at 7 am. Voluntary water intake was determined through the difference between supply, evaporation, and surplus. Water intake via food was calculated as the difference between fresh food intake and DM intake according to Cordova-Torres et al. (2017).

Table 1. Composition of the ingredients of experimental diets.

Nutrients ($g\ kg^{-1}$DM)	Ingredients					
	Cereus	*Opuntia*	*Nopalea*	Sabiá hay	Ground Corn	Soybean meal
Dry matter	104.1	79.0	118.3	887.4	882.2	883.7
Organic matter	842.0	781.9	876.8	942.6	983.6	927.4
Ash	158.0	218.1	123.2	57.4	16.4	72.6
Crude protein	154.4	65.7	25.8	152.9	92.2	529.9
Ether extract	13.0	15.1	14.4	52.6	44.4	15.4
Neutral detergent fiber	374.1	252.8	311.8	495.9	113.4	144.9
apNDF	316.1	179.3	282.6	371.1	79.8	134.0
Acid detergent fiber	246.7	147.5	128.9	457.0	56.1	123.9
Total carbohydrates	674.5	701.1	837.4	738.0	847.0	382.1
Non-fibrous carbohydrates	300.4	448.2	518.4	242.1	733.6	237.2
Lignin	9.2	16.3	47.0	158.0	27.0	15.2
ADIP	1.0	0.9	0.9	2.1	1.3	2.5
NDIP	8.2	4.4	2.4	4.1	2.9	3.8
TDN*	646.7	600.8	697.5	555.8	862.2	781.1

apNDF = ash and protein corrected neutral detergent fiber; NDIP = neutral detergent insoluble protein; ADIP = acid detergent insoluble protein; *Estimated total digestible nutrients.

Table 2. Chemical composition of experimental diets based on DM.

Item	*Diets*		
	Cereus	*Opuntia*	*Nopalea*
Ingredients ($g\ kg^{-1}$)			
Cactus	430.9	525.7	492.1
Sabiá hay	233.8	194.7	208.7
Corn meal	199.6	166.2	178.1
Soybean meal	113.7	94.7	101.4
Mineral mix	22.0	18.7	19.7
Chemical Composition ($g\ kg^{-1}$)			
Dry matter	271.4	154.3	240.0
Organic matter	885.0	845.9	897.4
Ash	115.0	154.10	102.6
Crude protein	180.9	129.8	114.8
Ether extract	28.3	26.8	27.3
Neutral detergent fiber	316.3	262.0	291.8
Acid detergent fiber	238.4	187.6	181.4
Lignin	48.0	45.3	41.6
ADIP	1.5	1.3	1.4
NDIP	5.5	4.0	2.9
Total carbohydrates	675.7	689.2	755.7
Non-fibrous carbohydrates	359.4	427.1	460.3
TDN*	670.0	641.7	692.4

NDIP = neutral detergent insoluble protein; ADIP = acid detergent insoluble protein; *Estimated total digestible nutrients.

A representative sample (300g) of the food was taken to characterize it daily during the data collection period. The dietary leftovers were also weighed, which formed a sample composed of the experimental unit. The samples of leftovers and food offered were kept in a freezer at -10°C. The feces were collected at 24 hours of each day and weighed at 7h from the 15^{th} to the 21^{st} day. After material homogenization, a daily aliquot of 10% was taken to prepare a sample composed for each animal.

The samples of food, leftovers, and feces were pre-dried in a 55°C forced-air oven for 72 hours. Next, they were ground in a Wiley mill with a 1 mm sieve to determine the 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) concentrations, according to Association of Official Analytical Chemists (AOAC, 1997).

The determination of neutral detergent fiber (NDF) values was performed according to the method defined by Soest, Robertson and Lewis (1991). Correction of NDF for ash and protein corrected (apNDF) was performed using the methodologies for crude protein and ash. The values for total carbohydrates (TC), non-fiber carbohydrates (NFC), and total nutrients digestible (TDN) were estimated agreeing with Sniffen, O'Connor and Soest (1992), Hall (2000) and Weiss, Conrad and Pierre (1999): according to the following equations, respectively.

$$TC = 100 - (\%\,CP + \%\,EE + \%\,ash)$$

$$NFC = 100 - (\% CP + \% EE + \% ash + \% NDF)$$

$$TDN = dCP + dNDF + dNFC + (dEE \times 2.25)$$

where: dCP: digestible CP; dNDF: digestible NDF; dNFC: digestible NFC and dEE: digestible EE.

The apparent digestibility of nutrients was calculated according to Silva and Leão (1979):

$$\text{Digestibility coefficient} = \frac{(\text{g nutrient ingested} - \text{g nutrient excreted})}{\text{g nutrient ingested}} x\ 1000$$

Observations on ingestive behavior were performed used the instant scan methodology with an interval of ten minutes for 24 hours (Johnson & Combs, 1991). In the interval's observation parameters, the time parameters were determined of feeding and rumination times. The results for feeding and rumination efficiencies according to DM (g of DM) for time (h day^{-1}) were obtained according to Polli, Restle and Senna (1996), using the following equations: feeding efficiency = intake/feeding time; rumination efficiency = intake/rumination time.

The obtained data were submitted to the analysis of variance by the generalized linear model's method, and the means were compared by the Tukey test at 5% of significance using the R program (R Core Team, 2017).

Results and Discussion

There was no difference ($p > 0.05$) in the intakes of dry matter (DM), organic matter intake (OM), ether extract (EE), neutral detergent fiber (NDF), total carbohydrate (TC), non-fibrous carbohydrate (NFC), and total digestible nutrient (TDN) by lambs fed with different cacti (Table 3).

Table 3. Nutrient intake by sheep fed different cacti diets.

Item	Diets			CV (%)
	Cereus	*Opuntia*	*Nopalea*	
DMI (g day^{-1})	777.50	780.00	843.33	15.53
DMI (%BW)	4.13	4.33	4.61	13.42
OMI (g day^{-1})	692.68	669.03	759.23	15.98
CPI (g day^{-1})	145.10^{a}	109.94^{ab}	100.09^{b}	22.09
EEI (g day^{-1})	23.50	23.41	24.29	13.43
NDFI (g day^{-1})	247.59	207.76	240.05	15.67
TCI (g day^{-1})	537.01	547.96	648.64	17.94
NFCI (g day^{-1})	289.42	340.15	405.13	22.49
TDNI (g day^{-1})	502.39	518.73	552.83	16.98

DMI = dry matter intake; BW = body weight; OMI = organic matter intake; CPI = crude protein intake; EEI = ether extract intake; NDFI = neutral detergent fiber intake; TCI = total carbohydrate intake; NFCI = non-fibrous carbohydrate intake; TDNI = total digestible nutrient intake; CV = Coefficient of variation. Means followed by distinct letters in the lines differ ($p < 0.05$) by Tukey test.

Although the diets showed small differences in NDF and NFC levels, this was not enough to influence DM intake, with the average DMI of 800.3 g day^{-1} and 4.36% of body weight (BW) in the treatments (Table 3) it revealed the high palatability of the experimental diets, probably due to the low NDF concentration and the high NFC (Table 2). By fulfilling the balance of NFC, NDF, and ADF nutrients contained in the experimental diets it probably promoted adequate fermentation, which favors greater rumen degradability, higher passage rate, higher rumen emptying rate, consequently favoring the DMI, moreover the physical effectiveness of NDF provided greater chewing and rumination, ensuring normal rumen conditions (Pinho et al., 2018). Studies that evaluated the use of cactus pear in the diet of sheep observed DMI between 3.9 to 4.7% of body weight, using between 28 to 60% of cactus in sheep diet (Tegegne, Kijora, & Peters, 2007; Costa et al., 2012; Lopes et al., 2020), like the present study.

The average OM intake in the diets was 706.98 g day^{-1}. The lack of significance of this parameter is explained by the similar behavior for DM intake. Reinforcing this intake, Costa et al. (2012) reported that digestible organic matter is important in providing energy to ruminal microorganisms which is essential for microbial protein synthesis. Consequently, the absence of effect of diets on the TDN intake, with a mean of 524.65 g day^{-1}, shows the same behavior observed for DM and other nutrients intakes, due to the similarity on the energy value among the cacti.

The intake of crude protein (CP) was higher ($p < 0.05$) for the animals that received the *Cereus* diet compared to the animals that received the cactus pear diet (Table 3). This result may be explained by the higher CP concentration in the *Cereus* treatment compared to the others (Table 2).

There was a difference ($p < 0.05$) for water intake via food (WIF) between diets, with the highest water intake via food observed for lambs fed *Opuntia* diet (4,478.61 g day^{-1} of water) (Table 4). It occurred because it presented lower DM concentration (Table 2), and the lowest water intake via food was observed by the *Cereus* diet (2,827.12 g day^{-1} of water) due to its greater concentration of dry matter in the diet (Table 2).

Table 4. Intake water of lambs fed with different cacti.

Item	Diets			CV (%)
	Cereus	*Opuntia*	*Nopalea*	
WIF (g day^{-1})	2,827.12^{b}	4,478.61^{a}	3,164.57^{ab}	27.06
SWI (g day^{-1})	403.12	147.33	666.38	14.69
TWI (g day^{-1})	3,230.24^{b}	4,625.94^{a}	3,830.95^{ab}	20.23

WIF - water intake through food; SWI - supplied water intake; TWI - total water intake. Means followed by different letters in the lines differ ($p < 0.05$) by Tukey test.

For total water intake (TWI), the animals that received the *Opuntia* and *Nopalea* cactus cladodes ingested more water than the animals that received the *Cereus* treatment (Table 4). According to the equation of NRC (2007), the estimated supplied water intake requirement would be 2.01; 2.02, and 2.26 L for the diet with *Cereus*, *Opuntia*, and *Nopalea* treatments, respectively. Although cacti have high concentrations of water in their cellular contents, the animals also consumed water from the drinking bottle, which may be related to the diuretic effect of cacti. The total amount of water ingested by animals was almost double the estimated need (NRC, 2007). In a study with sheep replacing up to 70% tifton hay with *Nopalea* with total water restriction, Cordova-Torres et al. (2017) stated that total water restriction and interaction with experimental diets did not affect animal performance.

The different species of forage cacti did not influence voluntary water intake (VWI) (Table 4). This may have occurred because, although there were differences for WIF and TWI, there is a balance between the amount of total water ingested by the animal, regardless of the source, and its physiological demands. This behavior differs from Silva et al. (2010), who observed a difference in voluntary water intake in sheep fed mandacaru or xiquexique and Sabiá hay under different experimental and climatic conditions. Góes Neto et al. (2021) also observed a difference in voluntary water intake by dairy goats fed different forage cacti. Several studies in the literature have shown a reduction in voluntary water intake in sheep as dietary cactus levels rise (Ben Salem, Nefzaoui, & Orskov, 1996; Bispo et al., 2007; Costa et al., 2012; Cordova-Torres et al., 2017). This is due to the supply of part of the demand for water from food since cacti have a high amount of water in their composition.

The digestibility of DM and OM, NDF, TC, NFC, and TDN did not differ ($P > 0.05$) between the experimental diets (Table 5).

Table 5. Apparent digestibility coefficient (g kg^{-1}) of nutrients by sheep fed on different cacti.

Item	Diets			
	Cereus	*Opuntia*	*Nopalea*	CV (%)
Dry matter	670.2	707.4	665.5	4.28
Organic matter	686.6	724.0	682.8	4.09
Crude protein	592.6^{ab}	640.5^{a}	491.2^{b}	11.66
NDF	558.0	593.6	539.5	8.23
Total carbohydrates	710.4	752.9	734.8	3.95
NFC	840.9	850.3	849.3	2.24
Total digestible nutrients	646.6	665.1	655.3	3.13

NDF = neutral detergent fiber; TC = Total carbohydrate; NFC = Non-fibrous carbohydrate; TDN = total digestible nutrients; CV = Coefficient of variation. Means followed by distinct letters in the lines differ ($p < 0.05$) by Tukey test.

Previous studies have observed intermediate to high digestibility values of DM and OM, ranging from 660.1 to 809.0 g kg^{-1}, and 672.6 to 832.0 g kg^{-1}, respectively, in diets of sheep fed *Cereus* and forage cactus*, or in vitro* study (Bispo et al., 2007; Costa et al., 2012; Magalhães et al., 2019; Lopes et al., 2020). These values are influenced by the high NFC and low NDF values of these cacti. Thus, it reinforces its great nutritional values and the importance for semiarid regions these plants.

There was a difference ($p < 0.05$) between diets for the CP digestibility coefficient. The CP digestibility of the diet with the *Opuntia* was higher than *the Nopalea* diet but did not differ from the *Cereus* diet (Table 5). The highest CP digestibility coefficient of 64.05% presented by the diet containing the *Opuntia* may be linked to the NFC/CP ratio of the experimental diet, because the fermentation pattern results in a better energy/protein balance, what maximizes the availability and nutrient utilization for the ruminal microorganisms, thus supplying volatile fatty acids and microbial protein to the animal, consequently influencing digestibility (Lopes et al., 2020).

The feeding times differed ($p < 0.05$) between diets, being higher in the diet containing *Opuntia* diet (Table 6). In the diet containing *Opuntia* diet, the animals spent more time feeding, i.e, they spent more time selecting the feed, possibly due to the lower concentration of DM and NDF, and more amount of water (Table 2). Thus, there may have been a faster filling and emptying effect due to the greater amount of water in this diet, consequently increasing the frequency of search for feed by the animals.

Table 6. Feeding behavior by sheep fed on different cacti.

Item	Diets			CV%
	Cereus	*Opuntia*	*Nopalea*	
Feeding time (h day^{-1})	4.5b	6.05a	3.83b	28.18
Rumination time (h day^{-1})	6.34	5.33	5.00	24.04
FE (g DM^{-1} h^{-1})	191.53	128.64	221.19	28.42
RUE (g DM^{-1} h^{-1})	129.31	146.85	168.70	22.65

CV = Coefficient of variation; FE = feeding efficiency, RUE = rumination efficiency. Means followed by distinct letters in the lines differ ($p < 0.05$) by Tukey test.

The rumination times, feeding efficiency (FE), and rumination efficiency (RUE) variables were not influenced ($p > 0.05$) by the cacti used in diets (Table 6). Lopes et al. (2020) also did not observe differences in rumination times and feeding, and rumination efficiencies when comparing the varieties of *Nopalea* and *Opuntia*.

Studies have shown values for times spent with ingestion of 3.10 to 5.2 h day^{-1} and rumination between 5.4 to 9.9 h day^{-1} by sheep as a function of cactus concentration in the diets (Oliveira et al., 2017; Lopes et al., 2020), close to the values of the present research. The absence of effects between rumination times is related to the similarity between NDF levels between diets. According to Soest (1994), the rumination time spent is proportional to the cell wall content of the food. Likewise, when increasing the NDF concentration of the diet, there will be an increase in the time spent with rumination.

Conclusion

The *Cereus* cactus, *Opuntia*, and *Nopalea* associated with sabiá hay and concentrate have similar nutritional value and can be used in sheep diet.

Acknowledgements

To professor Dr. Emerson Moreira de Aguiar (*in memory*) for his tireless work dedicated to the Animal Nutrition Laboratory at UFRN, and for his research on the Caatinga biome.

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