Received: 4 December 2017 | Accepted: 3 April 2018
DOI: 10.1111/asj.13043

ORIGINAL ARTICLE

WILEY Animal Science Journal

Does the level of forage neutral detergent fiber affect the ruminal fermentation, digestibility and feeding behavior of goats fed cactus pear?

Ricardo Martins Araujo Pinho[1] | Edson Mauro Santos[1] | Juliana Silva de Oliveira[1] | Gleidson Giordano Pinto de Carvalho[2] | Thiago Carvalho da Silva[3] | Alberto Jefferson da Silva Macêdo[1] | Yohana Rosaly Corrêa[1] | Anderson de Moura Zanine[4]

[1]Departamento de Zootecnia, Universidade Federal da Paraíba, Areia, PB, Brazil
[2]Departamento de Zootecnia, Universidade Federal da Bahia, Salvador, BA, Brazil
[3]Departamento de Zootecnia, Universidade Federal de Goiás, Goiânia, GO, Brazil
[4]Departamento de Zootecnia, Universidade Federal do Maranhão, Chapadinha, MA, Brazil

Correspondence
Ricardo Martins Araujo Pinho, Departamento de Zootecnia, Universidade Federal da Paraíba, Areia, PB, Brazil.
Email: ricardo-zootec@hotmail.com

Funding information
Conselho Nacional de Desenvolvimento Científico e Tecnológico

Abstract

This study aimed to evaluate the effects of forage neutral detergent fiber (fNDF) levels on the voluntary feed intake, digestibility, ruminal fermentation and feeding behavior of goats fed diets with cactus pear. Five non-lactating ruminally cannulated goats fed ad libitum were randomly assigned to a 5 × 5 Latin square design. Treatments consisted of levels of fNDF at 0, 109, 222, 339 and 463 g/kg of dry matter (DM) in cactus pear-based diets. The intakes of DM and NDF were quadratically affected ($p \leqq .045$) by fNDF levels. Voluntary water intake (VWI) increased linearly as the fNDF levels increased in the diet. The digestibility coefficients of organic matter, NDF and ether extract and total digestible nutrients concentration were quadratically affected ($p \leqq .048$) by fNDF levels. The ruminal pH linearly increased ($p = .001$) with fNDF levels, ranging from 5.44 to 5.81 for diets containing 0 and 463 g fNDF/kg DM, respectively. The fNDF levels promoted a linear increase ($p = .006$) in chewing time, linearly decreased ($p = .007$) resting time and quadratically affected ($p = .033$) rumination time. The inclusion of fNDF in the diets provided favorable conditions for ruminal function, digestibility and feeding behavior in goats fed diets containing cactus pear.

KEYWORDS
chewing activity, *Opuntia ficus indica*, ruminal ammonia nitrogen, semiarid, volatile fatty acids

1 | INTRODUCTION

In livestock systems, for both beef and milk production purposes, the goals of the farmers are to improve productivity and production stability. Nevertheless, animal performance is often limited by the availability of forage in arid and semiarid regions. One way to overcome this limitation is to provide concentrate feeds to the animals, but this practice increases the production costs.

The use of forage crops adapted to the climate and soil conditions is an alternative to decrease production costs and to increase production efficiency (Tegegne, Kijora, & Peters, 2007). In this context, cactus pear is widespread in arid and semiarid regions around the world because of its tolerance to drought and high productivity (Costa et al., 2009; Misra et al., 2006; Tegegne et al., 2007). In addition, cactus pear can be a source of water during the dry season (Tegegne et al., 2007).

Cactus pear is known by its high energetic value and high concentration of non-fibrous carbohydrates (NFC) (Bispo et al., 2007; Costa et al., 2009). These characteristics and the low physically effective neutral detergent fiber (NDF) of cactus pear have resulted in metabolic disorders with diarrhea and weight loss when ruminant animals were fed cactus pear without any other forage source (Tegegne et al., 2007). In this context, the addition of NDF from other forage sources in diets containing cactus pear could increase the physically effective dietary fiber and promote rumination by stimulated chewing activity, which maintains the flow of saliva and ruminal pH buffering (Branco et al., 2010; Li et al., 2014).

A few studies evaluating cactus pear in diets for small ruminants have concluded that the inclusion of fiber from a forage source is mandatory in diets containing cactus pear in order to increase productive performance (Bispo et al., 2007; Vieira et al., 2008). Thus, it is necessary to include fiber sources in the diets of goats fed cactus pear. However, there is no information regarding the necessary minimum amount of forage NDF (fNDF) that does not impair ruminal fermentation and nutrient utilization in goats fed cactus pear. Thus, it was hypothesized that at least 100 g fNDF/kg of dry matter (DM) is necessary to maintain normal rumen functions. Therefore, the objective of this trial was to evaluate the effects of fNDF on intake, digestibility, ruminal fermentation and feeding behavior of goats fed diets with cactus pear. In addition, we aimed to identify the minimum amount of fNDF that would maximize the use of cactus pear in goat production systems.

2 | MATERIALS AND METHODS

2.1 | Location

The experiment was conducted under field conditions at the Pendência Experimental Station ("Estação Experimental de Pendência") of the State Agribusiness Research Company of Paraíba ("Empresa de Pesquisa Agropecuária da Paraíba"), PB, Brazil. This research station is located at an average altitude of 534 m, with a 7°8′18″S latitude and 36° 27′2″W longitude. The climate is classified by Köppen standards as Bsh (steppe [semi-arid] hot arid), with a relative humidity of approximately 68% and an annual average precipitation of 400 mm.

2.2 | Experimental diets

The experimental diets consisted of cactus pear, Tifton-85 (*Cynodon* spp.) hay and concentrate made with corn and soybean meal. The forage-to-concentrate ratio was 60:40 on a DM basis. The diets were formulated to meet fNDF levels of 0, 109, 222, 339 and 463 g/kg of DM using Tifton-85 hay as the source of effective fiber. Those levels were used to characterize the diets, which were formulated to meet the requirements for goats in maintenance, according to the National Research Council (NRC, 2007). The chemical composition of the forages and the concentrate ingredients are shown in Table 1. The ingredient proportion and the chemical composition of the diets and concentrates are shown in Table 2.

2.3 | Experimental design, animal management and data collection

The experimental procedures were approved by the Committee of Ethics on Animals at the Federal University of Paraiba (approval number: 2105/2013). All animals were treated with ivermectin (Merial, SP, Brazil), which was administered by a subcutaneous injection at the dose of 1 ml/50 kg body weight (BW), for the control of parasites.

Five non-lactating goats ruminally cannulated with an average initial BW of 36 ± 4 kg were randomly assigned to a 5 × 5 Latin square design. All the animals were housed in individual 2 m^2 pens with feeders and water troughs and were fed twice daily at 08;00 and 16:00 hours, ad libitum intake allowing for a maximum 10% of orts. Each experimental period lasted for 15 days: 10 days for

TABLE 1 Chemical composition (g/kg of DM) of the forages and concentration ingredients

Item	Cactus pear	Tifton hay	Corn ground	Soybean meal
DM	144.9	923.7	905.4	915.5
Organic matter	874.6	946.0	988.4	944.1
Ash	125.4	54.0	11.4	55.9
Crude protein	44.8	65.1	85.4	520.3
Ether extract	9.2	7.7	38.0	15.6
Neutral detergent fiber	349.1	731.0	283.2	133.6
Acid detergent fiber	222.3	345.4	56.3	94.0
Hemicellulose	126.8	385.6	226.9	39.6
NFC	471.5	142.2	582.0	274.6

DM, dry matter % on a fresh matter basis; NFC, non-fiber carbohydrates, calculated as 1000 – ([crude protein – urea derived crude protein + urea] + neutral detergent fiber + ether extract + ash).

TABLE 2 Ingredient proportions and the chemical composition of the experimental diets

	fNDF levels (g/kg of DM)				
Item	0	109	222	339	463
Percentage of ingredients (g/kg of DM)					
Cactus pear	622.0	475.8	324.2	167.1	0.0
Tifton hay	0.0	139.7	284.2	434.1	593.5
Soybean meal	162.6	165.4	168.5	171.6	174.9
Corn ground	207.0	212.1	217.7	223.3	229.4
Urea	8.4	7.0	5.5	3.9	2.3
Chemical composition (g/kg of DM)					
DM	212.4	259.3	336.1	485.2	918.2
Organic matter	910.6	921.1	932.1	943.5	955.6
Ash	89.4	78.9	67.9	56.5	44.4
Crude protein	153.7	154.3	154.7	155.1	155.7
Ether extract	16.1	16.1	16.1	16.1	16.1
Neutral detergent fiber	297.5	350.4	405.1	461.8	522.2
NFC	458.4	413.1	366.1	317.6	256.8

fNDF, forage neutral detergent fiber; DM, dry matter % on a fresh matter basis; NFC, non-fiber carbohydrates, calculated as 1000 – ([crude protein – urea derived crude protein + urea] + neutral detergent fiber + ether extract + ash).

adaptation to the diet and 5 days for data collection. Body weight was recorded at the beginning and at the end of each experimental period. Dry matter intake and daily nutrient intake were calculated as the difference between amounts offered and refused based on chemical analysis. Water was individually provided ad libitum. Water was previously weighed to calculate voluntary water intake (VWI), which also considered loss due to evaporation during data collection. Daily samples of feed and orts were collected from the 11th to the 13th days of the experimental periods, placed in labeled plastic bags, and stored in a freezer at −15°C.

Between the 12th and the 14th days of each experimental period, the digestibility trial was performed. Fecal samples were collected from each goat every 9 hr. The schedule of the sample collections were as follows: 00:00, 09:00, 18:00, 03:00, 12:00, 21:00, 06:00 and 15:00 hours. The feces were then placed in labeled plastic bags and stored at −15°C. To estimate the fecal output, orts, feces, and the ingredients of the diets were analyzed for indigestible NDF (iNDF) using the INCT-Ac F-009/1 method using non-woven textile bags and a 288 hr in situ incubation procedure (Detmann et al., 2012). Digestion coefficients were calculated based on the nutrients intake and the estimated fecal excretion of the animals.

Rumen fluid samples were collected every 4 hr on the 14th day of each experimental period. The schedule of the sample collections were as follows: before morning feeding (time 0) and 4, 8, 12, 16 and 20 hr thereafter. Rumen fluid samples were analyzed for pH, ammonia nitrogen (NH_3–N), and volatile fatty acids (VFA). The pH was immediately measured after collection by using a portable digital potentiometer (HANNA, HI 96108 model, Woonsocket, USA). Following pH measurement, the samples were filtered through four layers of cheesecloth, placed in 2.0 ml Eppendorf tubes, and stored in a freezer at −15°C for subsequent analysis of ruminal NH_3-N and VFA.

2.4 | Feeding behavior

Feeding behavior data were recorded on the 11th day of each experimental period. Animals were observed for 24 hr with visual observations made at 5 min intervals. Ruminating, feeding and chewing measurements were carried out to ascertain if there was any influence of the treatments on masticatory activity (Bürguer et al., 2000).

Results regarding feeding behavior factors were obtained according to the following equations:

$$\text{DM Feeding Efficiency (g of DM intake/h)} = \text{DMI/Feeding Time;}$$

$$\text{NDF Feeding Efficiency (g of NDF intake/h)} = \text{NDFI/Feeding Time;}$$

$$\text{DM Rumination Efficiency (g of DM intake/h)} = \text{DMI/Rumination Time;}$$

$$\text{NDF Rumination Efficiency (g of NDF intake/h)} = \text{NDFI/Rumination Time;}$$

$$\text{Chewing time (min/day)} = \text{Feeding Time} + \text{Rumination Time}$$

where DMI (g) = DM daily intake and NDFI (g) = NDF daily intake according to the equations adapted from Bürguer et al. (2000).

2.5 | Chemical analysis

The samples of feed, orts, feces, and rumen digesta were dried at 55°C for 72 hr in a forced air oven, ground in a Wiley mill (Wiley mill, Arthur H. Thomas, Philadelphia, PA, USA) to a particle size of 1 mm and stored in plastic containers for the determination of DM (method 934.01; AOAC, 1990), mineral matter (method 930.05; AOAC, 1990), crude protein (CP; method 920.87; AOAC, 1990), and ether extract (EE; method 920.85; AOAC, 1990). The following parameters were also measured: NDF (Mertens, 2002), acid detergent fiber (ADF) (method 973.18; AOAC, 1990), and sulfuric acid lignin (Robertson & Van Soest, 1981). The NDF content was corrected for ash and protein (NDFap), which were performed according to Licitra, Hernandez, and Van Soest (1996) and Mertens (2002). Hemicellulose content was obtained by the difference between the NDF and ADF. The orts and feces were analyzed for DM, organic matter (OM), CP, EE, ash, NDF and NFC. The samples used for the determination of iNDF were milled to pass 2 mm screen openings and submitted to ruminal incubation for 288 hr, according to Huhtanen, Kaustell, and Jaakkola (1994). The concentrations of iNDF in the feed, orts and feces were used to calculate the fecal DM and consequently the digestibility of nutrients. NFC were calculated according to Detmann and Valadares Filho (2010) as follows: NFC (g/kg) = 1000 − ([CP − CPU + urea] + NDFap + EE + ash) where CP is the crude protein (%) and CPU is the CP content from urea (%).

The energy value in the diets was estimated using apparent digestibility obtained in the experiment according to the equation proposed by the NRC (2007).

Rumen fluid samples were treated with calcium hydroxide [$Ca(OH)_2$] and cupric sulfate ($CuSO_4$) to determine the concentrations of VFA by high-performance liquid chromatography (HPLC) (Siegfried, Ruckermann, & Stumpf, 1984). The HPLC (SPD-10 AVP; Shimadzu, Osaka, Japan) apparatus was equipped with a refractive index detector and used an Aminex HPX-87H column (BIO-RAD, Hercules, CA, USA) with the mobile phase containing 0.005 mol/L H_2SO_4 and a flow rate of 0.6 ml/min at 50°C. The concentration of NH_3-N was determined by using a colorimetric method according to Chaney and Marbach (1962).

2.6 | Statistical analysis

All data were analyzed in a 5 × 5 Latin square. Homogeneity of variances between the treatments was assumed. The results were subjected to an analysis of variance and regression to assess the effects of increasing fNDF levels on the evaluated variables. All statistical procedures were conducted by using 0.05 as the critical probability level for a type I error.

Data from nutrient intake and nutrient apparent digestibility were analyzed using the MIXED procedure of SAS (2008), considering the following statistical model:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + Þ_k + \Sigma_{ijk},$$

where Y_{ijk} = dependent variable, μ = overall mean, α_i = fixed effect of the ith levels of fNDF, β_j = random effect of the jth animal, $Þ_k$ = random effect of the kth period, and $\sum_{ijk}$ = random error associated with each observation.

Ruminal fluid variables (0, 4, 8, 12, 16 and 20 hr after morning feeding) were analyzed as repeated measures, ordered by time, using the MIXED procedure of SAS (2008), and considering the following statistical model:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + Þ_k + h_l + (\alpha h)_{il} + \Sigma_{ijkl},$$

where Y_{ijkl} = dependent variable, μ = overall mean, α_i = fixed effect of the ith levels of fNDF, β_j = random effect of the jth animal, $Þ_k$ = random effect of the kth period, h_l = fixed effect of the lth time, $(\alpha h)_{il}$ = interaction between the levels of fNDF and time, and $\sum_{ijkl}$ = random error associated with each observation.

Feeding behavior was analyzed as a negative binomial using the GLIMMIX procedure of SAS (2008) and the same model as mentioned for ruminal fluid.

3 | RESULTS

3.1 | Intake and digestibility

The DM and NDF intake, both g/day and g/kg BW, had a quadratic effect ($p \leqq .045$) by fNDF levels in the diet (Table 3). The maximum DM intake was observed at the level of 109 g fNDF/kg DM. Additionally, the maximum NDF intake was estimated at 577.96 g/day ($\hat{Y}$ = 343.05 + 1.628 fNDF − 0.0028 fNDF^2) and 15.0 g/kg BW ($\hat{Y}$ = 8.7213 + 0.0421 fNDF − 0.00007 fNDF^2) with 288.6 and 300 g fNDF/kg DM in the animals' diet, respectively. There was a linear increase (p = .001) in VWI due to increased levels of fNDF in the diet (Table 3). There were no effects ($p \geqq .179$) of the dietary fNDF levels on OM, CP, EE, NFC and TDN intake.

Apparent digestibility of DM, CP and NFC were not affected by the dietary fNDF levels ($p \geqq .263$; Table 4). However, the fNDF levels in the diet quadratically affected ($p \leqq .048$) the digestibility coefficients of OM, NDF and EE and TDN concentrations. The maximum digestibility coefficient of NDF was estimated at 587.5 g/kg with 319.5 g of fNDF/kg DM ($\hat{Y}$ = 362.83 + 1.4061 fNDF − 0.0022 fNDF^2). The content of the TDN diets ranged from 499.4 to 675.3 g/kg for the levels 0 and 339 g fNDF/kg DM, respectively.

3.2 | Ruminal fermentation

There were no fNDF levels × collection time interactions for the ruminal fermentation variables ($p > .050$; Table 5). Ruminal pH was linearly increased (p = .001) by fNDF levels, ranging from 5.44 to 5.81. On the other hand, the increase of fNDF levels did not affect ($p \geqq .105$) the concentration of ruminal NH_3-N, rumen VFA concentration, and the molar proportions of acetate, propionate, butirate and acetate-to-propionate ratios.

The sampling period did not affect ($p > .050$) ruminal pH (Figure 1). However, it can be noted that for all the treatments, there was a decrease in ruminal pH 4 hr after feeding, for both feeding times (8:00 and 16:00 hours, Figure 1).

3.3 | Feeding behavior

Feeding time, feeding efficiency in g DMI/hr, and rumination efficiency in g NDFI/hr were not affected by dietary fNDF levels ($p \geqq .060$; Table 6). However, rumination time was quadratically affected (p = .033), with the maximum time spent ruminating was estimated at 335 min/day with 333 g fNDF/kg DM ($\hat{Y}$ = 120.19 + 1.3276 fNDF − 0.002 fNDF^2) in the animals' diet. There was a linear increase (p = .006) in chewing time with fNDF levels in the diet. On the other hand, the inclusion of fNDF levels promoted a linear decrease (p = .007) in resting time (Table 6). Rumination efficiency (g DMI/hr) linearly decreased (p = .006) with the increase in fNDF levels in the diet.

4 | DISCUSSION

4.1 | Intake and digestibility

Animals that were fed a diet containing higher levels of fNDF decreased their DMI. This behavior can probably be related to the decrease of the passage rate and the filling effect in the rumen caused by forage fiber (Tavares et al., 2005) once NDF intake was increased by the dietary fNDF levels.

The increase of DM content in the diets by the inclusion of the fNDF levels (Table 2) promoted an increase in VWI. Thus, each percentage addition in fNDF level increased the VWI by 63.9 ml, which is consistent with the existence of a linear relationship between VWI and DMI in ruminants (NRC, 2007), including goats (Silanikove, 1989). Additionally, the presence of cactus pear in the animals' diet reduced the VWI because of its high moisture content (Table 1). In this case, Tegegne et al. (2007), Bispo et al. (2007), Costa et al. (2009) and Andrade-Montemayor, Cordova-Torres, Gracía-Gasca, and Kawas (2011) also reported similar results in goats around the world, showing that increasing cactus pear levels decreased the necessity of drinking water. Therefore, the results are an important consideration when this forage is used in arid and semi-arid regions where water is scarce and might be a limiting factor for animal production (Ben Salem & Smith, 2008; Misra et al., 2006).

The reduction of NDF digestibility in diets containing high proportions of cactus pear (more than 470 g/kg on a DM basis) may reflect the high content of NFC (Table 4). This can be explained by the fast fermentation of NFC that causes a decrease in ruminal pH (Table 5). Thus, the increase in the passage rate and a low ruminal pH causes a decrease in cellulolytic activity and consequently

TABLE 3 Effects of forage neutral detergent fiber (fNDF) on nutrient intake and voluntary water intake (VWI) in goats

	fNDF levels (g/kg of DM)						*p* value	
Item	0	109	222	339	463	*SEM*	*L*	*Q*
g/day								
DM	1120	1397	1275	1073	767.2	67.3	.011	.014
OM	1019.9	1286.8	1188.4	1012.4	733.1	57.1	.511	.960
CP	178.2	211.4	212.7	213.1	166.2	9.69	.179	.760
NDF	343.0	499.4	529.7	604.3	480.7	27.8	.045	.019
EE	16.1	20.5	20.6	19.20	15.61	0.93	.382	.853
NFC	336.7	406.3	359.7	313.8	180.1	24.8	.679	.872
TDN	562.3	694.3	787.3	826.8	545.0	39.3	.790	.836
g/kg of body weight								
DM	29.2	34.9	32.8	29.0	21.2	0.16	.019	.014
NDF	8.9	12.5	13.7	16.4	13.1	0.07	.022	.037
L/day								
VWI	0.760	0.797	2.07	2.56	3.56	4.24	.001	.640

DM, dry matter; OM, organic matter; CP, crude protein; NDF, neutral detergent fiber; EE, ether extract; NFC, non-fiber carbohydrates; TDN, total digestible nutrients; VWI, voluntary water intake; *SEM*, standard error of mean; *L*, linear effect; Q, quadratic effect.

TABLE 4 Effects of forage neutral detergent fiber (fNDF) on nutrient apparent digestibility and total digestible nutrients (TDN) in goats

	fNDF levels (g/kg of DM)						*p* value	
Item	0	109	222	339	463	*SEM*	*L*	Q
g/kg								
DM	642.9	606.2	680.3	634.0	606.5	1.81	.721	.508
OM	631.4	606.0	690.0	708.2	631.2	1.14	.139	.028
CP	798.0	771.9	808.3	816.4	766.6	1.01	.736	.263
NDF	393.3	425.6	586.5	628.9	531.8	2.19	.001	.004
EE	481.8	488.0	618.1	567.6	551.6	1.64	.031	.043
NFC	789.2	745.4	775.5	798.7	791.8	1.29	.523	.587
TDN	499.4	515.8	618.2	675.3	608.0	2.03	.004	.048

DM, dry matter; OM, organic matter; CP, crude protein; NDF, neutral detergent fiber; EE, ether extract; NFC, non-fiber carbohydrates; TDN, total digestible nutrients; *SEM*, standard error of mean; *L*, linear effect; Q, quadratic effect.

decreases fiber digestibility (Ørskov, 2000). On the other hand, the increase in NDF digestibility in diets with high proportions of fNDF, more than 222 g fNDF/kg DM, may occur due to the longer time spent in rumination (Table 6). Such behavior decreases the particle size, and at the same time, it increases the flow of saliva in the rumen, providing favorable conditions for the growth of microorganisms responsible for carbohydrate degradation (Yang & Beauchemin, 2005).

4.2 | Ruminal fermentation

The increase in ruminal pH with the inclusion of fNDF levels could be attributed to high dietary fiber that stimulates chewing activity (Li et al., 2014), thus promoting an increase in the flow of saliva. Saliva production is very important for rumen function because it has a high buffering capacity as a result of a high concentration of bicarbonate and phosphate (Bailey & Balch, 1961). Food moisture content also affects saliva production, and diets with high moisture content reduce saliva production (Berchielli, Pires, & Oliveira, 2011). This fact can explain the low buffering rumen in the diets with high proportions of cactus pear.

In addition to the dietary fiber content and flow of saliva, ruminal pH is regulated by a complex system that depends on the net income between the production and absorption of VFA (Branco et al., 2010). The mucilage contained in cactus pear can form a foamy bloat in the rumen (Vieira et al., 2008), which may reduce VFA absorption, resulting in a decrease in the ruminal pH (Bispo et al., 2007). In the present study, we observed the foam consistency of the ruminal fluid when samples were collected from animals fed diets with the absence of a fiber source and those fed 109 g fNDF/kg DM.

Another reason for the low pH in diets with a high proportion of cactus pear is the high proportion of NFC (Vieira et al., 2008), which are rapidly degraded in the rumen. In such cases, animals may develop certain kinds of digestive disorders and decrease nutrient intake and digestibility, consequently reducing animal performance (Lammers, Buckmaster, & Heinrichs, 1996). This could explain why the lowest values of nutrient digestibility were observed in the diets with less than 222 g fNDF/kg DM (Table 4).

The concentration of ruminal NH_3-N was not affected by fNDF levels, probably because of the similar dietary protein levels and CP digestibility among diets. However, all the ruminal NH_3-N values were higher than 5 mg/dl, which is considered the minimum level of ruminal NH_3-N required to maintain normal rumen function (Satter & Slyter, 1974). According to the results obtained, the values of

TABLE 5 Effects of forage neutral detergent fiber (fNDF) on ruminal fermentation in goats

	fNDF levels (g/kg of DM)						*p* value	
Item	0	109	222	339	463	*SEM*	*L*	Q
pH	5.44	5.50	5.67	5.69	5.81	0.08	.001	.746
NH_3-N	17.79	24.81	17.39	29.69	25.44	2.85	.390	.748
VFA	161.60	162.56	163.01	146.40	142.18	7.61	.107	.535
Volatile fatty acids, molar proportions (mol/100 mol)								
Acetate (A)	57.00	56.37	57.66	58.05	55.28	0.54	.338	.111
Propionate (P)	29.00	29.07	27.92	27.97	29.83	0.37	.558	.444
Butirate	14.00	14.56	14.41	13.97	14.89	0.20	.203	.826
A/P	2.02	1.97	2.12	2.12	1.90	0.04	.654	.105

NH_3-N, Ammonia nitrogen (mg/dl); VFA, total volatile fatty acids (mmol/L); A/P, acetate to propionate ratio; *SEM*, standard error of mean; *L*, linear effect; *Q*, quadratic effect.

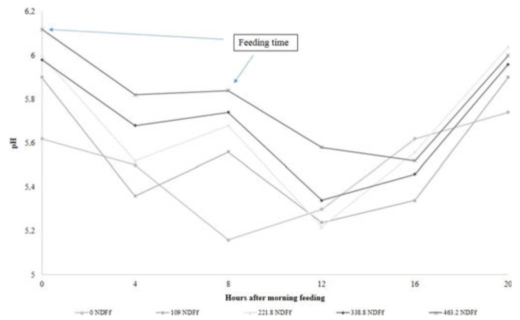

FIGURE 1 Effect of dietary forage neutral detergent fiber (g/kg of DM) levels on ruminal pH in goats.

ruminal NH_3-N indicate that there was no limitation of nitrogen supply in the rumen.

The rapid digestion of food consumed soon after feeding resulted in increased microbial activity and an increase in the concentration of VFA, leading to a pH decrease (Branco et al., 2010; Misra et al., 2006). Higher values of ruminal pH were observed during the night, which was probably due to animal behavior; during the nightfall, goats spent more time ruminating (Miotto et al., 2014).

Although there was an absence of effects on total VFA, it was possible to observe a decrease in the numerical values in total VFA from the inclusion of 339 g fNDF/kg DM in the diet. The high concentration of fNDF resulted in lower total VFA compared with diets with low concentrations of fNDF (Li et al., 2014). In this study, a high amount of cactus pear (622.0 and 475.8 g/kg on a DM basis) used in the diets with 0 and 109 g fNDF/kg DM, respectively, promoted an increased production of VFA due to these diets having the highest contents of NFC, which are fast-degrading carbohydrates. In addition to the intake of rapidly fermentable carbohydrates, other factors such as the passage rate of ruminal content and the ruminal epithelium absorptive capacity affected the ruminal VFA concentration (Penner, Aschenbach, Gabel, Rackwitz, & Oba, 2009).

4.3 | Feeding behavior

The effects of fNDF levels on chewing activity has been reported in previous studies using different sources of roughage and animals (Tavares et al., 2005; Zhao, Zhang, Xu, & Yao, 2011). These studies noticed an increase at time spent ruminating in animals fed diets composed of cactus pear and levels of hay. In this study, animals fed diets with the highest level of fNDF (463 g/kg DM) spent more time ruminating (+232 min) when compared to a level 0 g fNDF/kg DM.

TABLE 6 Effects of forage neutral detergent fiber (fNDF) on feeding behavior in goats

	fNDF levels (g/kg of DM)						*p* value	
Item	0	109	222	339	463	*SEM*	*L*	Q
FT min/day	194	206	268	214	288	12.6	.105	.706
RT min/day	104	260	354	280	336	20.6	.002	.033
CT min/day	298	466	622	494	624	27.4	.006	.210
Resting time min/day	1,142	974	818	946	816	27.3	.007	.221
FE, g DMI/hr	343	448	299.6	310.5	162.2	30.3	.270	.154
RE, g DMI/hr	477	342.2	225.4	235	148.7	74.5	.006	.104
FE, g NDFI/hr	99.1	149.3	124.8	170.6	101.9	7.74	.565	.008
RE, g NDFI/hr	146	123.5	94.5	129.8	92.5	25.7	.062	.166

FT, feeding time; RT, rumination time; CT, chewing time; FE, feeding efficiency; RE, rumination efficiency; DMI, dry matter daily intake; NDFI, neutral detergent fiber daily intake; *SEM*, standard error of mean; *L*, linear effect; *Q*, quadratic effect.

Increases of dietary fNDF levels decreased resting time, which was expected due to chewing activity being stimulated by forage sources (Li et al., 2014).

5 | CONCLUSIONS

The inclusion of fNDF in the diets provided favorable conditions for ruminal function, digestibility and feeding behavior in goats fed diets containing cactus pear. Animals fed diets with fNDF below 109 g/kg DM had compromised ruminal fermentation with drastic decreases in rumination and NDF digestibility.

The minimum of dietary fNDF (109 g/kg DM) can be recommended in order to increase animal performance, by including more cactus pear in the diet without compromising rumination. The inclusion of high levels of cactus pear in diets reduces the dependence of energy concentrates due to its high NFC concentration and contributing significantly to reduction in feeding costs. In addition, cactus pear has a substantial contribution in satisfying the water requirements of goats during dry seasons and drought periods in dry areas of the tropics and subtropics.

ACKNOWLEDGMENTS

The authors wish to thank the members of GEF (Brazilian Forage Research Group) for their contributions during the field trials, the National Council for Scientific and Technological Development (CNPq) and Maranhão State Research Foundation (FAPEMA) for their financial support, and the Coordination for the Improvement of Higher Education Personnel (CAPES) for providing scholarships.

ORCID

Ricardo Martins Araujo Pinho http://orcid.org/0000-0002-2816-1610
Gleidson Giordano Pinto de Carvalho http://orcid.org/0000-0002-4108-6782
Alberto Jefferson da Silva Macêdo http://orcid.org/0000-0002-2789-0221
Anderson de Moura Zanine http://orcid.org/0000-0003-0100-3652

REFERENCES

Andrade-Montemayor, H. M., Cordova-Torres, A. V., Gracía-Gasca, T., & Kawas, J. R. (2011). Alternative foods for small ruminants in semiarid zones, the case of Mesquite (*Prosopis laevigata* ssp.) and Nopal (*Opuntia* ssp.). *Small Ruminant Research*, *98*, 83–92. https://doi.org/10.1016/j.smallrumres.2011.03.023

AOAC (1990). *Official methods of analysis* (15th ed.). Arlington, VA: Association of Official Agricultural Chemists.

Bailey, C. B., & Balch, C. C. (1961). Saliva secretion and its relation to feeding in cattle. 1. The composition and rate of secretion of parotid saliva in a small steer. *The British Journal of Nutrition*, *15*, 371–382. https://doi.org/10.1079/bjn19610047

Ben Salem, H., & Smith, T. (2008). Feeding strategies to increase small ruminant production in dry environments. *Small Ruminant Research*, *77*, 174–194. https://doi.org/10.1016/j.smallrumres.2008.03.008

Berchielli, T. T., Pires, A. V., & Oliveira, S. G. (2011). *Nutrição de Ruminantes* (2nd ed.). Jaboticabal, SP: Funep.

Bispo, S. V., Ferreira, M. A., Véras, A. S. C., Batista, A. M. V., Pessoa, R. A. S., & Bleuel, M. P. (2007). Palma forrageira em substituição ao feno de capim-elefante. Efeito sobre consumo, digestibilidade e características de fermentação ruminal em ovinos. *Revista Brasileira de Zootecnia*, *36*, 1902–1909. https://doi.org/10.1590/s1516-35982007000800026

Branco, R. H., Rodrigues, M. T., Rodrigues, C. A. F., Silva, M. M. C., Leão, M. I., & Pereria, V. V. (2010). Efeito dos níveis de fibra em detergente neutron oriunda de forragem sobre a eficiência microbiana e os parâmetros digestivos em cabras leiteiras. *Revista Brasileira de Zootecnia*, *39*, 372–381. https://doi.org/10.1590/s1516-35982010000200021

Bürguer, P. J., Pereira, J. C., Queiroz, A. C., Silva, J. F. C., Valadares Filho, S. C., Cecon, P. R., & Casali, A. D. P. (2000). Comportamento ingestivo em bezerros holandeses alimentados com dietas contendo diferentes níveis de concentrado. *Revista Brasileira de Zootecnia*, *29*, 236–242. https://doi.org/10.1590/s1516-35982000000100031

Chaney, A. L., & Marbach, E. P. (1962). Modified reagents for determination of urea and ammonia. *Clinical Chemistry*, *8*, 130–132.

Costa, R. C., Beltrão Filho, E. M., Medeiros, A. N., Givisiez, P. E. N., Queiroga, R. C. R. E., & Melo, A. A. S. (2009). Effects of increasing levels of cactus pear (*Opuntia ficus-indica* L. Miller) in the diet of dairy goats and its contribution as a source of water. *Small Ruminant Research*, *82*, 62–65.

Detmann, E., Souza, M. A., Valadares Filho, S. C., Queiroz, A. C., Berchielli, T. T., Saliba, E. O. S., … Azevedo, J. A. G. (2012). *Métodos para análise de Alimentos*. Visconde do Rio Branco, MG: Suprema.

Detmann, E., & Valadares Filho, S. C. (2010). On the estimation of non-fibrous carbohydrates in feeds and diets. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, *62*, 980–984. https://doi.org/10.1590/s0102-09352010000400030

Huhtanen, P., Kaustell, K., & Jaakkola, S. (1994). The use of internal markers to predict total digestibility and duodenal flow of nutrients in cattle given six different diets. *Animal Feed Science and Technology*, *48*, 211–227. https://doi.org/10.1016/0377-8401(94)90173-2

Lammers, B. P., Buckmaster, D. R., & Heinrichs, A. J. (1996). A simple method for the analysis of particle sizes of forage and total mixed rations. *Journal of Dairy Science*, *79*, 922–928. https://doi.org/10.3168/jds.s0022-0302(96)76442-1

Li, F., Li, Z., Li, S., Ferguson, J. D., Cao, Y., Yao, J., … Yang, T. (2014). Effect of dietary physically effective fiber on ruminal fermentation and the fatty acid profile of milk in dairy goats. *Journal of Dairy Science*, *97*, 2281–2290. https://doi.org/10.3168/jds.2013-6895

Licitra, G., Hernandez, T. M., & Van Soest, P. J. (1996). Standardization of procedures for nitrogen fractionation of ruminant feeds. *Animal Feed Science and Technology*, *57*, 347–358. https://doi.org/10.1016/0377-8401(95)00837-3

Mertens, D. R. (2002). Gravimetric determination of amylase-treated neutral detergent fiber in feeds with refluxing in beakers or crucibles: Collaborative study. *Journal of AOAC International*, *85*, 1217–1240.

Miotto, F. R. C., Neiva, J. N. M., Restle, J., Falcão, A. J. S., Castro, K. J., & Maciel, R. P. (2014). Comportamento ingestivo de tourinhos alimentados com dietas contendo níveis de gérmen de milho integral. *Ciência Animal Brasileira*, *15*, 45–54.

Misra, A. K., Misrha, A. S., Tripathi, M. K., Chaturvedi, O. H., Vaithiyahathan, S., Prasad, D., & Jakhmola, R. C. (2006). Intake, digestion and microbial protein synthesis in sheep on hay supplemented with prickly pear cactus [*Opuntia ficus-indica* (L.) Mill.] with or without groundnut meal. *Small Ruminant Research*, *63*, 125–134. https://doi.org/10.1016/j.smallrumres.2005.02.014

National Research Council (NRC) (2007). *Nutrient requirements of small ruminants*. Washington, D.C.: National Academy Press.

Ørskov, E. R. (2000). New concepts of feed evaluation for ruminants with emphasis on roughages and feed intake. *Asian-Australian Journal of Animal Science*, *13*, 128–136.

Penner, G. B., Aschenbach, J. R., Gabel, G., Rackwitz, R., & Oba, M. (2009). Epithelial capacity for apical uptake of short chain fatty acids is a key determinant for intraruminal pH and the susceptibility to subacute ruminal acidosis in sheep. *The Journal of Nutrition*, *139*, 1714–1720. https://doi.org/10.3945/jn.109.108506

Robertson, J. B., & Van Soest, P. J. (1981). The detergent system of analysis and its application to human foods. In W. P. T. James, & O. Theander (Eds), *The analysis of dietary fiber in food* (pp. 123–158). New York: Marcel Dekker.

SAS (2008). *User's guide* (9.2 ed.). Cary, NC: SAS Inc.

Satter, L. D., & Slyter, L. L. (1974). Effect of ammonia concentration on rumen microbial protein production in vitro. *British Jounal of Nutrition*, *32*, 199–208. https://doi.org/10.1079/bjn19740073

Siegfried, V. R., Ruckermann, H., & Stumpf, G. (1984). Method for the determination of organic acids in silage by high performance liquid chromatography. *Landwirtschaftliche Forschung*, *37*, 298–304.

Silanikove, N. (1989). Interrelationships between water, food and digestible energy intake in desert and non desert goats. *Appetite*, *12*, 163–170. https://doi.org/10.1016/0195-6663(89)90114-1

Tavares, A. M. A., Véras, C., Batista, A. M. V., Ferreira, M. A., Vieira, E. L., & Silva, R. F. S. (2005). Níveis crescentes de feno em dietas à base de palma forrageira para caprinos em confinamento: Comportamento ingestivo. *Acta Scientinarum: Animal Science*, *27*, 497–504.

Tegegne, F., Kijora, C., & Peters, K. J. (2007). Study on the optimal level of cactus pear (*Opuntia ficus-indica*) supplementation to sheep and its contribution as source of water. *Small Ruminant Research*, *72*, 157–164. https://doi.org/10.1016/j.smallrumres.2006.10.004

Vieira, E. L., Batista, A. M. V., Guim, A., Carvalho, F. F., Nascimento, A. C., Araújo, R. F. S., & Mustafa, A. F. (2008). Effects of hay inclusion on intake, in vivo nutrient utilization and ruminal fermentation of goats fed spineless cactus (*Opuntia ficus-indica* Mill) based diets. *Animal Feed Science and Technology*, *141*, 199–208. https://doi.org/10.1016/j.anifeedsci.2007.05.031

Yang, W. Z., & Beauchemin, K. A. (2005). Effects of physically effective fiber on digestion and milk production by dairy cows fed diets based on corn silage. *Journal of Dairy Science*, *88*, 1090–1098. https://doi.org/10.3168/jds.s0022-0302(05)72776-4

Zhao, X. H., Zhang, T., Xu, M., & Yao, J. H. (2011). Effects of physically effective fiber on chewing activity, ruminal fermentation, and digestibility in goats. *Journal of Animal Science*, *89*, 501–509. https://doi.org/10.2527/jas.2010-3013

How to cite this article: Pinho RMA, Santos EM, de Oliveira JS, et al. Does the level of forage neutral detergent fiber affect the ruminal fermentation, digestibility and feeding behavior of goats fed cactus pear? *Anim Sci J*. 2018;00:1–8. https://doi.org/10.1111/asj.13043