Replacement of hay by red cactus in goat diets affects feed intake, digestibility, growth, and gastrointestinal morphology

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Abstract

Cactus is currently being used as a livestock feed across arid regions of the world due to its availability and nutritive value. However, limited knowledge exists on the effects of some cactus species on ruminant metabolism. In this context, this study was conducted to evaluate the effects of increasing levels [25, 50, and 75% on dry matter (DM) basis] of crushed red cactus [*Opuntia stricta* (Haw.) Haw.] on hay-based diets for goats. Response variables included intake, nutrient digestibility, performance, intestinal morphology, and gastrointestinal organs of goats. Fifteen young bucks (non-castrated male goats), averaging 11.7±0.9 kg body weight (BW) at the beginning of the study, were used. The trial lasted 75 days and the goats were fed individually. Feed was offered twice a day, at 09h00 and 16h00. Water was offered *ad libitum* throughout the experimental period. Voluntary water intake decreased with increasing quantities of red cactus. The digestibility of DM, organic matter (OM), and crude protein (CP) presented greater values with 50 and 75% DM of red cactus compared with 25%. Significant differences (P=0.0021) were observed for daily BW gain with the greatest value (46 g/day) recorded in goats fed with 50% DM red cactus, whereas the lowest value (14 g/day) was recorded in goats fed with 25% DM red cactus. Red cactus intake decreased the length and width of duodenum villi. It is concluded that the inclusion of red cactus in goat diet up to 50% DM promotes an efficient nutrient utilization and animal performance, without causing digestive disturbances and adverse effects on the intestinal mucosa.

Keywords: *Opuntia stricta*, raketamena, goat performance, Madagascar

INTRODUCTION

Cactus (*Opuntia* subsp.) plants are adapted to arid and semi-arid regions. They are known for their ability to grow in environments considered stressful for most plant species (Le Houérou, 2002). Cactus is a particularly interesting plant because of its relatively easy propagation, efficiency in producing fresh material, and nutritive value (Tegegne, 2001a). Compared to many other common crops and forages, cactus is easy to establish, maintain, and use. Cactus, generally recognized as a fruit crop for human consumption, is also used as livestock feed during periods of drought or feed shortage (De Waal et al., 2006). The fodder cacti are composed of several species of *Opuntia* and *Nopalea* genera, both from the cactus family *Cactaceae*. Several studies have shown that cacti are highly digestible by sheep (Costa et al., 2012; Tegegne et al., 2005a) and goats (Cardoso et al., 2018; Felix et al., 2015) and can be used as a dietary supplement. Dry matter and fibre digestibility coefficients of 762 g/kg and 691 g/kg, respectively, have been reported with a diet containing cactus (*Opuntia mills*) up to 50% DM.

Although cactus plants are considered as a feed for ruminants in several regions of the world, data on the use of certain cactus species, for example, the red cactus (*Opuntia stricta*), is limited. This cactus, also known as raketamena, is considered an invasive species in the southwestern region of Madagascar. Many attempts to eradicate it have been made in the past, however, none was successful. The invasiveness of the red cactus might be related to land-use change and degradation of the natural vegetation. One of the potential approaches to combat the invasiveness of this species is to find potential ways to utilize it. To our knowledge, no studies have been published on the nutritional value of red cactus. It is necessary to find an alternative use for the red cactus in the southern portion of the island where livestock is present and there is a lack of fodder. According to farmers' testimonies, this cactus is not used because even after passing it through fire flames (traditional method), small spines remain on the surface or inside the plant leading to animal digestive disorders. The present study was conducted to determine the effect of including crushed red cactus in hay-based diets of goats on intake, nutrient digestibility, growth, intestinal villous morphology, and digestive tract.

MATERIALS AND METHODS

This experiment complied with the ARRIVE guidelines and was carried out in accordance with the U.K. Animals (Scientific Procedures) Act, 1986, and associated guidelines.

Study area

The experiment was carried out at the experimental station of NGO GRET, located in the city of Ambovombe, Androy, Madagascar (25°09'55.3''S, 46°06'04.2''E). The climate is characterized by aridity and prevailing winds from east to west, with an annual average rainfall of 550 mm and an average temperature of 23°C.

Animals and diets

Fifteen 8-month-old bucks (non-castrated goat males) with average body weight (BW) of 11.7±0.9 kg were used in a 75-day experiment. Goats were randomly divided into three groups (n=5) and fed different experimental diets. Goats were housed in individual sheds (1×7m), part of which (1x2m) was covered and with cement floors. Three experimental diets were formulated (Table 1) to obtain a linear replacement of *Cynodon* and *Brachiaria* hay by red cactus (C) at levels of 25, 50, and 75% dry matter (DM) for the C25, C50, and C75 diets, respectively.

Table 1. Ingredients and chemical composition of the experimental diets

	Diets		
	C25	**C50**	**C75**
Ingredients (% dry matter)			
Cynodon hay	54.7	32.1	9.5
Brachiaria hay	8.3	4.9	1.5
Red cacti	25.5	51.0	76.5
Cajanus meal	10.0	10.0	10.0
Urea	1.5	2.0	2.5
Chemical composition (% dry matter)			
DM (as fed)	31.3	21.8	14.4
Ash	10.7	11.2	14.4
Organic matter	89.3	88.8	85.6
Crude fibre	28.7	22.2	14.4
Crude protein target value	10.0	10.0	10.0
Crude protein analytical value	7.1	10.1	9.9

Cactus cladodes were crushed with a machine specially designed for this purpose (MTCn, Laboremus, Brazil). Diets were adjusted with urea to obtain a similar nitrogen (N) concentration. The randomly selected goats were allotted to three dietary treatments. Feed was offered twice a day, at 09h00 and 16h00, and diet ingredients were mixed in a total mixed ration before feeding. The amount of feed offered, and refusals were daily weighed to calculate the voluntary intake, maintaining a level of 5-10% refusals. Water was offered *ad libitum*. Each animal was weighed once every week over the 75-day experimental period; the first 17 days animals were allowed to adapt to the shed and diets, and the other 58 days were used for data collection. Digestibility was determined over a 5-day period from days 18 to 23.

Digestibility measurements

Each feed material and the complete diets were sampled at regular intervals during the experiment to carry out chemical analyses and adjust diet composition, if necessary. Diets, feed refusals, and faeces were sampled for five days to measure the apparent digestibility of nutrients. The faeces of each animal were collected using a plastic bag attached to the rear part of the animal's body. These plastic bags have been attached to the animal for 24-hour periods, namely 1 hour after feeding and removed the next day, 1 hour after feeding. The digestibility coefficients (DC; g/kg) of DM, mineral matter (ash), organic matter (OM), CP, and crude fibre (CF) were calculated as DC = [(kg of the portion ingested – kg of the portion excreted in faeces) / (kg of the portion ingested)] × 1000.

Measurements at slaughter

After 73 days of confinement, the animals were randomized in a slaughter order, submitted to the fasting of solids for 16 hours, and weighed to obtain the body weight at slaughter. The carcass was eviscerated and weighed. All fractions of the digestive tract (rumen, reticulum, omasum, abomasum, and intestine) were weighed full, and then empty after hand rinsing, to determine the weight of digestive tract contents. Three samples, of 2 cm^2 each, were collected in several sections of the digestive tract. To avoid changes in the material *post-mortem*, the samples were immersed in a fixing solution consisting of a mixture of 10% formalin and 90% saline. After 48 hours of fixation, the fragments were transferred to saline solution. The samples were also photographed with a digital microscope. Samples were also taken from the digestive tract of two animals that were kept as part of a group of animals for possible replacement of sick animals. These two goats consumed a diet with *Cynodon* and *Brachiaria* hay and Cajanus meal, without cacti.

Chemical analysis of feed and faeces

Samples of feed, refusals, and faeces were oven-dried at 60°C for 72 h to determine the DM concentration according to the method described by the AOAC (1995). Samples were ground with a Wiley mill (RETSCH) to pass a 1-mm sieve, homogenized and subsamples stored in airtight plastic containers, and analysed for ash, CF, and CP according to AOAC (1995) methods.

Histological and morphometric assessment

Methods for assessing the morphology of sections of the alimentary tract (reticulum, rumen, omasum, abomasum, and duodenum) were described by Wang et al. (2009). Bands of villus-crypt units were cut and further isolated from the connective tissue, using a fine-gauge syringe needle under a dissecting microscope. The intact regions of the slides were selected, with no artefacts and with a preserved morphological structure. The preparation was placed on a glass slide in a drop of 45% acetic acid. Villus length was obtained by measuring the apex of the villus to its point of implantation and the width in the medial region of the villus. Villus length, width, and surface were measured using a 4x objective. Image capture was performed using the Olympus BX-51 optical microscope (Tokyo, Japan) coupled to the camera and connected to a computer. Histomorphometry measurements were performed with the aid of the computational software image J (USA). Mean values of these parameters were determined for 15 individual duodenal villi from each animal.

Statistical analysis

Data were analysed using proc mixed from SAS (SAS Institute Inc., Cary, North Carolina, USA). Fixed effects included levels of red cactus inclusion in the diet. Blocks were considered random effects. LSMEANS were compared using the PDIFF procedure adjusted by Tukey at 5% probability. If inclusion levels were significant, orthogonal polynomial contrasts were performed using the estimate procedure from SAS and the orthogonal coefficients to test for linear and quadratic responses.

RESULTS

Chemical composition

The DM and CF concentrations decreased with the addition of red cactus in the diets (Table 1). Mineral matter concentration increased by about 35% when the inclusion of cacti increased from 25 to 75% DM. Despite our objective of formulating isonitrogenous diets, at a rate of 10% DM, laboratory analyses revealed a 30% lower CP level for the C25 diet compared to the other two diets (C50 and C75).

Feed and water intake

Throughout the experiment, the health status of goats was good. On average, there was a significant linear reduction in DMI. For diet C75, DMI was significantly lower than the other groups (P=0.009) (Table 2). The DMI was 18% lower in goats fed diet C75 compared to those fed diets C25 and C50. Voluntary water intake decreased linearly (P < 0.05) as the red cactus levels in the diet increased. Compared with the diet C25-fed animals, those fed diets C50 and C75 drank about 45% less water per day.

Table 2. The effect of dietary treatments on performance and intake

	Diet				***P*-value[+]**		
Variables	**C25**	**C50**	**C75**	**s.e.**	**Treat**	**Lin**	**Quad**
Initial body weight (kg)	11.36	12.36	11.48	0.86	0.8090	0.7963	0.5326
Final body weight (kg)	12.34[b]	15.54[a]	13.18[ab]	0.86	0.0155	0.0317	0.0388
Average daily gain (g d^{-1})	14.03[b]	46.05[a]	24.28[b]	0.62	0.0021	0.1264	0.0009
Dry matter intake (%BW)	3.95[a]	3.94[a]	3.26[b]	0.20	0.0094	0.0063	0.0747
Water intake (L/d)	0.23[a]	0.11[b]	0.09[b]	0.03	0.0089	0.0048	0.1136

[a,b,c] Within a row, means without a common superscript letter differ (P< 0.05).
[+]Treatment (Treat), linear (Lin), and quadratic responses (Quad) to the rate of inclusion of cactus.

Goat performance

The BW of goats at the beginning of the trial was similar, on average 11.7±0.9 kg (Table 2). The BW of goats fed diets C25, C50 and C75 have increased9.0%, 26.9%, and 15.9%, respectively, during the experiment. Animals fed diet C50 had the greatest daily growth (46 g/day). Animals fed diets C25 and C75 grew4 and 14 g/day daily, respectively.

Digestibility

There was a positive linear effect on DM, OM, and CP digestibility with increasing red cactus levels in the diet (Table 3). Dry matter digestibility of animals fed diets C50 and C75, compared to diet C25, increased by 11% and 18%, respectively. The same effect was observed for OM apparent digestibility, which increased by 10% and 17% respectively for diets C50 and C75. Crude protein digestibility was on average 30% higher in animals fed diets C50 and C75, compared with diet C25. The CF digestibility decreased linearly with increasing levels of red cactus inclusion in the diet (Table 3).

Table 3. Effect of the experimental diets on the total apparent digestibility coefficients)

	Diet				*P*-value+		
Nutrient	**C25**	**C50**	**C75**	**s.e.**	**Treat**	**Lin**	**Qua**
Dry matter	0.615^{c}	0.684^{b}	0.743^{a}	1.6	0.0005	0.0001	0.7656
Ash	0.489^{ab}	0.479^{b}	0.558^{a}	1.6	0.0214	0.0246	0.0616
Organic matter	0.629^{b}	0.705^{a}	0.768^{a}	1.8	0.0008	0.0002	0.7222
Crude protein	0.627^{b}	0.799^{a}	0.803^{a}	1.7	0.0004	0.0002	0.0060
Crude fibre	0.537	0.408	0.417	3.6	0.0602	0.0445	0.1533

^{a,b,c} Within a row, means without a common superscript letter differ (P <0.05).
+Treatment (Treat), linear (Lin), and quadratic responses (Quad) to the rate of inclusion of cactus.

Gastrointestinal organ weight, staining, and intestinal morphology

There were no differences in carcass weights between the three diets (Table 4). Also, carcass yield was not affected by diet treatments. There were no significant differences between groups for the digestive tract and their contents.

Table 4. Effect of diets on hot carcass and gastrointestinal tract mass (% BW)

	Diet				*P*-value+		
Variables	**C25**	**C50**	**C75**	**s,e,**	**Treat**	**Lin**	**Quad**
Hot Carcass	34.0	46.0	42.0	0.0400	0.2185	0.2294	0.1856
Full Rumen	24.2	24.2	12.8	0.0329	0.1116	0.0702	0.2342
Empty Rumen	3.9	4.2	3.8	0.0049	0.7549	0.8269	0.4997
Full Small Intestine	4.6	5.9	4.2	0.0064	0.2621	0.6503	0.1317
Empty Small Intestine	2.6	3.0	2.3	0.0039	0.5338	0.6969	0.3179
Full Large Intestine	3.9	5.6	4.7	0.0117	0.6166	0.6416	0.4110
Empty Large Intestine	1.9	2.4	2.2	0.0030	0.5811	0.5838	0.3982

^{a,b,c} Within a row, means without a common superscript letter differ (P <0.05).
+Treatment (Treat), linear (Lin), and quadratic responses (Quad) to the rate of inclusion of cactus.

The colour of the rumen and reticulum was darker with an increasing inclusion rate of the cactus (Figure 1). Regarding the abomasum, the presence of cactus spikes was observed attached to the mucosa in animals that consumed diets with cactus. The number of spines increased with the percentage of cactus in the diet (data not shown).

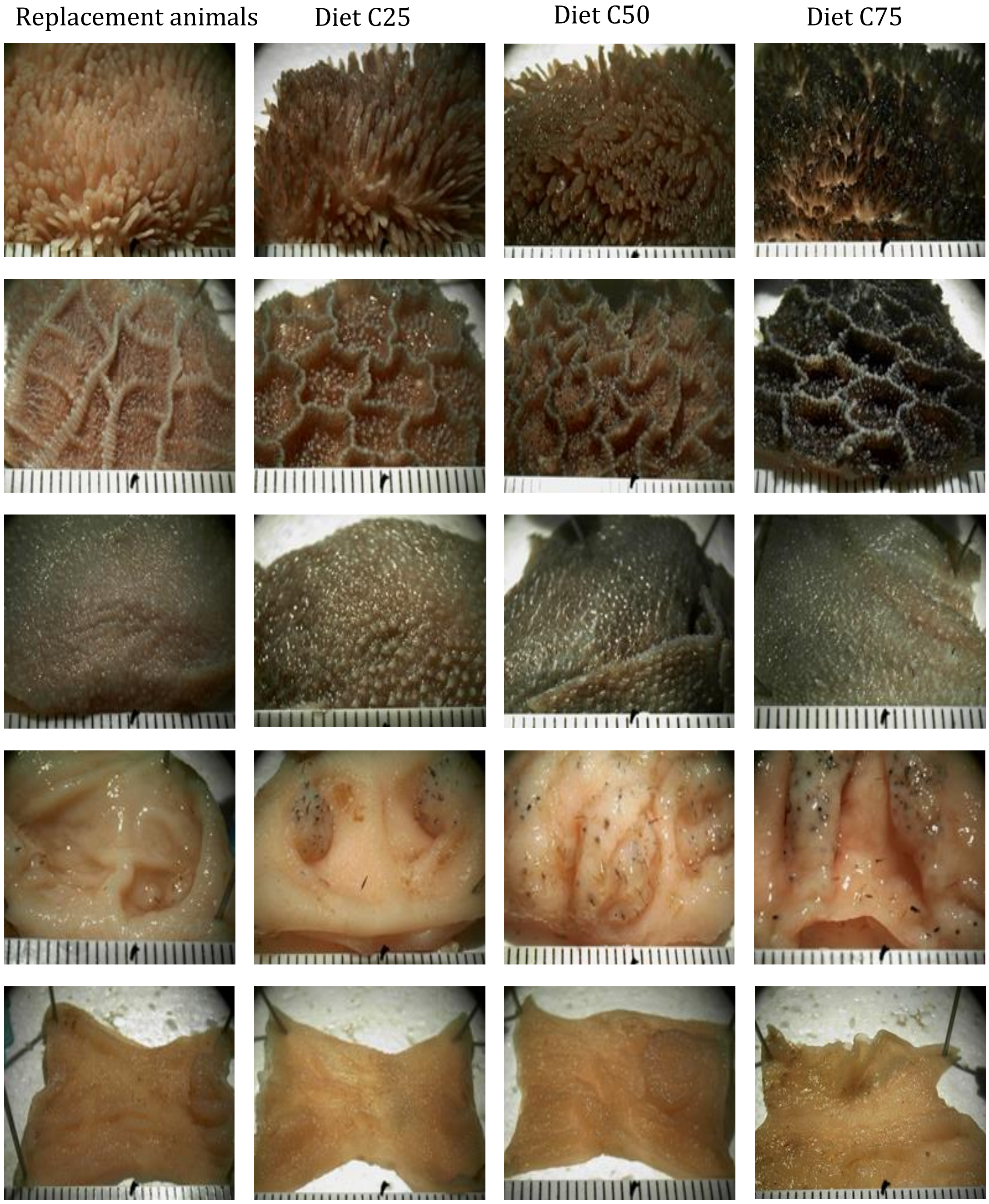

Figure 1. Characteristics and staining of the digestive tract. (a) rumen - top row; (b) reticulum – second row; (c) omasum – third row; (d) abomasum – second last row; (e) small intestine – bottom row. The distances between two vertical lines on the sliding rulers are 1.0 mm

The tissue was quite rigid to the touch. Regarding the small intestine, no differences were observed between groups, nor anomalies visible to the naked eye. Significant differences in histological measurements (length and width of villi) were observed between the diet C25 and C75 groups (Figure 2). In the duodenum, villi length and width were 41% and 53% lower, respectively, in animals fed diet C75 than those fed diet C25.

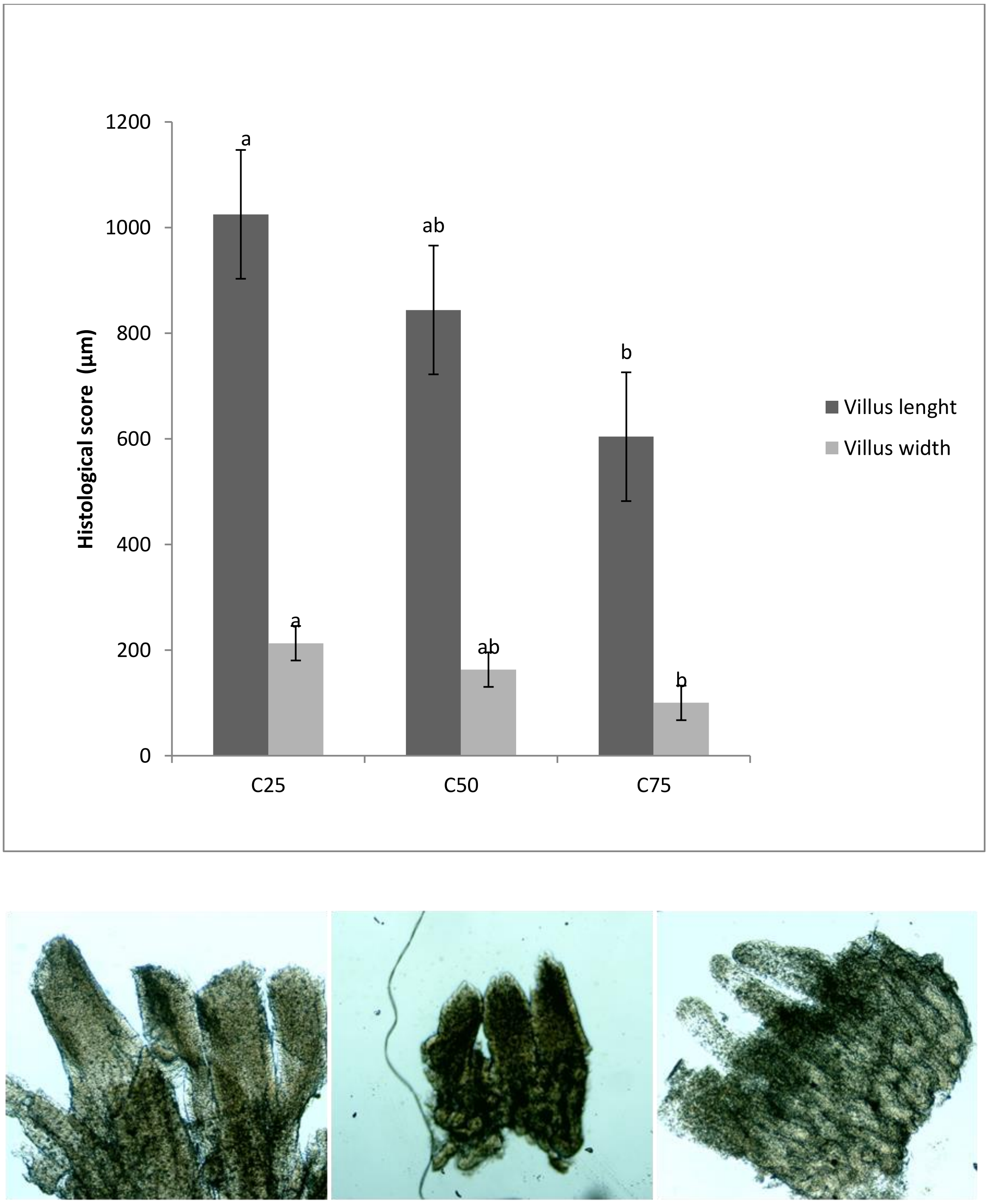

Figure 2. Histological score of goat duodenal villi

DISCUSSION

Chemical composition

The introduction of the red cactus, a feed rich in water and low in fibre, to a fibrous diet, naturally decreased DM and CF concentrations of the diet. A diet rich in cactus (75% DM) may cause bloating and diarrhoea in animals (Gebremariam et al., 2006). These symptoms are most likely related to the high water and mineral content of the diet. However, the use of fibrous component of diets such as hay can reduce the incidence of digestive disorders, even when the rate of cactus is 75% DM (Vieira et al., 2008; Santos et al., 2009). During our study, we did not observe diarrhoea in animals.

A greater value of CP (10% DM) was expected in diet C25. This is probably due to a lower CP concentration of *Cynodon* hay compared to the samplings carried out previously, but also to an unrepresentative diet sampling for chemical analysis. In fact, during the sampling of diet C25, a very fibrous diet, the exact proportion of urea was probably not sampled due to the lack of homogeneity in the mixture. Urea is a very important ingredient in this diet because it provides a large amount of CP in the diet.

Feed and water intake

In similar studies, using a diet based on hay and cactus, an intake of about 4.0% BW has been reported by sheep (Costa et al., 2012) and by lambs (Cardoso et al., 2018). In our study, the DM intake (DMI) did not change up to 50% inclusion of red cactus. Pessoa et al. (2013) verified that the association of different supplements (wheat bran, soybean meal, cottonseed meal, and whole cottonseed) with spineless cactus did not affect the DMI in sheep, which was considered satisfactory to provide adequate nutrient intake. However, we observed that goats fed diet C75 decreased DMI. This was probably due to the high moisture content of red cactus. The level of water exceeding 78% in fresh forage is claimed to have a negative effect on voluntary feed intake (Tegegne, 2001b). The National Research Council (2001) showed a DMI reduction in diets with more than 70% water. Similar results have been reported in sheep for which total DMI decreased as the proportion of cactus increased up to 60% inclusion (Tegegne et al., 2005b). De Kock (1980) also demonstrated that a high-water content of cactus limited its intake by sheep due to volume consideration. Costa et al. (2012), Porto Filho et al. (2015), and Cordova-Torres et al. (2017) observed a quadratic effect of cactus on DMI. These results suggest that the inclusion of cactus is beneficial for DMI up to a certain level, probably because of the low fibre content, high palatability, and passage rate of this feed.

The voluntary water intake decreased with increasing inclusion levels of red cactus with its high-water content. The water in the diet supplied most of the water requirement of animals, thus reducing their voluntary water intake (Table 2). Other studies have shown reductions in voluntary water intake in goats and sheep with the inclusion of forage cactus in the diet (Abidi et al., 2009; Costa et al., 2009; Tegegne et al., 2007). This response is very important for semi-arid regions due to water scarcity.

Goat performance

A higher average daily gain (ADG) was expected for all groups. It seems that the diet did not contain enough protein (and/or other nutrients) to optimize the performance of goats. This could also be related to DM intake, which is an important determinant of animal performance (Oliveira et al., 2016). An earlier study reported that *Opuntia ficus-indica* when included at levels up to 100% significantly decreased the ADG of sheep (Costa et al., 2012). In contrast, a recent study reported that the ADG of lambs was significantly increased by *Nopalea cochenillifera* at levels from 0 to 45% (Cardoso et al., 2018). Moreover, Oliveira et al. (2017) reported that spineless cactus up to 50% DM diet was able to improve the growth performance of finishing lambs. Einkamerer et al. (2009) did not observe significant differences in the ADG of young sheep when fed diets containing from 24 to 36% *Opuntia ficus-indica var. Algerian*. The low ADG of goats fed dietC75 is most likely related to their lower feed intake. According to Tegegne et al. (2005a), in a diet containing cactus up to 80% of the DM, the ADG of the sheep was almost zero. The low ADG may also be related to a genetic component of the animals used in our experiment.

Digestibility

The high *in vivo* nutrient digestibility of diets indicate that diets were well digested. Moreover, in this study, low-quality hay, with low digestibility, was replaced with a feed of better nutritional quality and digestibility. According to Ferreira (2005), non-fibrous carbohydrates (NFC) that form the largest fraction of the total carbohydrates in spineless cactus pears are readily fermented in the rumen. An increase in diet NFC content favours microbial growth, mainly because NFC, which is readily fermented in the rumen, provides energy support for microorganisms (Oliveira et al., 2017). Consequently, the increase of DM and OM digestibility related to the greater intake of NFC in diet C75 was partially due to the greater use of carbohydrates in the diet. These results corroborate with other studies (Menezes et al., 2010; Oliveira et al., 2016; Siqueira et al., 2017), which also observed an increase in DM digestibility and other nutrients with the increase of cactus fodder levels in sheep and cattle diets. In this study, the apparent CF digestibility coefficients of the diets did not differ significantly. This suggests that the fibre present in the three diets was equally digestible. The lack of significant differences between the apparent CF digestibility coefficients of the diets can probably be attributed to the low fibre content of *Opuntia* cladodes, corroborating with Zeeman (2005). The apparent CP digestibility coefficients of the diets C50 and C75 were significantly high compared to C25. This was probably because urea was used to supplement CP levels of the diets to compensate for the lower CP content of *Opuntia* cladodes and hay. Urea is utilised quickly and almost completely by the microorganisms, therefore it was expected that the CP of diets C50 and C75 would have higher apparent digestibility. These results corroborate several studies (Costa et al., 2012; Felix et al., 2015; Zeeman, 2005).

In general, *in vivo* nutrient digestibility increases as intake decreases (Van Soest, 1994). This occurred in our study with diet C75. Even if the animals in the diet C75 group had a higher nutrient digestibility, they grew less than the animals in the diet C50 group. This probably means that the improvement in nutrient digestibility could not compensate for the decrease in the amount of feed ingested by the animals fed diet C75. The results suggest that goats efficiently digested nutrients provided by cactus if cactus is fed as part of a nutritionally balanced diet.

Gastrointestinal organ weight, staining, and intestinal morphology

Carcass weight was not affected by diets. On conventional diets with hay and concentrates, gut-weight in goats varied according to protein level (Atti et al., 2004). In this study, the weight of organs was not affected by dietary treatments, probably due to the close content of CP in all three diets which was a positive result. However, it seemed that the rumen content of animals fed 75% red cactus in the diet was approximately 50% less (Table 4), which is consistent with the higher digestibility coefficient of this treatment.

The colour of alimentary tract mucosa shows that there is a direct effect on the digestive tract of animals that have consumed red cactus. The darker colour of the rumen and the reticulum is probably the consequence of the high consumption of chlorophyll. Between the abomasum and the duodenum, the passage for digesta is narrow, and it is in this region of the digestive tract. Most cactus spines were observed in the abomasum.

The small intestine is the main site of the absorption of nutrients. Absorption is mainly taking place through the villi in the walls of the small intestine (Li et al., 2002). An increase in the length of the intestinal villus increases the surface area of the small intestine to absorb nutrients, so the length of the intestinal villi directly affects animal growth (Wilson et al., 2018). When the intestine is affected or stressed, the villi can be damaged and shortened. Therefore, the short and narrow villi of goats fed diet C75 means that the intestinal mucosa was damaged and therefore these animals have a lower nutrient absorption capacity than animals fed diets C50 and C25. However, animals fed diet C75 digested feeds better. Results in this study only focused on the duodenum, while the most important part of absorption in the small intestine is in the jejunum.

CONCLUSION

This study provides evidence that red cactus can serve as an effective feed for goats. The feeding trial showed that mixing hay and red cactus led to better results. The data indicate that red cactus has a significant effect on DMI and ADG in young goats. Although DMI decreased when including a high level of cactus (>50% DM) in diets, DMI and ADG improved in animals fed red cactus up to 50% DM. Results obtained with the inclusion of 25% DM red cactus in diets highlighted its high palatability but with poor weight gains. The inclusion of red cactus at 75% DM improves nutrient digestibility. However, this reduces voluntary DMI, causes low weight gain, and damages the duodenal mucosa. It can be concluded that, in our experimental conditions, the optimum inclusion level of red cactus was at 50% DM.

DECLARATION OF INTEREST

No conflicts of interest are declared by all authors.

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