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Macromineral balance in lambs fed diets containing spineless cactus species

[*Balanço macromineral em cordeiros alimentados com dietas contendo espécies de palma forrageira*]

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ABSTRACT

The purpose of the present study was to evaluate the effects of spineless cactus species in diets of feedlot lambs on intake, apparent absorption and retention of macrominerals. Thirty-six uncastrated male Santa Inês lambs presenting an average body weight of 22.0±2.87 kg were distributed in a completely randomized design with three treatments [diet containing Tifton-85 hay as exclusive roughage (control), Miúda cactus cladodes-based diet or Orelha de Elefante Mexicana (OEM) cactus cladodes-based diet] and twelve replicates. The calcium (Ca) and magnesium (Mg) intakes (from feed and total) were higher (P=0.001) for animals fed diets supplemented with Miúda spineless cactus. The spineless cactus, regardless of species, caused a mean decrease of 45.4% in sodium intake (P=0.001). There was a net loss of Ca by lambs fed OEM spineless cactus (P=0.001). The absorption and retention of P was higher in control diet compared to the OEM diet (P<0.05). The amount apparently absorbed, and body retention of Mg were higher for lambs fed Miúda spineless cactus-diet (P=0.001). Therefore, the diet containing Miúda spineless cactus increases the intake and body retention of Ca and Mg in lambs. However, the use of OEM spineless cactus may be unsuitable for a long-term.

Keywords: sheep, apparent absorption, cactus cladodes, mineral elements, semiarid

RESUMO

O objetivo do presente estudo foi avaliar os efeitos de espécies de palma forrageira, em dietas para cordeiros confinados, sobre o consumo, a absorção aparente e a retenção de macrominerais. Trinta e seis cordeiros Santa Inês, machos, não castrados, com peso médio de 22,0±2,87kg, foram distribuídos em delineamento inteiramente ao acaso, com três tratamentos [dieta contendo feno de Tifton-85 como volumoso exclusivo (controle), dieta à base de palma miúda ou palma orelha-de-elefante-mexicana (OEM)] e 12 repetições. Os consumos de cálcio (Ca) e magnésio (Mg) (via dieta e total) foram maiores (P=0,001) para os animais alimentados com dietas suplementadas com palma forrageira miúda. A palma forrageira, independentemente da espécie, causou diminuição média de 45,4% na ingestão de sódio (P=0,001). Houve perda líquida de Ca pelos cordeiros alimentados com palma OEM (P=0,001). A absorção e a retenção de P foram maiores com a dieta controle em comparação à dieta OEM (P<0,05). A quantidade aparentemente absorvida e a retenção corporal de Mg foram maiores nos cordeiros alimentados com palma miúda (P=0,001). Portanto, a dieta contendo palma miúda aumenta o consumo e a retenção corporal de Ca e Mg por cordeiros. No entanto, o uso de palma OEM pode ser insustentável a longo prazo.

Palavras-chave: ovinos, absorção aparente, cladódios de palma, elementos minerais, semiárido

INTRODUCTION

Spineless cactus (*Opuntia* and *Nopalea*) is a forage crop well-established as a nutritional alternative for ruminants in semiarid environments. However, there are studies that have already reported unbalanced mineral relationships in the different species and varieties of spineless cactus used to feed ruminants in the tropics: high concentrations of Ca, Mg and K,

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and low levels of P and Na (Carvalho *et al*., 2020; Sipango *et al*., 2022). Furthermore, spineless cactus have oxalates that can affect the utilization of dietary minerals (Silva *et al*., 2021).

In the gastrointestinal tract of ruminants, synergistic or antagonistic interactions can occur between the minerals that make up the feed and between other substances in the diet (Pordeus Neto *et al*., 2016), which implies in predisposition to mineral imbalances. According to Underwood and Suttle (1999) and Mayberry *et al*. (2010), factors such as ruminal pH, cation-anionic difference, and rate of passage of diets through the gastrointestinal tract can affect the absorption of minerals.

Diets with increasing levels of spineless cactus *cv*. Baiana (*Nopalea cochenillifera* Salm-Dyck) cause linear decrease in ruminal pH of sheep (Lima *et al*., 2018). Additionally, Costa *et al*. (2016) reported an increase in the passage rate with the inclusion of spineless cactus in the diet for cattle. Thus, it is possible that the dietary levels of spineless cactus usually used in diets for ruminants (300-500g/kg of dry matter - DM) may cause changes in the absorption of minerals. Previous studies have reported changes in serum levels and bone content of macrominerals in lambs fed diets containing cactus cladodes (Silva *et al*., 2023a, 2023b). However, there is a gap in scientific knowledge regarding the effects of diets containing spineless cactus species on macrominerals balance in small ruminants.

In this context, it is hypothesized that diets containing spineless cactus change macromineral dynamics in sheep. Therefore, the purpose of the present study was to evaluate the effects of spineless cactus in diets of feedlot lambs on intake, apparent absorption, and retention of macrominerals.

MATERIAL AND METHODS

The procedures in this experiment were approved by the Committee of Ethics in the Use of Animals of the Federal Rural University of Pernambuco (UFRPE) (License 142/2018). The study was carried out at the Department of Animal Science, UFRPE, Recife, Pernambuco, Brazil. This research is a part of a larger project with methodology based on previous studies (Lopes *et al*., 2020; Silva *et al*., 2022, 2023a).

Thirty-six uncastrated male Santa Inês lambs, with approximately six months and average body weight (BW) of 22.0±2.87kg were distributed in a completely randomized design, with three treatments and twelve replicates per treatment. All animals were maintained in a covered shed and housed in individual pens with a suspended slatted floor, equipped with feeder and drinker. The experimental period lasted 86 days, with 30 days of adaptation. Before starting the experiment, the lambs were identified, weighed, treated against parasites with doramectin 1% (Dectomax®, Guarulhos, SP, Brazil) and vaccinated against clostridiosis (Covexin 9®, São Paulo, SP, Brazil).

The treatments consisted of three diets formulated to meet the requirements to gain 200g/day (Nutrient…, 2007): (1) diet containing Tifton hay as exclusive roughage (control); (2) diet with partial replacement of Tifton hay by Miúda spineless cactus (*Nopalea cochenillifera* Salm Dyck) or (3) diet with partial replacement of Tifton hay by Orelha de Elefante Mexicana (OEM) spineless cactus (*Opuntia stricta* Haw.), with roughage:concentrate ratio of 60:40. The experimental diets were composed of two spineless cactus species, Tifton-85 hay (*Cynodon* spp.), ground corn, soybean meal, mineral mix and urea (Table 1).

The chemical composition of diets and ingredients proportion are presented in Table 2. The total mixed ration (TMR) was provided *ad libitum* twice daily (08:00 am and 03:00 pm), allowing leftovers of 15% of total DM offered. To avoid selection of the TMR, the mixture of ingredients was conducted manually in the feeders. The spineless cactus mucilage allowed a uniform aggregation of the other dietary ingredients. Further information regarding the processing and chemical analysis of feed and leftovers, as well as feces collection, were reported by Lopes *et al*. (2020), and the water and urine collections were described by Silva *et al*. (2022).

Table 1. Chemical composition of ingredients of experimental diets (g/kg dry matter, unless stated)

Item	Tifton hay	Miúda cactus	OEM[a] cactus	Ground corn	Soybean meal	Mineral mix	Urea	Water (mg/L)
Dry matter[b]	895.5	123.6	97.2	877.1	882.7	990.0	990.0	-
Ash	83.9	129.4	149.0	12.3	70.3	-	-	-
Crude protein	86.0	40.0	55.0	85.0	487.0	-	2800.0	-
Ether extract	22.6	13.8	17.8	38.3	15.0	-	-	-
$_{ap}$NDF[c]	669.4	252.7	198.0	146.7	134.5	-	-	-
Non-fibrous carbohydrates	138.0	563.9	580.0	717.6	293.0	-	-	-
Oxalates	3.80	2.91	5.77	5.59	1.88	-	-	-
Calcium (Ca)	7.47	36.90	27.99	0.36	4.80	117.39	1.10	15.96
Oxalates:Ca ratio	0.51	0.08	0.21	15.53	0.39	-	-	-
Phosphorus (P)	4.18	0.91	4.08	5.05	14.10	142.42	2.16	0.16
Ca:P ratio	1.79	40.55	6.86	0.07	0.34	0.82	0.51	99.75
Magnesium	2.96	19.64	13.69	1.00	4.40	5.38	0.04	9.34
Sodium	0.96	0.14	0.13	0.04	0.12	70.50	0.01	25.82
Potassium	24.86	19.54	26.01	3.39	28.82	2.34	--	26.75

[a] orelha de elefante mexicana spineless cactus, [b] fresh matter, [c] neutral detergent fiber assayed with a heat stable amylase and corrected for ash and nitrogenous compounds, (-) not determined, (--) not detected.

Table 2. Ingredients proportion and chemical composition of the experimental diets

Ingredients (g/kg)	Diets		
	Control	Miúda	OEM[a]
Tifton hay	600	150	150
Miúda spineless cactus	0	450	0
OEM [a] spineless cactus	0	0	450
Ground corn	270	271	273
Soybean meal	110	100	100
Urea	5	14	12
Mineral mix	15	15	15
Diet composition (g/kg dry matter)			
Dry matter[b]	890.8	234.8	190.3
Ash	76.0	95.8	104.7
Crude protein	142.1	141.8	143.2
Ether extract	25.6	21.5	23.4
$_{ap}$NDF[c]	456.1	267.4	243.1
Non-fibrous carbohydrates	300.2	473.4	485.8
Oxalates	4.0	3.6	4.9
Calcium (Ca)	6.87	20.08	16.07
Oxalates:Ca ratio	0.58	0.18	0.30
Phosphorus (P)	7.57	5.98	7.41
Ca:P ratio	0.91	3.36	2.17
Magnesium	2.61	10.07	7.40
Sodium	1.66	1.29	1.28
Potassium	19.04	16.36	19.28

[a] orelha de elefante mexicana spineless cactus, [b] fresh matter, [c] neutral detergent fiber assayed with a heat stable amylase and corrected for ash and nitrogenous compounds.

The quantification of minerals in samples of water, feed, leftovers, and feces were reported by Silva *et al*. (2023a), and urine mineral analyzes were performed according to Silva *et al*. (2022), in studies previously published by our research group. The mineral element intake was calculated by the difference between the amount of the mineral offered and its leftover. Apparent

absorption of minerals was calculated as mineral intake − mineral fecal output. The mineral retention was calculated by the following equation: mineral intake – (mineral fecal output + mineral urine output).

A completely randomized design with three treatments and twelve replications was used, considering initial BW as a covariate, according to the model below:

$Y_{ij} = \mu + T_i + \beta(X_{ij} - X) + e_{ij}$

Where Y_{ij} = the observed dependent variable; μ = general mean; T_i = treatment effect; $\beta(X_{ij} - X)$ = covariate effect (initial BW); and e_{ij} = experimental error.

The data were submitted to analysis of variance (ANOVA), considering significant differences ($P<0.05$) as the critical probability level for type I error. The averages were compared by the Tukey's test ($P<0.05$), in the statistical SAS software (Statistical…, 2009).

RESULTS

The Ca and Mg intakes (from feed and total) were higher (P=0.001) for animals fed diets supplemented with Miúda spineless cactus. On the other hand, this diet provided a lower P intake (P=0.014), compared to the control treatment. The spineless cactus, regardless of species, caused a mean decrease of 45.4% in Na intake (P=0.001) (Table 3).

Table 3. Macrominerals intake by lambs fed spineless cactus-based diets

Item	Diets				
	Control	Miúda	OEM[a]	SEM[b]	P-value
Dry matter (g/day)[*]	1129b	1290a	1172ab	30.00	0.020
Ash (g/day)	87.6b	122.8a	117.6a	5.35	0.001
Total oxalates (g/day)[#]	4.98b	4.68b	6.21a	0.27	0.001
Voluntary water (kg/day)[#]	3.57a	1.13b	0.82b	0.24	0.001
Calcium (g/day)					
Intake from feed[**]	8.42c	25.7a	16.7b	1.021	0.001
Intake from water	0.06a	0.02b	0.01b	0.003	0.001
Total intake	8.48c	25.7a	16.7b	1.022	0.001
Phosphorus (g/day)					
Intake from feed[**]	9.56a	8.09b	8.83ab	0.338	0.014
Intake from water	0.0006a	0.0002b	0.0001b	0.000	0.001
Total intake	9.56a	8.09b	8.83ab	0.338	0.014
Magnesium (g/day)					
Intake from feed[**]	3.08c	13.8a	7.01b	0.505	0.001
Intake from water	0.04a	0.01b	0.01b	0.002	0.001
Total intake	3.12c	13.8a	7.02b	0.506	0.001
Sodium (g/day)					
Intake from feed[**]	2.10a	1.33b	1.01b	0.083	0.001
Intake from water	0.09a	0.03b	0.02b	0.005	0.001
Total intake	2.19a	1.36b	1.03c	0.086	0.001
Potassium (g/day)					
Intake from feed [**]	21.6	21.5	21.3	0.987	0.968
Intake from water	0.10a	0.03b	0.02b	0.005	0.001
Total intake	21.7	21.5	21.3	0.989	0.954

[a] orelha de elefante mexicana spineless cactus, [b] standard error of the mean, [*]values obtained by Lopes *et al*. (2020), [#]values obtained by Silva *et al*. (2022), [**]values obtained by Silva *et al*. (2023a). Averages in rows followed by different letters are statistically different by Tukey's test at 5% probability.

The fecal excretion of Ca was 336% and 460% higher by animals fed Miúda and OEM spineless cactus, respectively, compared to the control group. The apparent absorption of Ca was higher in diets control and containing Miúda spineless cactus. Furthermore, there was a net loss of Ca

by lambs fed OEM spineless cactus (P=0.001) (Table 4). There was greater apparent absorption and body retention of Ca by lambs that received Miúda spineless cactus, and Ca total excretion was higher in animals fed spineless cactus (P=0.001) (Table 4).

Table 4. Apparent absorption and macromineral retention by lambs fed spineless cactus-based diets

Item	*Diets*				
	Control	*Miúda*	*OEMa*	*SEMb*	*P-value*
Calcium					
Feces (g/day)	5.12c	17.2b	23.5a	1.593	0.001
Absorption (g/day)	3.36b	8.50a	-6.79c	1.113	0.001
Absorbed (%)	39.6a	33.5a	-39.6b	5.342	0.001
Urine (g/day)	0.13a	0.05a	0.13a	0.022	0.023
Total excretion (g/day)*	5.25c	17.2b	23.7a	1.596	0.001
Retained (g/day)	3.23b	8.45a	-6.93c	1.371	0.001
Retained (%)[1]	38.1a	33.3a	-40.4b	5.387	0.001
Retained (%)[2]	96.1b	99.2a	-3.43c	0.991	0.001
Phosphorus					
Feces (g/day)	4.61	4.52	6.61	0.765	0.120
Absorption (g/day)	4.95a	3.57ab	2.22b	0.574	0.009
Absorbed (%)	51.8a	44.1ab	25.1b	6.123	0.016
Urine (g/day)	0.05a	0.01b	0.01b	0.010	0.032
Total excretion (g/day)*	4.66	4.54	6.62	0.766	0.125
Retained (g/day)	4.90a	3.56ab	2.21b	0.532	0.010
Retained (%)[1]	51.2a	44.0ab	25.0b	5.892	0.018
Retained (%)[2]	98.9	99.7	99.5	0.474	0.222
Magnesium					
Feces (g/day)	1.85c	4.55b	5.84a	0.357	0.001
Absorption (g/day)	1.27b	9.22a	1.18b	0.380	0.001
Absorbed (%)	41.7b	67.1a	16.9c	3.396	0.001
Urine (g/day)	0.05b	0.07ab	0.08a	0.010	0.031
Total excretion (g/day)*	1.90c	4.63b	5.93a	0.356	0.001
Retained (g/day)	1.22b	9.14a	1.09b	0.374	0.001
Retained (%)[1]	40.1b	66.5a	15.7c	3.347	0.001
Retained (%)[2]	95.9b	99.2a	91.7c	0.660	0.001
Sodium					
Feces (g/day)	3.70a	0.26b	0.22b	0.425	0.001
Absorption (g/day)	-1.51b	1.10a	0.81a	0.415	0.001
Absorbed (%)	-67.7b	80.2a	75.3a	19.818	0.001
Potassium					
Feces (g/day)	3.93a	1.25b	1.27b	0.655	0.009
Absorption (g/day)	17.8	20.2	20.0	1.028	0.189
Absorbed (%)	82.2b	94.1a	94.2a	3.089	0.014

[a] orelha de elefante mexicana spineless cactus, [b] standard error of the mean, *sum of excretion via urine and feces, [1]consumed, [2]absorbed. Averages in rows followed by different letters are statistically different by Tukey's test at 5% probability.

The diet containing OEM spineless cactus caused negative Ca absorption and retention (Tab. 4). The absorption and retention of P was higher in control diet compared to the OEM diet (P<0.05) (Table 4). The amount apparently absorbed, and body retention of Mg were higher by lambs fed Miúda spineless cactus-diet (P=0.001; Table 4). The diet containing OEM spineless cactus caused

greater urinary excretion of Mg compared to the control diet (P=0.031), and animals that received spineless cactus species excreted more Mg (total excretion) (P=0.001; Table 4). The apparent absorption of Na and K was higher in diets containing spineless cactus (Table 4).

DISCUSSION

The macrominerals intake observed in animals that consumed all diets were greater than the requirements for growing lambs (Nutrient…, 2007). Ca intake by lambs fed Miúda diet represented 658% of the requirements of this macromineral, which indicates an excess in the diets offered. Additionally, the macrominerals intake via water decreased with the addition of spineless cactus (P=0.001) (Table 3), being a result of the greater voluntary intake of water by lambs fed the control diet. The highest excretion of Ca occurs through the faeces, with very low losses through the urine due to the renal reabsorption (Santos *et al*., 2009). The Miúda spineless cactus showed higher levels of Ca (Silva *et al*., 2023a), which increased the intake, absorption, and body retention.

Negative Ca absorption and retention caused by diet containing OEM spineless cactus may be related to the highest intake of oxalates (Table 3), since these can bind with Ca, forming insoluble Ca oxalate. Rumen bacteria can partially metabolize the soluble oxalate (Ward *et al*., 1979). However, most of the Ca oxalate passes intact through the ruminant digestive tract (Rahman *et al*., 2013). In this study, the total oxalates intake by lambs fed OEM spineless cactus represented 0.53% of the DM intake and this level of oxalates intake was able to cause a net loss of Ca. Panda and Sahu (2002), using bulls, reported that the total oxalates intake at the level of 1.19% of the DM intake caused a negative balance of Ca. These results indicate that low levels of oxalates, despite not causing intoxication, may make some dietary minerals unavailable.

The greater intake of P by lambs of the control treatment (P=0.014) was reflected in the greater absorption and retention (P<0.05) of this element. In contrast, animals in this group excreted more P via urine (P=0.032). According to Louvandini and Vitti (2007), the greater excretion of P via urine indicates that the dietary levels of this mineral were able to meet the requirements of the lambs, with urine being a route of homeostatic control. Silva *et al*. (2023b), in research related to the present study, reported that serum P levels remained within the physiological range, regardless of dietary treatment.

Lambs fed Miúda spineless cactus absorbed and retained more Mg in the body due to the greater supply of this mineral provided by this diet, which increased the intake of Mg and its use by the organism. Silva *et al*. (2021) also reported higher Mg concentrations in the Miúda species compared to the OEM species, using cladodes of the same age and cultivated under the same edaphoclimatic and management conditions. The absorption of Mg from the gastrointestinal tract is reduced when sheep are fed diets containing high levels of Ca and K (Newton *et al*., 1972). The diet with OEM cactus caused lower absorption of Mg, but the intake and absorption of Ca was higher by the animals that received the diet containing Miúda cactus (P=0.001). These results suggest that Ca was probably little available.

The control di*et al*so contains oxalates in its composition (Silva *et al*., 2023c), which may have caused the negative Na balance. In hay, the oxalate is predominantly forming crystals with monovalent cations, such as Na, but are more soluble in comparison to Ca oxalate (Rahman *et al*., 2013). There was lower Na intake with the addition of cacti in the diets. However, fecal excretion of Na by animals submitted to these diets decreased, resulting in greater absorption of this element (average of 77.7%), result similar to that reported by Lucena (2011): Na absorption rates of 71% and 75% by lambs fed diets containing Tifton hay + cactus or only cactus, respectively.

The reduction in fecal K excretion provided by cactus based diets increased its absorption rate. Silva *et al*. (2023c) reported this same behavior when evaluating the replacement of Buffel grass hay by OEM spineless cactus in sheep diets. According to Cuppari and Bazanelli (2010), minimal amounts of K are excreted through feces and sweat, being the renal excretion responsible for regulating the body balance of this element. Most of the K consumed by ruminants are

absorbed from the small intestine and excreted by the kidneys (McDowell, 1992).

CONCLUSIONS

The diet containing Miúda spineless cactus increases the intake and body retention of calcium and magnesium by lambs. However, the use of Orelha de Elefante Mexicana spineless cactus may be unsuitable for lambs long-term. Thus, further studies are required to fully evaluate the mineral balance of sheep fed diets based-spineless cactus species.

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REFERENCES

CARVALHO, C.B.M.; EDVAN, R.L.; NASCIMENTO, K.S. *et al*. Methods of storing cactus pear genotypes for animal feeding. *Afr. J. Range Forage Sci.*, v.37, p.173-179, 2020.

COSTA, C.T.F.; FERREIRA, M.A.; CAMPOS, J.M.S. *et al*. Intake, total and partial digestibility of nutrients, and ruminal kinetics in crossbreed steers fed with multiple supplements containing spineless cactus enriched with urea. *Livest. Sci.*, v.188, p.55-60, 2016.

CUPPARI, L.; BAZANELLI, A.P. *Funções plenamente reconhecidas de nutrientes: potássio*. São Paulo: ILSI Brasil, 2010. 16p. (Série de Publicações ILSI Brasil, 11).

LIMA, T.J.; COSTA, R.G.; MEDEIROS, G.R. *et al*. Ruminal and morphometric parameters of the rumen and intestines of sheep fed with increasing levels of spineless cactus (*Nopalea cochenillifera* Salm-Dyck). *Trop. Anim. Health Prod*., v.51, p.363-368, 2018.

LOPES, L.A.; FERREIRA, M.A.; BATISTA, A.M.V. *et al*. Intake, digestibility, and performance of lambs fed spineless cactus cv. Orelha de Elefante Mexicana. *Asian Australas. J. Anim. Sci.*, v.33, p.1284-1291, 2020.

LOUVANDINI, H.; VITTI, D.M.S.S. Phosphorus kinetics using mathematical models for adult sheep. *Pesqui. Agropecu. Bras.*, v.42, p.1467-1472, 2007.

LUCENA, R.B. *Utilização da palma forrageira (Nopalea cochenillifera* Salm-Dyck*) nas formas in natura e desidratada sobre: consumo, digestibilidade, balanço hídrico e absorção dos minerais em ovinos*. 2011. 74f. Dissertação (Mestrado em Zootecnia) - Universidade Federal Rural de Pernambuco, Recife, PE.

MAYBERRY, D.; MASTERS, D.; VERCOE, P. *et al*. Mineral metabolism of sheep fed saltbush or a formulated high-salt diet. *Small Rumin. Res*., v.91, p.81-86, 2010.

MCDOWELL, L.R. *Minerals in animal and human nutrition*. San Diego: Academic Press, 1992. p.33-100.

NEWTON, G.L.; FONTENOT, J.; TUCKER, R.E. *et al*. Effects of high dietary potassium intake on the metabolism of magnesium by sheep. *J. Anim. Sci.*, v.35, p.440-445, 1972.

NUTRIENT requirements of small ruminants: sheep, goats, cervids, and new world camelids. Washington: National Academic Press, 2007.

PANDA, N.; SAHU, B.K. Effect of dietary levels of oxalic acid on calcium and phosphorus assimilation in crossbred bulls. *Indian J. Anim. Res*., v.19, p.215-220, 2002.

PORDEUS NETO, J.; SOARES, P.C.; BATISTA, A.M.V. *et al*. Balanço hídrico e excreção renal de metabólitos em ovinos alimentados com palma forrageira (*Nopalea cochenillifera* Salm Dyck). *Pesqui. Vet. Bras*., v.36, p.322-328, 2016.

RAHMAN, M.M.; ABDULLAH, R.B.; WAN KHADIJAH, W.E. A review of oxalate poisoning in domestic animals: tolerance and performance aspects. *J. Anim. Physiol. Anim. Nutr*., v.97, p.605-614, 2013.

SANTOS, K.L.L.; GUIM, A.; BATISTA. A.M. *et al*. Balanço de macrominerais em caprinos alimentados com palma forrageira e casca de soja. *Rev. Bras. Saúde Prod. Anim*., v.10, p.546-559, 2009.

SILVA, M.P.; CARVALHO, F.F.R.; BATISTA, A.M.V. *et al*. Nutritional and mineral composition of *Opuntia stricta* Haw: Balance of macrominerals, renal function and blood metabolites in sheep. *Arq. Bras. Med. Vet*., v.75, p.333-346, 2023c.

SILVA, T.G.P.; BATISTA, A.M.V.; GUIM, A. *et al*. Cactus cladodes cause intestinal damage, but improve sheep performance. *Trop. Anim. Health Prod.*, v.53, p.1-10, 2021.

SILVA, T.G.P.; LOPES, L.A.; CARVALHO, F.F.R. *et al*. Blood biochemical parameters of lambs fed diets containing cactus cladodes. *Arq. Bras. Med. Vet*., v.75, p.48-60, 2023b.

SILVA, T.G.P.; LOPES, L.A.; CARVALHO, F.F.R. *et al*. Water balance and urinary parameters of lambs fed diets containing cactus cladodes varieties. *J. Agric. Sci*., v.160, p.557-563, 2022.

SILVA, T.G.P.; LOPES, L.A.; MUNHAME, J.A. *et al*. Effect of diets containing cactus cladodes on physical and histomorphometric parameters, and bone mineral content of feedlot lambs and goats. *Small Rumin. Res*., v.221, 106946, 2023a.

SIPANGO, N.; RAVHUHALI, K.E.; SEBOLA, N.A. *et al*. Prickly pear (*Opuntia* spp.) as an invasive species and a potential fodder resource for ruminant animals. *Sustainability*, v.14, p.1-16, 2022.

STATISTICAL analysis system. User's guide. Version 9.0. Inc. Cary: SAS Institute Inc., 2009.

UNDERWOOD, E.J.; SUTTLE N.F. *The mineral nutrition of livestock*. 3.ed. New York: CAB International, 1999. 614p.

WARD, G.; HARBERS, L.H.; BLAHA, J.J. Calcium-containing crystals in alfalfa: their fate in cattle. *J. Dairy Sci.*, v.62, p.715-722, 1979.