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Corn grain rehydration methods: Water vs. cactus pear in the diet for feedlot lambs

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A R T I C L E I N F O

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A B S T R A C T

The goal was to evaluate the productive performance, nutrient digestibility, nitrogen balance and blood parameters of feedlot lambs fed silages of corn grain rehydrated with water or cactus pear. Thirty male intact lambs, mixed breed, and with an average initial weight of 22 ± 4.29 kg were assigned to a completely randomized design with three treatments and ten replications. The treatments were defined as diet containing ground dry corn grain - CG (Control); diet containing corn grain silage rehydrated with water (CW) and; diet containing corn grain silage rehydrated with cactus pear (CCP). No significant differences were observed ($P > 0.05$) among the treatments in terms of dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), total carbohydrate (TCHO), and metabolizable energy (ME). However, the ME content ($P = 0.0204$) of the diets containing rehydrated corn grain silage (CW) (2.57 Mcal/kg DM) was significantly higher than that of the CG diets (2.29 Mcal/kg DM). This difference in ME was associated with improved digestibility of DM ($P = 0.0148$), OM ($P = 0.0032$), and TCHO ($P = 0.0027$) in the CW diets. Animals fed the CG diets exhibited lower total weight gain, daily weight gain, and reduced feed efficiency. Additionally, a higher percentage of starch was found in the feces of animals consuming CG diets. In contrast, animals fed the CCP diet had higher plasma glucose concentrations ($P = 0.0177$). The inclusion of rehydrated corn grain silage in the diets proved to be a valuable nutritional strategy to enhance the overall nutritive value of corn grain for lambs, leading to improved animal performance. Furthermore, the utilization of cactus pear as a source of rehydration for grain silage can be particularly advantageous in regions where water resources are limited.

1. Introduction

Corn is the most used energy concentrate ingredient in ruminant feeds in the world. However, some physical and chemical factors influence its use by the digestive tract of animals. Among these factors, the vitreousness of the corn grain decreases the digestion of starch by the animals (Arcari et al., 2016).

There are corn cultivars with different vitreousness, and in tropical countries, high vitreousness cultivars prevail (Daniel et al., 2019). The predominance of cultivars with vitreous endosperm in this climate is due to breeding programs that prioritized resistance to climatic variation to the detriment of the nutritional value of corn grain.

Prolamins responsible for vitreousness are characterized by a protein matrix that surrounds the starch granules. As the degree of vitreosity increases, the digestibility of starch in the digestive tract tends to decrease (Artuzo et al., 2019).

The adoption of corn grain silage rehydrated with water has become a nutritional tool to increase the nutritional value of corn grain, reducing

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its vitreous content, in addition to allowing the producer to reduce storage costs in commercial silos (Arcari et al., 2016). Through the process of grain rehydration and ensiling, prolamins are broken down, increasing starch digestibility (Artuzo et al., 2019; Bueno et al., 2020).

The rehydration process usually consists of adding water to the ground dry corn grain, and after reaching the desired moisture, the material must be ensiled under anaerobic conditions (Pereira et al., 2021). Despite satisfactory results, some authors observed that corn grain silages rehydrated with water presented fermentation problems, with low aerobic stability after silo opening (Arcari et al., 2016; Ferraretto et al., 2018). The addition of additives to improve the fermentation characteristics of these silages can promote improvements in the fermentation process and the quality of the wet grain silage.

Cactus pear, due to its high moisture content, can be a source of rehydration for grain silage, considering that it has desirable nutritional characteristics for animal nutrition and high-water content (Costa et al., 2017). Studies show that through the formation of a hydrocolloid called mucilage, cactus pear, in addition to providing nutrients, triggers heterolactic fermentation, sufficient to inhibit the development of spoilage microorganisms in the silo (Toit et al., 2018; Mokoboki et al., 2016; Pereira et al., 2021). Therefore, we proposed using cactus pear as a humidifying additive in the rehydration of corn for finishing lambs in the Brazilian semi-arid region.

Cactus pear still contains buffering compounds, which prevent a rapid drop in pH, making the consumption of soluble carbohydrates gradual and not accentuated (Basso et al., 2014; Carvalho et al., 2014), improving the silage fermentation profile.

Therefore, our hypothesis suggests that rehydration of ground corn grain silage with cactus pear versus water can significantly enhance the availability of starch and energy in the animals' diet, while also providing an essential water supply, particularly valuable in semi-arid regions. The presence of fermentable acids in forage cactus plays a important role in promoting a beneficial fermentation profile of the silage, thereby contributing to its preservation when compared to water.

Furthermore, another hypothesis posits that the rehydration process of corn grain, whether with water or forage cactus, facilitates increased availability and digestibility of starch, owing to the fermentative processes involved, because it provides extra protein and carbohydrates and Lactobacillus sp. The inclusion of forage cactus as an additive to moisten corn grain in the animals' diet may promote better performance efficiency, alongside improvements in nitrogen balance parameters in the organism, resulting in heightened dietary energy availability and facilitating starch utilization. This approach aimed at achieving a desirable heterolactic fermentation profile in silage not only helps mitigate adverse effects in the corn ensiling process, such as the formation of molds that can be responsible for aerobic deterioration, but also extends the shelf life of the silage in the feeding trough.

Thus, our objective was to investigate the impact of including water and cactus pear as additives for rehydrating corn grain in the diet of feedlot lambs, assessing their effects on intake, nutrient digestibility, animal performance, nitrogen balance, and serum parameters.

2. Materials and methods

2.1. Ethical principles of experimentation and experimental site

This study was conducted in strict compliance with the Brazilian legislation for research and experimentation with animals and was approved by the Committee of Ethics in the Use of Animals of the Federal University of Paraiba (Protocol nº 8681210920/2020). The experiment was carried out on a private property located in the municipality of São José dos Cordeiros, state of Paraíba, located in the Borborema mesoregion and in the Western Cariri microregion, Brazil. The climate of the region of Cariri in the state of Paraíba is semi-arid, BSh, according to the Köppen classification (Alvares et al., 2013), with an average annual rainfall of around 551.7 mm, distributed between the months of February and June, and with an average annual temperature of 23.0 °C.

The material was ensiled to contain 60% dry matter (DM) for both corn grain silage rehydrated with water and corn grain silage rehydrated with cactus pear. For this purpose, samples of cactus pear cladodes were previously collected to determine the DM of the plant, as well as samples of corn grains according to (AOAC, 2016), protocol 934.01.

The ground corn used in the three treatments came from the same commercial batch, with a particle size of 3 mm on average. Two additives were used to rehydrate the ground corn grain: water and cactus pear. Ensiling corn grain with water, corn was rehydrated using a watering can. The ratio used was 470 mL water to rehydrate one kilogram of ground corn grain.

The cactus pear used was the variety Mexican elephant ear (*Opuntia* spp) with 2 years of age. For ensiling corn grain with cactus pear, the ratio used was 375 g cactus pear per 625 g of ground corn grain. The cactus pear was chopped in a stationary forage machine (PP-35, Pinheiro Máquinas, Itapira, São Paulo, Brazil) to approximately 2.0 cm and mixed with ground corn to be ensiled. Silages were homogenized and packed in plastic bags with a capacity of 100 kg, the material was compacted to reach a specific density of approximately 850 kg/m^3. At the end of this process, silos were sealed and stored at room temperature in a covered, dry, and ventilated place until opening, 60 days later.

2.2. Animals and dietary treatments

The experimental period lasted 60 days, with 15 days for adaptation to diets and facilities, and 45 days of confinement for evaluation and data collection. Experimental animals were thirty male intact lambs, mixed breed, with an average initial weight of 22.57 ± 4.29 kg, housed in individual stalls, provided with feeders and drinkers. Before the onset of the experiment, all animals were identified, weighed and dewormed against endo and ectoparasites and vaccinated against clostridiosis.

Animals were distributed in a completely randomized design, with three treatments and 10 replicates. The treatments consisted of different forms of corn in the diet: diet containing ground dry corn grain (CG; Control); diet containing corn grain silage rehydrated with water (CW) and diet containing corn grain silage rehydrated with cactus pear (CCP). The other components of the diet consisted of sorghum silage, soybean meal, urea, ammonium chloride, and mineral premix. The diets were formulated to be isonitrogen and isoenergetic according to the NRC (2007) for lambs with an average weight of 22 kg and an average daily gain of 200 g/animal/day (Tables 1 and 2).

Diets were provided twice a day, at 8:00 a.m. and 2:00 p.m, in equal proportions. The diets were adjusted by collecting and weighing refusals daily before the first supply of the day, establishing up to 10% refusals of the total offered. The intake of dry matter and nutrients was estimated

Table 1
Chemical composition of the ingredients of the experimental diets on a dry matter basis.

Ingredients Item (g/kg)	Sorghum silage	Ground corn	Soybean meal	Cactus pear
Dry matter[1]	248.0	910.0	905.0	91.5
Ash	59.5	15.7	64.8	116.3
Organic matter	940.5	984.3	935.2	883.7
Crude protein	50.0	98.0	424.0	80.0
Ether extract	33.9	40.7	17.1	19.3
NDFap[2]	585.0	152.1	112.2	157.8
ADFap[3]	355.0	14.9	82.1	78.6
Non-fiber carbohydrates	271.6	693.5	38.19	626.6
Total carbohydrates	856.6	845.6	49.41	784.4
Digestibility (% DM)	55.0	80.0	90.0	60.0
Metabolizable Energy (Mcal/kg DM)	2.50	2.29	2.7	3.91

Dry matter, on natural matter; 2Neutral detergent fiber corrected for ash and protein; 3Acid detergent fiber corrected for ash and protein.

Table 2
Proportion of ingredients and composition of experimental diets, on a dry matter (DM) basis.

Ingredients (g/kg)	Diets		
	CG[1]	CW[2]	CCP[3]
Sorghum silage	387.24	386.70	403.16
Ground dry corn	434.08	0.00	0.00
Corn silage rehydrated with water	0.00	433.63	0.00
Corn silage rehydrated with cactus pear	0.00	0.00	453.63
Soybean meal	115.26	115.16	112.17
Cactus pear	32.53	32.48	0.00
Urea	4.85	6.13	5.81
Ammonium chloride	11.74	11.69	11.36
Mineral core[4]	14.29	14.20	13.88
Item (g/kg)			
Dry matter[5]	391.81	359.14	396.15
Ash	61.04	61.94	61.12
Crude Protein	124.26	124.25	124.39
Non-fiber carbohydrates	578.93	604.69	577.37
NDFap[6]	264.73	239.16	266.52
Ether extract	32.77	32.81	30.72
Starch (%)	63.65	60.50	65.60
Metabolizable Energy (Mcal/kg DM)	2.29	2.60	2.68

[1]dry corn grain; [2] corn grain silage rehydrated with water; [3]corn grain silage rehydrated with cactus pear. 4mineral core composition: Calcium (min.) 110.00 g/kg Calcium (max.) 135.00 g/kg, Phosphorus 87.00 g/kg, Sulfur 8.00 g/kg, Sodium 147.00 g/kg, Cobalt 15.00 mg/kg, Copper 590.00 mg/kg, Chromium 20.00 mg/kg, Iodine 50.00 mg/kg, Manganese 2000.00 mg/kg, Molybdenum 300.00 mg/kg, Selenium 20.00 mg/kg, Zinc 3800.00 mg/kg, Fluorine (max.) 870.00 mg/kg. 5 On a natural matter basis; 6 neutral detergent soluble fiber corrected for ash and protein. Non-fibrous carbohydrates (NFC) according to Hall (2000): NFC g/kg = 1000 - NDFap + (CP - CPu + U) where: NDFap = neutral detergent fibre corrected for ash and protein, CPu = urea content of CP, U = urea content.

by the difference between the amount present in the feed supplied daily and the refusals of the following day.

2.3. Nutrient intake and digestibility

The intake of dry matter and nutrients was estimated by the difference between the amount present in the feed supplied daily and the refusals of the following day. To determine digestibility, samples of the diets provided were taken, in addition to refusals and feces during the seven days that each animal remained in the individual folds. Fecal samples were taken directly from the rectal ampulla during the last three days of the collection period, being day 5 (06:00 a.m and 14:00 p.m), day 6 (08:00 a.m and 16:00 p.m) and day 7 (10:00 a.m and 18:00 p.m) following the methodology of (Bispo et al., 2007).

The ingredients, refusals, and 2 mm particle-sized feces were packed in synthetic non-woven textile bags (100 g/m^2), measuring 50 × 50 mm^2, with an approximate porosity of 50 µm. The bags were sealed and incubated in the bovine rumen for 288 h. After the incubation period, the samples were removed and washed with room temperature water until the final rinse was clear. The amount of excreted fecal dry matter, used to determine apparent nutrient digestibility and total digestible nutrient (TDN) content, was estimated from the iNDF concentration obtained after in situ incubation of feed, leftovers, and feces in triplicate. The samples were then dried in a forced ventilation oven at 55 °C for 72 h. Following this process, the samples were washed in a neutral detergent solution according to the methodology described by Detmann et al. 2012, to determine the indigestible fraction of neutral detergent fiber (iNDF) using the following formula.

•FDMP = indicator consumption (kg) / indicator concentration in feces (%)

The digestibility of nutrients and total digestible nutrients (TDN) were determined. The digestibility coefficients (DC) of DM, organic matter (OM), CP, EE, NDF, NFC were calculated using the following equation:

• DC = [(amount ingested - amount excreted) / (amount ingested)] × 100

To estimate the total digestible nutrients (TDN) content, the equation proposed by Weiss (1999). TDN = CPd + EEd* 2.25 + NFCd + NDFapd, where CPd = (ingested crude protein – fecal crude protein), EEd = (ingested extract ethero - fecal EE), NFCd = (ingested NFC - fecal NFC) and NDFcpd = (ingested NDFap – fecal NDFap).

2.4. Nitrogen (N) balance

Spot urine was collected on day 32th, 33th, 33th, 35th, 36th of the experimental period, four hours after the morning meal, during spontaneous urination, using collection bags (adapted colostomy bags, 65 mm) attached to the animals. After, the sample from each animal was filtered and weighed. Aliquots of 10 mL were taken and immediately diluted in 40 mL 0.036 N sulfuric acid (Valadares et al., 1999). After quantifying nitrogen in urine using the Kjeldahl method, similar to the analysis performed on diet and fecal samples, nitrogen balance was determined. The following equations were used to calculate balance: N absorbed = N ingested − N fecal; N retained = N ingested − (fecal N + urinary N). These values were expressed in g/day.

2.5. Blood metabolites

Blood samples were drawn four hours after the morning meal on the 38th experimental day. Blood was collected in 7 mL vacuum tubes by jugular venipuncture after disinfection with iodine alcohol. After collection, samples were immediately centrifuged at 2500 rpm for 15 min (Centrífuga Fanem Ltda Baby I, Mod. 206. Av. General Ataliba Leonel 1790, São Paulo, SP, Brazil) and the supernatant was separated in an Eppendorf tube of 1.50 mL, which was stored at − 20 °C for subsequent analysis of glucose and urea in a biochemical analyzer (Thermo Scientific Genesys 10 S Vis. USA) with a multiple wavelength photometer. The tests were performed using commercial kits (Labtest).

2.6. Growth performance

Animals were weighed weekly to monitor their nutritional status. On day 1 (initial body weight) and on day 45 (final body weight) of the experimental period, animals were fasted for solids for 16 h, before weighing. Daily weight gain was evaluated as the difference between final and initial weight and divided by the number of days in the feedlot.

Feed efficiency was calculated by dividing the average daily gain by the average DM intake of each animal. Data on the intake of dry matter and other nutrients were obtained by averaging the records of food offered and refusals, and the collection of samples of diets and refusals, throughout the experimental period.

2.7. Chemical analysis

The leftover samples, ingredients, and feces were pre-dried at 55 °C for 72 h and ground using a 1 mm sieve in a Wiley-type knife mill (Tecnal, Piracicaba City, State of São Paulo, Brazil) for additional laboratory analysis of dry matter (DM; method 934.01), crude protein (CP; method 954.01), ether extract (EE; method 920.39), ash (method 942.05), and lignin (method 973.18) according to AOAC (2016) procedures. The Van Soest et al. (1991) methodology was employed to determine neutral (NDF) and acid (ADF) detergent fiber using an ANKOM 200 fiber analyzer (ANKOM Technology Corporation, Fairport, NY, USA).

The starch content of the feces was determined through titration using the Machado et al. (2011). NDF and ADF contents were corrected for ash and protein (NDFap and ADFap) according to Licitra et al. (1996) and Mertens (2002). To estimate non-fiber carbohydrates (NFC), the equation recommended by Hall (2000) was used, in which:

• NFC g/kg = 1000 - NDFap + (CP - CPu + U)

where: NDFap = neutral detergent fibre corrected for ash and protein, CPu = urea content of CP, U = urea content where: CPu = CP content from urea (or mixture of urea and ammonium sulfate); U = urea content.

The value of total digestible nutrients (TDN) was determined using the equation proposed by Weiss (1999): TDN intake = (CP intake – leftover CP) + 2.25 × (EE intake – leftover EE) + (NDF intake – NDF in feces) + (NFC intake – NFC in feces). To estimate total carbohydrates (TC), the equation proposed by Sniffen et al. (1992), in which, TC = 100 – (%CP + %EE + %Ashes). TDN = (TDN intake / DM intake*100) calculated according to methodology Sniffen et al. (1992).

Dietary ME values were calculated using the formula proposed by the NRC (2007), considering that 1 kg TDN is equal to 4.409 Mcal digestible energy (DE) and 1 Mcal DE equals 0.82 Mcal of metabolizable energy (ME).

2.8. Statistical analysis

Data were tested by analysis of variance and analyzed using the MIXED procedure of SAS, version 9.3 (SAS Inst. Inc., Cary, NC). Means were compared by Tukey's test, considering a 5% probability, adjusting to the statistical model below:

$$Yij = \mu + Ti + eij$$

Where:Yij = nutrient intake and digestibility, performance, nitrogen balance, ruminal and blood parameters; μ = overall mean common to all observations; Ti = diet effect (CG; CW and CCP); eij = random residual error.

3. Results

There were no significant differences in dry matter and nutrient intake among animals fed different corn grain treatments. However, a notable variation was observed in ME intake, with an average intake of 2.01 Mcal/day (Table 3). A significant difference in DM digestibility (P = 0.0148) was evident, with the CCP diet demonstrating higher digestibility compared to the GC diet (Table 4).

Diets containing CG exhibited lower digestibility of OM (P = 0.0032), TCHOT (P = 0.0027), and TDN (P = 0.0134) in contrast to diets containing corn grain silages CW and CCP. Fecal starch concentration was elevated in animals consuming CG, while animals fed CW displayed the lowest fecal starch concentration (P < 0.0001). Conversely, no significant differences were observed in digestibility between different diets for CP (P = 0.0905), NDF (P = 0.1512), and NFC (P = 0.1433).

There were no significant differences in any of the nitrogen balance parameters among animals fed diets containing ground corn or rehydrated corn grain silages (Table 5). However, a statistical distinction emerged for plasma glucose levels, with animals on CW diets displaying higher blood glucose concentrations (46.67 mg/dL) compared to those on CG diets (37.00 mg/dL).

Additionally, there were no significant differences in initial body weight (P = 0.7405) and final body weight (P = 0.3051) (Table 6). Nevertheless, total weight gain, daily weight gain, and feed efficiency exhibited variation, with higher averages observed in animals fed the CW diet, followed by the CCP diet.

Table 3
Intake of nutrients of lambs fed diets containing rehydrated corn grain silages.

Variables	Experimental diets			SEM[12]	P-Value[13]
	CG[1]	CW[2]	CCP[3]		
Intake per body weight (%)	3.02	2.99	3.01	0.11	0.644
Dry matter	851.85	839.00	844.12	25.28	0.958
Organic matter	793.12	780.00	799.89	22.49	0.872
Ash	138.35	141.90	128.41	6.68	0.363
Crude protein	139.77	148.61	134.20	7.23	0.428
Ether extract	31.81	36.08	31.62	1.62	0.331
NDFap	238.84	272.30	246.60	11.36	0.510
Non-fiber carbohydrates	440.00	493.00	414.50	21.79	0.253
Total carbohydrates	650.00	693.00	652.00	24.31	0.609
Metabolizable Energy (Mcal/kg DM)	2.29b	2.51ab	2.57a	0.05	0.020

[1]diet containing dry corn grain; [2] diet containing corn grain silage rehydrated with water; [3]diet containing corn grain silage rehydrated with cactus pear. *Neutral detergent fiber with thermolabile amylase corrected for ash; 12SEM=Standard error of the mean; 13Value of probability; a and b differ from each other (P < 0.05) by Tukey's test.

Table 4
Digestibility coefficient of nutrients of lambs fed diets containing rehydrated corn grain silages.

Variables (g/100 g of ingested)	Experimental diets			SEM[12]	P-Value[13]
	CG[1]	CW[2]	CCP[3]		
Dry matter	59.22b	63.97ab	66.83a	1.33	0.0148
Organic matter	60.04b	68.04a	69.27a	1.36	0.0032
Crude protein	89.21	89.95	89.10	1.69	0.0905
Ether extract	72.08	81.11	76.55	1.56	0.0621
Neutral detergent fiber	18.93	35.71	37.14	3.97	0.1512
Non-fiber carbohydrates	86.52	89.17	92.13	1.06	0.1433
Total carbohydrates	61.76b	69.24a	70.24a	1.34	0.0027
TDN†	72.85b	81.61a	86.30a	0.82	0.0134
Fecal starch	38.56a	30.350c	33.330b	3.34	< 0.0001

[1]diet containing dry corn grain; [2] diet containing corn grain silage rehydrated with water; [3]diet containing corn grain silage rehydrated with cactus pear; †Total digestible of nutrients; 12SEM=Standard error of the mean; 13Value of probability; a and b differ from each other (P < 0.05) by Tukey's test.

4. Discussion

4.1. Nutrient intake

The lack of effect on the intake of DM and nutrients (OM, Ash, CP, EE, NDF, NFC, TC, and TDN) of animals on ground dry corn and rehydrated corn can be explained by the similarity in the composition of the experimental diets (Table 2). The diets were prepared to contain the same amount of corn and similar chemical compositions.

The CP intake of the animals on all diets was higher than the CP requirement (101 g/day) estimated according to the NRC (2007) for sheep weighing 20 kg and daily weight gain of 200 g (Table 3). However, the energy intake of all diets was lower than estimated by the NRC (2007) for this animal category (2.87 Mcal/kg DM). On the other hand, the higher concentration of energy in the diets containing CW and CCP allowed the animals to achieve the recommended daily weight gain (Table 6).

Table 5
Nitrogen balance and blood metabolites content of lambs fed diets containing rehydrated corn grain silages.

Variables	Experimental diets			SEM[12]	P-Value[13]
	CG[1]	CW[2]	CCP[3]		
Urinary N excretion (g/day)	0.54	0.39	0.45	0.04	0.3798
Fecal N excretion (g/day)	2.35	2.55	2.30	0.05	0.1651
Ingested N (g/day)	22.21	25.38	21.12	1.28	0.2003
Absorbed N (g/day)	19.86	22.83	18.82	1.28	0.2485
Retained N (g/day)	19.32	22.44	18.37	1.28	0.2241
Plasma glucose, mg/dL	37.00b	38.67ab	46.67a	2.17	0.0177
Plasma urea N, mg/dL	21.17	20.33	21.33	0.67	0.8237

[1]diet containing dry corn grain; [2]diet containing corn grain silage rehydrated with water; [3]diet containing corn grain silage rehydrated with cactus pear. [12]SEM=Standard error of the mean; [13]Value of probability; a and b differ from each other (P < 0.05) by Tukey's test.

Table 6
Performance of lambs fed diets containing rehydrated corn grain silages.

Variables	Experimental diets			SEM[12]	P-Value[13]
	CG[1]	CW[2]	CCP[3]		
Initial body (kg)	22.82	22.22	21.62	0.63	0.7405
Final body (kg)	28.85	31.61	30.42	0.73	0.3051
Total weight gain (kg)	6.03b	9.39a	8.81a	0.41	0.0004
Daily weight gain (g)	133.91b	209.00a	195.69a	6.76	0.0004
Feeding efficiency	0,157b	0.249a	0.231a	7.01	0.0006

1diet containing dry corn grain; [2]diet containing corn grain silage rehydrated with water; [3]diet containing corn grain silage rehydrated with cactus pear. [12]SEM=Standard error of the mean; [13]Value of probability; a and b differ from each other ($P < 0.05$) by Tukey's test.

4.2. Digestibility

The greater digestibility of OM and TC for diets containing corn rehydrated with water or cactus pear, positively interfered with the available energy for the animal, possibly due to the hydrolysis of prolamins, promoting the reduction in vitreousness of the corn grain. Arcari et al. (2016) observed that lower vitreousness makes grains more accessible to rumen bacteria and improves nutrient digestibility.

In the same sense, the higher DM digestibility for animals fed CCP compared to animals fed CG was related to better fermentation of corn in the silo with the use of cactus pear than water. Several studies have shown that the use of cactus pear as a source of rehydration, promoted better results in the fermentation profile of the silages, preserving the soluble carbohydrates of the corn grain, in addition to reducing DM losses and reducing the proliferation of fungi and yeasts, which are responsible for the lower productive performance of animals in addition to silage spoilage (Basso et al., 2014; Carvalho et al., 2014; Silva et al., 2017).

Another positive point in using cactus pear as a source of rehydration is that in regions where water is scarce, such as arid and semi-arid regions, this forage is characterized as an adapted plant, with good production rates and high-water content (Bispo et al., 2007; Costa et al., 2017). Furthermore, unlike rehydration with water, cactus pear provides nutrients that are increased in the diet. Nevertheless, when hydrating corn with cactus pear, part of the corn DM is replaced by cactus pear, which despite decreasing the cost per kg of DM in the diet, decreases the concentration of NFC and increases the concentration of NDF (Table 2).

The grain ensiling process increases the breakdown of the protein matrix surrounding the starch in the grain, which allows for an increase in starch availability. Therefore, diets based on ensiled grains have a larger area exposed to enzymatic action by ruminal microorganisms compared to diets based on dry grains (Bueno et al., 2020), which provides greater availability of energy for animal metabolism, resulting in greater weight gain in animals fed diets containing rehydrated grain. This is proven by animals fed rehydrated corn that showed lower levels of starch in their feces, as a result of greater utilization of starch by animal metabolism (Table 3).

4.3. Performance

Lambs fed with the CW and CPP diets showed significantly higher average daily gains, as well as better feed efficiency coefficients. This was largely attributed to the higher energy intake in these diets. Furthermore, improved digestibility, especially through corn rehydration, combined with similar nutrient intake observed in lambs consuming these diets, facilitated a greater influx of nutrients and energy for animal metabolism. As a result of these factors, there was an overall increase in feed efficiency and, ultimately, a significantly higher weight gain when compared to animals fed diets containing CG (Table 6).

4.4. Nitrogen (N) balance and blood parameters

As the ensiling process breaks down the protein matrix that coats the starch, there may be changes in nitrogen balance in animals fed diets containing rehydrated corn grain silages. Although no difference was detected in nitrogen balance, the values obtained indicate that animals were in constant metabolism of nitrogen compounds (NRC, 2007).

Considering that urine nitrogen is derived from protein degraded in the rumen by bacterial metabolism, while fecal nitrogen is derived from indigestible protein not degraded in the rumen, the lack of effect of different diets on urinary and fecal N excretion demonstrates that there was no excess CP and no imbalance between protein degraded in the rumen and digestible OM.

The values found here for plasma urea concentrations are within the reference range for healthy lambs (15.62 mg/dL to 42.05 mg/dL) (Werner et al., 2004). Values within the normal range of plasma urea indicate that the diet was efficient in synchronizing protein and energy (Van Soest, 1994).

The elevated plasma glucose level in the CCP diet (46.67 mg/dL), in contrast to the CW diet (37 mg/dL), signifies the higher presence of starch available in the CCP diet, as detailed in Tables 1 and 2. Unlike water, cactus pear contains starch in its composition, which suggests a potential increase in hepatic gluconeogenesis and energy availability, accompanied by a reduction in urea concentrations in urine. Therefore, when rehydrating corn with cactus pear, there is an augmentation in the starch content of the diet, leading to an overall increase in energy intake. In addition, because cactus pear has characteristics that favor better fermentation and preservation of corn grain silage, also reduces losses from starch hydrolysis during fermentation in the silo (Mokoboki et al., 2016).

Thus, the use of rehydrated corn grain silages was more efficient in terms of energy intake, nutrient digestibility (DM, OM, EE, TCHOT and TDN), animal performance (total weight gain; daily weight gain and feed efficiency) and plasma metabolites (plasma glucose) than a conventional diet with ground corn.

Thus, the alternative of using cactus pear for corn grain rehydration in regions that cultivate this cactus is viable and can bring benefits to sheep farming. Among the benefits are: when using cactus pear to replace water, part of the corn is replaced with this forage, taking into account the energy provided by the food, reducing the cost per kilogram of rehydrated corn, without, however, decreasing the nutritional value of the food; lower losses during fermentation in the silo and; animals consuming CW and CCP had similar and superior performances to animals consuming CG.

5. Conclusion

The supply of corn rehydrated with water or cactus pear results in better performance of feedlot lambs compared to the inclusion of ground dry corn in the diet. Cactus pear can be a good alternative in regions of water scarcity, improving fermentation and partially replacing corn grain in lamb diets.

Declaration of Competing Interest

None.

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