Performance, eating behavior and carcass characteristics of feedlot lambs fed diets without forage containing sodium bicarbonate

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Performance, eating behavior and carcass characteristics of feedlot lambs fed diets without forage containing sodium bicarbonate

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ABSTRACT

The study was carried out to evaluate the effect of inclusion of sodium bicarbonate (SB) in diets based on ground corn without forage for feedlot lambs. Twenty-eight ram lambs (Dorper x Santa Inês), with initial body weight of 30.2 ± 4.5 kg and 94 ± 8.4 days old were used. They were assigned to a randomized complete block design. Experimental diets were positive control, diet without forage containing soybeans hulls replacing ground flint corn in 400g/kg of dry matter (DM) (CONT); and three diets without forage based on ground flint corn containing 10 (10SB), 20 (20SB) or 30 (30SB) g/kg DM of SB. The inclusion of SB quadratically increased final body weight ($P = 0.02$), dry matter intake (DMI; $P < 0.01$), average daily gain ($P < 0.01$), feed eficiency ($P < 0.01$), slaughter body weight ($P = 0.02$), hot and cold carcass weight ($P = 0.02$), loin muscle area ($P = 0.05$), leg compacity index ($P = 0.05$) and the weights of: neck ($P = 0.01$), shoulder ($P = 0.02$), rib ($P = 0.03$) and leg ($P = 0.01$), with higher values for the 20SB. Feeding SB linearly decreased the area ($P < 0.01$) and height ($P = 0.01$) of the papillae. The use of SB improved the performance and increased hot and cold carcass weights, with better results observed in the 20 g/kg level (20SB), showing to be efficient in diets without forage for feedlot lambs.

Key words: high-concentrate diets, confinement, slaughter, corn,

1. Introduction

Sheep meat is a protein source of high nutritional value and can contribute to meet increasing demand for animal protein. Lamb meat production chain faces the challenge of forage production seasonality, which results in oscillation of quantity and quality of the forage, resulting in impaired animal growth and perfomanceas, as well as the carcass and meat quality. Aiming to increase performance of animals for early slaughter, the use of diets with a high proportion of concentrate has been more frequent (Gastaldello Júnior et al., 2010; Ferreira et al., 2011a; Polizel et al., 2016), since these diets are an alternative to provide higher average daily gain (ADG) and shortening time necessary for finishing animals (Parente et al., 2016).

However, high concentrate diets are a challenge due to the high proportion of fermentable carbohydrates available and low fiber, which can reduce ruminal pH and contribute to the development of rumen lesions and formation of liver abscesses (Jensen et al., 1954), compromising animal performance. The addition of buffers, like sodium bicarbonate, to these diets helps to prevent fluctuations in ruminal pH, favoring microbial growth and animal performance (Santra et al., 2003). Information regarding the effect of adding sodium bicarbonate in high concentrate diets is still controversial. Sen et al. (2006) reported an increased slaughter weight of lambs finished with high concentrate diets, and Santra et al. (2003) reported greater ADG and total body weight gain for sodium bicarbonate fed group. On the other hand, Gastaldello Júnior et al. (2010) found no effect of feeding sodium bicarbonate in high concentrate diets for feedlot lambs.

Diets without forage for feedlot lambs is still a recent topic, and to the best of our knowledge, there are no studies reporting the combinate use of diets without forage associated with sodium bicarbonate, since the studies found used some roughage source (Sen et al., 2006; Kawas et al., 2007; Gastaldello Júnior et al., 2010; Supratman et al., 2018). Therefore, this study is important, as it aims to define the best dose of sodium bicarbonate to be used in diets without forage for finishing lambs.

2. Material and methods

This study was carried out at the facilities of Sheep and Goats Intensive Production System (SIPOC) of Animal Sciences Department, “Luiz de Queiroz” College of Agriculture, São Paulo University, located in Piracicaba, São Paulo (22°42′24″ S and 47°37′53″ W), Brazil. The research protocol was reviewed and approved by the Animal Care and Use Committee at the same institution (number 8846110320).

2.1 Animals and Housing

Twenty-eight Dorper x Santa Inês ram lambs (30.2 ± 0.8 kg of body weight (BW) and 94 ± 1.6 d old) were individually alloted to 28 indoor pens with a concrete floor, feed bunk and waterer, protected from direct sunlight and rain. At the onset of the experiment, animals were dewormed with 1 mL/10 kg of 5% levamisole hydrochloride (Ripercol® L, Zoetis Indústria de Produtos Veterinários Ltda., Campinas, São Paulo, Brasil).

2.2 Experimental Design and Diets

Animals were assigned in a randomized complete block design with 7 blocks and 4 treatments. Each block was defined by BW and age at the beginning of the experiment. The experimental period consisted of an 84-d, with 3 periods of 28-d.

Experimental diets were: positive control, diet without forage containing soybeans hulls replacing ground flint corn in 400g/kg of dry matter (DM) (CONT); and three diets without forage based on ground flint corn containing 10 (10SB), 20 (20SB) or 30 (30SB) g/kg DM of sodium bicarbonate (SB). Diets were formulated using Small Ruminant Nutrition System (SRNS), presented on Table 1. Twenty-five milligrams of monensin (Rumensin200, Elanco Animal Health, Greenfield, USA) was added per kilogram of diet. Samples of diets and ingredients were frozen at -20 ºC for later analysis.

Corn was ground (without sieve) and the particle size distribution was >2.0mm = 26.9%, 2.0 to 0.51mm = 29.8%, 0.51 to 0.42mm = 21.1%, 0.42 to 0.297mm = 5.8%, 0.297 to 0.18mm = 3.4% and <0.18mm = 13.0%. Total mixed ration was offer *ad libitum* everyday at 8h and adjustments were made when needed so that refused feed did not exceed 10% of daily intake.

Animals of all treatments started the experiment receiving their respective diets, however, they were subjected to an adaptation by restriction, with a progressive increase in the amount offered over the period until reaching *ad libitum* consumption, as follows: 1^{st} d: offer of total feed equivalent to 2.0% of the animal's BW; 2^{nd} d: offer of total feed equivalent to 2.4% of the animal's BW; 3^{rd} d: offer of total feed equivalent to 2.8% of the animal's BW; 4^{th} d: offer of total feed equivalent to 3.2% of the animal's BW; 5^{th} d: offer of total feed equivalent to 3.6% of the animal's BW; from the 6th d: offer of total ration to ensure *ad libitum* consumption.

The BW was recorded after a 16-h fast on d 0, 28, 56 and 84 of the experimental period to determine the ADG and feed efficiency (FE). At the end of each period, orts were recorded and composited by treatment, then a sample were frozen at -20 ºC for later analysis.

2.3 Eating behavior

Eating behavior observations were visually recorded every 5 min for 24 h on d 26, 54 and 82 of the feeding trial. One observer was used for each 3-h interval. The time spent with ingestion, rumination, chewing, leisure and water were determined in min/d. The time spent on each activity (expressed in min/d) was calculated by multiplying the number of observations by 5. The total chewing time was considered as the sum of the ingestion and rumination times (Weidner and Grant, 1994). Ingestion, rumination and chewing times were also expressed in min/g DM and min/g neutral detergent fiber (NDF) ingested.

2.4 Feces score

At the end of each period, the fecal score of each animal was evaluated for three consecutive days according to the methodology described by Dickson and Jolly (2011). Grades from 1 to 5 were assigned: 1 - uniformly shaped and rigid feces; 2 - slightly uneven and friable feces; 3 - uneven feces, forms a soft pile; 4 - pasty feces forms a loose pile; 5 - liquid feces, including diarrhea.

2.5 Gastrointestinal tract evaluation

After slaughter, animals were eviscerated and rumen compartment was isolated and a fragment of 1 cm² was collected from the ventral region of cranial sac of rumen. The evaluated macroscopic morphological variables were number of papillae/cm² of wall (NP), height, width and mean area of the papillae (MAP), absorptive surface area/cm² of wall (ASA) and percentage of papillae per absorptive surface area (% papillae/ASA). The absorptive surface area as well as the area and height of the papillae were measured using the ImageJ (image analysis software). The ASA in cm² was calculated as: $1+(NPxMAP)-(NPx0.002)$ where 1 represents 1 cm² of collected fragment and 0.002 is the estimated basal area of the papillae in cm². The area of the papillae, expressed as a percentage of ASA, was calculated as: $(NPxMAP)/(ASAx100)$ (Resende Junior et al., 2006; Pereira et al., 2020). The average number of papillae/cm² was evaluated as the number of papillae inserted in each fragment manually counted by 3 evaluators, where the final value was the average of the 3 counts.

The classification regarding lesions suggestive of ruminitis was performed by the longitudinal opening of the rumen, where the presence of lesions in the rumen epithelium was observed and classified according to Garcia Neto (2018) in type I, II, III, IV, V and VI injuries. Where I: adherent patches, II: erosive lesion with hemorrhage, III: pseudomembranous lesion with diphtheria membrane, IV: ulcerative, V: scar retraction, VI: adhered villi. The liver was separated and palpations and longitudinal cuts of the organ were performed. The classification was carried out according to Brown et al. (1975), with 0 = no abscess; A- = one or two small abscesses or remnants of abscess scars; A = two to four well-organized abscesses; A+ = one or more large abscesses or multiple small, active abscesses.

2.6 Slaughtering and carcass assessment

At the end of the 84-d feeding trial, all animals were slaughtered after a 16-h fast. The hot carcasses were weighed (HCW) and chilled at 4 °C for 24 hours, being weighed again to obtain the chilled carcass weight (CCW). The hot (HCY) and chilled (CCY) carcass yields and chilling loss (CL) were calculated by the formulas: $HCY = (HCW / BW)x100$; $CCY = (CCW / BW)x100$ and $CL = [(HCW - CCW) / HCW]x100$.

The carcass external length (CEL), leg perimeter (LP) and rump perimeter (RP) were measured in the chilled carcasses. Then the carcass was split into two identical longitudinal halves, between the 12th and 13th ribs on both sides of the carcass the marbling score (MS), subcutaneous fat thickness (SF) and body wall thickness (BWT) were evaluated using a digital caliper (Battery, model SR44) graduated in mm. The exposed face of the *Longissimus lumborum* muscle was drawn on acetate paper to obtain the longissimus muscle area (LMA). From the values obtained on the right and left sides of each carcass, the arithmetic mean of SF, BWT and LMA per carcass was calculated. Carcass internal length (CIL), chest depth (CD) and leg length (LL) were also measured. The carcass compactness index (CCI): $CCI = CCW / CIL$ and the leg compactness index (LCI): $LCI = legweight / LL$ were also determined (Cezar and Wandrick, 2007). The right half-carcass was weighed and separated into the following commercial cuts: neck, shoulder, skirt steak, rib, leg, tail and loin, which were weighed separately. The perirenal fat (PF) was also weighed.

2.7 Laboratory Analyses and Calculations

Feed, orts and ingredients samples were dried in a forced-air oven at 55 °C for 72 h, and ground with a Wiley mill (Marconi, Piracicaba, São Paulo, Brazil) to pass a 1-mm screen. The DM was determined by oven drying at 105 °C for 24 h, and organic matter (OM) was determined by difference after heating at 550

°C for 4 h (AOAC, 1990# 930.15 # 942.05). Nitrogen content was determined using a Leco FP528 combustion nitrogen analyzer (Leco Corporation, St. Joseph, MI, USA; AOAC, 1997# 990.03). NDF and acid detergent fiber (ADF) were determined using a Ankom 2000 (Ankom Tech. Corp., Fairport, NY, USA; AOAC, 1990; # 968.06), according to Van Soest et al. (1991), using heat-stable α-amylase and sodium sulfite. Ether extract (EE) was also measured according to AOAC (1990# 920.39) methods. Nonfiber carbohydrates (NFC) were estimated according to the following equation: $NFC = 100\% - (\%NDF + \%CP + \%EE = \%ash)$.

The particle size distribution of ingredients and diets was determined dry-sieving, by inserting 100-g samples in an oscillating sieve shaker (Produtest T Model, Telastem, São Paulo, Brazil) with sieves of 2.0, 0.51, 0.42, 0.297 e 0.18-mm pore sizes. The shaking time used was 5 min. Particle size distribuition of CONT, 10SB, 20SB and 30SB diets was, respectively, >2.0mm = 12.3, 30.3, 28.0 and 24.7%, 2.0 to 0.51mm = 34.4, 33.9, 29.2 and 31.0%, 0.51 to 0.42mm = 28.9, 17.7, 19.0 and 20.4%, 0.42 to 0.297mm = 7.4, 3.6, 5.6 and 4.6%, 0.297 to 0.18mm = 4.0, 2.5, 3.1 and 2.1% and <0.18mm = 13.0, 12.0, 15.1 and 17.2%. Particle size distribution of soybean hulls and soybean meal was, respectively, >2.0mm = 1.3 and 1.6%, 2.0 to 0.51mm = 54.0 and 44.5%, 0.51 to 0.42mm = 27.2 and 33.1%, 0.42 to 0.297mm = 5.8 and 7.5%, 0.297 to 0.18mm = 4.2 and 3.5% and <0.18mm = 7.5 and 9.8%.

2.8 Statistical Analyses

The data were analyzed using the MIXED procedure of SAS (9.4 version, 2018). For repeated measures over time, the model used was $Y = \mu + A_i + B_j + T_k + P_l + (TP)_{kl} + E_{ijkl}$ where μ= overall mean, A_i= animal effect (1 to 28), $B_{j=}$ block effect (1 to 7), T_k= treatment effect (1 to 4), P_l= period effect (1 to 3), $(TP)_{kl}$= interaction between treatment and period, E_{ijkl}= resiual error. For only measures, the model used was $Y = \mu + A_i + B_j + T_k + E_{ijk}$ where μ = overall mean, A_i = animal effect (1 to 28), $B_{j\,=}$ block effect (1 to 7), T_k = treatment effect (1 to 4), E_{ijk} = residual erro.

The averages were obtained using the comand LSMEANS. The effects of sodium bicarbonate levels on diets were evaluated using linear and quadratic orthogonal polynomials. One contrast was performed: CONT *vs.* diets containing sodium bicarbonate. The effects of period and interaction between treatments and periods were determined by the F test of the analysis of variance. Effects were declared significant when P ≤ 0.05.

3.Results

3.1. Performance

The performance of the animals was evaluated over three experimental periods. No interaction between treatments and experimental periods was observed for any of the variables evaluated.

The final body weight (FBW) had a quadratic response (P = 0.02) among SB levels, with highest value observed in the 20SB. Regarding the contrasts, there was no difference between the animals that received CONT or sodium bicarbonate. The DMI showed a quadratic response in kg/d (P < 0.01), % of BW (P = 0.01) and in g/kg of $BW^{0.75}$ (P = 0.02) according to SB levels, with highest value for 20SB. A higher DMI in kg/d, % BW and g/kg of $BW^{0.75}$ (P = 0.0001, P < 0.0001 and P < 0.0001, respectively) was observed for animals fed CONT when compared to those fed sodium bicarbonate (Table 2).

There was a quadratic effect (P < 0.01) on the ADG in response to SB levels, with highest value observed for 20SB. However, there was no difference between SB *vs*. CONT groups (Table 1). The FE also presented a quadratic response (P < 0.01) among SB levels, with higher value for animals that received 20SB.

3.2 Ingestive behavior

There was a quadratic effect (P < 0.01) of SB levels on DMI, with highest values for the animals that received 20SB. Furthermore, the DMI was higher for CONT compared to the SB groups (P < 0.0001; Table 3).

Animals fed CONT showed higher neutral detergent fiber consumption (NDFC) values compared to the SB groups (P < 0.001; Table 3). Among SB levels, there was no difference in NDFC.

The ingestion time in min/g of DM showed a quadratic response (P < 0.01) among SB levels, with lowest value for the animals that received 20SB. However, when CONT was compared to SB groups, there was no difference. The ingestion time in min/g of NDF did not differ between the levels of sodium bicarbonate, but it was lower for CONT compared to SB (P < 0.001), while ingestion in min/d did not differ (Table 3).

There was a negative linear association between SB levels and rumination time in min/d (P = 0.04) and in min/g of NDF (P = 0.03), with lower values for 30SB. Rumination time in min/g DM showed a quadratic response (P < 0.01), with lower values for animals that received 20SB. The rumination time in min/d was higher for the CONT compared to SB groups (P < 0.001), but when expressed in min/g of NDF it was smaller (P < 0.001) for CONT, with no difference in min/g of DM (Table 3).

There was a quadratic effect between SB levels in chewing time in min/d (P = 0.04), min/g DM (P < 0.001) and min/g NDF (P = 0.04), with lower values for animals that received 20SB. Chewing time in min/d was higher for CONT (P < 0.01) and in min/g of NDF was lower for CONT (P < 0.001) compared to SB groups. There was no effect for chewing time in min/g DM (Table 3). Water consumption and idle time did not differ between treatments.

3.3 Gastrointestinal tract

There was a linear effect of SB levels on the papillae area (P < 0.01) and height (P = 0.01), with lowest values for 30SB. No treatments effects were observed for any other gastrointestinal traits characteristics (Table 4). No liver abscesses were observed. Regarding the presence of lesions in the rumen epithelium, three animals had type F lesions, two animals from the 30SB and one from the CONT (data not shown).

3.4 Carcass characteristics

The SB level was quadratically associated with BW, HCW, CCW, LMA and CCI (P < 0.05) with higher values observed for 20SB (Table 5). The other carcass characteristics were not affected by the treatments. There was a difference between the FBW and slaughter body weight (SBW) of the animals due to a difference of four days between the end of the experimental period and the day of slaughter.

For the carcass cuts, there was a quadratic association between SB level and the neck (P = 0.01), shoulder (P = 0.02), rib (P = 0.03) and leg weight (P = 0.01), with higher values observed for animals that received 20SB (Table 6). The other carcass cuts were not affected by treatments.

When CONT was compared with SB groups, there was no difference in any of the analyzed variables.

4.Discussion

4.1. Performance

The quadratic response in the DMI could be explained by a higher rate of passage caused by the addition of sodium bicarbonate. Leventini et al. (1990) conducted two experiments with steers, evaluating inclusion of sodium sesquicarbonate and found greater DMI on metabolism trial and numerical improvement in DMI on performance trial with adition of the buffer and they attributed to increased rate of outflow of fluid and particulate matter from the rumen, which leads to a greater turn over of particles in the rumen, with a corresponding increase in DMI. Besides that, according to Leek and Harding (1975), chemoreceptors are located in the rumen and reticulum, whose activity depends on pH, suggesting that DMI decreases with the decrease of ruminal pH, which affects ruminal motility. Althoug not evaluated in the current study, we conducted another trial with the same treatments evaluating ruminal characteristics and we found a quadratic response on ruminal pH with the inclusion of SB (data not published yet), improving rumen health and DMI. Quadratic responses in consumption in g/d were also found by Tripathi et al. (2004) with 15 g of SB supplementation for feedlot lambs fed high concentrate diets. Kawas et al. (2007) also found an increase in DMI during days 31-60 with the supply of 5g/kg DM of sodium bicarbonate for feedlot lambs, however, when considering the entire experimental period, they found no difference in DMI. According to the authors, this lack of effect may be due to the type of diet, since 50% of the sorghum grain that was supplied was ground and the rest was fed whole, so mastication of the whole grain may have contributed to the additional salivation, which contains bicarbonate, reducing the beneficial effect of the added SB to the ration.

The 30SB level decreased the DMI and it is in agreement with the results of González et al. (2008). This lower DMI may be due to a reduction in the palatability of the diet caused by the presence of the buffer. Keunen et al. (2003) made available sodium bicarbonate continuously and freely for cows, but the daily consumption did not exceed 40 g and the NRC (2001) reccomends 0.6 to 0.8% of DMI (~200 g. d^{-1}) of buffer for dairy cows. They attributed this lower intake of sodium bicarbonate to its organoleptic properties, which would decrease palatability.

Soybean hulls has lower energy density compared to corn, with TDN of 77 and 88%, respectively (NRC, 2007), which would have contributed to the higher DMI of the CONT when compared to diets containing bicarbonate.

Between SB levels, the ADG was higher for the 20SB, which can be justified by the higher DMI. These results are in agreement with those observed by Tripathi et al. (2004). They also found higher ruminal pH for lambs fed diet containing SB, which contributed to higher DMI and ADG, corroborating with information from Leek and Harding (1975) presented before.

4.2 Ingestive behavior

In the assessment of ingestive behavior, as observed on the performance experiment, the greater DMI for CONT when compared to SB diets can be explained by the lower energy density of soybean hulls (TDN = 77%; NRC, 2007) while corn has TDN = 88% (NRC, 2007).

The highest NDFC by animals that received CONT diet was due to the higher amount of NDF of this diet. The rumination and chewing time expressed in min/d also differed between CONT and SB, being higher for CONT, which can be attributed to the higher NDF content of this treatment, since the rumination time is highly correlated ($r^2 = 0.96$) with the consumption of NDF (Welch and Hooper, 1988). The NDF content of food is one of the main factors that influence the ingestive behavior of animals, with lowers amounts of NDF and/or the smaller particle size, less time will be spent on chewing activity (feeding and rumination; Carvalho et al., 2014).

Among the three SB contents, the lowest times (min/g DM) in the activities of ingestion, chewing and rumination for the animals that received 20SB must be attributed to the higher DMI, with larger amounts of food consumed, less time is spent ruminating per unit of DM or fiber intake (Welch and Smith, 1969; Deswysen et al., 1987).

4.3 Gastrointestinal tract

The smaller area and height of the papillae for the 30SB can be attributed to the high level of concentrate of this type of diet, which may be related to the lesions found in the rumen epithelium of two animals of this treatment (data not shown). High concentrate diets have a large proportion of highly fermentable carbohydrates in the rumen, which can cause metabolic disorders such as acidosis (Krause and Oetzel, 2006), that can cause rumenitis. With large quantities of short chain fatty acids (SCFA) due to high concentrate diets, a parakeratosis can occur, which will lead to damages in to the ruminal wall (Nagaraja, 2000) and rupture the epithelium (Owens et al., 1998), causing the injuries and reducing the area and height of the papillae.

Devant et al. (2016) evaluated high concentrate diets with or without straw supplementation for Holstein bulls, when straw was not supplemented all rumen samples had papillae fusion, whereas only 16.7% of bulls fed with straw (in diet containing concentrate in pellet form).

A study carried out by Tavares et al. (2019) that evaluated the impact of high energy diets on the rumen enviroment in confined cattle also reported changes in the ruminal enviroment that caused lesions in the rumen mucosa, with inflammatory reaction of the papillary region of animals that received only concentrate.

4.4 Carcass characteristics

The higher ADG of 20SB resulted in higher slaughter weight and, consequentily, higher hot and cold carcass weight for the animals of this group, since carcass weight is directly related to slaughter weight

(Oliveira et al., 2018). The weights of neck, shoulder, rib and leg were directly related with the carcass weights, being higher for animals that received 20SB, which in turn produced heavier carcasses. With higher leg weight, CIL was also higher.

The greater LMA for the 20SB can be attributed to the higher loin weight, since weight of commercial cuts are influenced by slaughter weight (Garcia et al., 2010). Sen et al. (2006) also found higher SBW and higher LMA for animals that received SB in their diets in amounts of 7.5; 15 and 22.5 g/kg of DM.

The chilling loss (CL) is usually inversely correlated with subcutaneous fat thickness (SF) (Rodrigues et al., 2008), but in the present study there was no effect of treatments on SF, that explains the similarity between the CL, which had an average of 1.59%.

In conclusion, the use of sodium bicarbonate improved the performance and increased hot and cold carcass weights, with better results observed in the 20g/kg level (20SB), showing to be efficient in diets without forage for feedlot lambs.

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Animal Rights Declaration

I, Ana Carolina Silva Vicente, declare that the experiments were conducted in accordance with laws and regulations and approved by the Ethics Committee on the Use of Animals (CEUA / ESALQ), protocol Nº 8846110320.

Conflict of interest statement

None of the authors declare to have a conflict of interest.

Statements and Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Ethics Approval

This study was conduceted in accordance with laws and regulations and approved by the Ethics Committee on the Use of Animals (CEUA / ESALQ), protocol number 8846110320.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Data Availability

The datasets generated during and/or analysed during the current study are not publicly available because they are part of a master's thesis that has not yet been defended but are available from the corresponding author on reasonable request.

Code Availability

SAS (9.4 version, 2018) **RRID**: SCR_008567.

Author Contributions

All authors contributed to the study conception, design, data collection and analysis. The first draft of the manuscript was written by Ana Carolina Silva Vicente and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Table 1.

Ingredients and chemical composition of experimental diets (g/kg of DM)

	Treatments[1]			
Ingredients	CONT	10SB	20SB	30SB
Ground flint corn	451	840	830	819
Soybean meal	85	85	85	85
Soybean hulls	400	-	-	-
Mineral premix[2]	45	45	45	45
Urea	9	10	10	11
Cane molasses	10	10	10	10
Sodium Bicarbonate	-	10	20	30
Chemical composition				
Dry matter	946	944	943	943
Organic matter	937	945	947	937
Ash	63	55	53	63
Crude protein	162	169	170	163
Neutral detergent fiber	322	87	74	83
Acid detergent fiber	213	35	31	34
Non-fiber-carbohydrates	431	655	671	657
Ether extract	22	34	32	34

[1]CONT: positive control diet without forage containing soybeans hulls replacing ground flint corn in 400g/kg of DM; 10SB: diet without forage based on ground flint corn containing 10g/kg of SB; 20SB: diet without forage based on ground flint corn containing 20g/kg of SB; 30SB: diet without forage based on ground flint corn containing 30g/kg of SB.

[2]Mineral premix included: 34 g/kg P; 221 g/kg Ca; 65 g/kg Na; 15 g/kg Mg; 35 g/kg S; 110 ppm Cu; 22 ppm Co; 18 ppm Zn; 6 ppm Se; 25 ppm Rumensin200.

Table 2.

Effect of adding increasing levels of sodium bicarbonate in diets without forage on performance of feedlot lambs

Itens[4]	Treatments[1]				SEM[2]	Effect[3]				
	CONT	10SB	20SB	30SB		L	Q	SB*CONT	Per	Treat*Per
Initial age, d	91.7	96.0	90.3	97.8	1.59	-	-	-	-	-
IBW, kg	30.3	30.2	30.2	30.2	0.85	-	-	-	-	-
FBW, kg	51.1	46.1	52.8	46.4	1.29	0.93	0.02	0.27	-	-
DMI										
kg/d	1.349	1.019	1.228	1.022	0.03	0.96	<0.01	0.0001	0.01	0.93
% BW	3.07	2.58	2.82	2.58	0.05	0.94	0.01	<0.0001	<0.0001	0.82
g/kg of $BW^{0,75}$	78.79	63.28	70.89	64.66	1.45	0.69	0.02	<0.0001	<0.01	0.97
ADG	0.248	0.189	0.269	0.193	0.01	0.87	<0.001	0.13	<0.0001	0.40
FE, ADG/DMI	0.18	0.18	0.22	0.18	0.01	0.85	<0.01	0.10	<0.0001	0.10

[1]CONT: positive control diet without forage containing soybeans hulls replacing ground flint corn in 400g/kg of DM; 10SB: diet without forage based on ground flint corn containing 10g/kg of SB; 20SB: diet without forage based on ground flint corn containing 20g/kg of SB; 30SB: diet without forage based on ground flint corn containing 30g/kg of SB.

[2]SEM: Standard error of the mean.

[3]L: linear effect, Q: quadratic effect, SB*CONT: diets without forage based on ground flint corn containing sodium bicarbonate vs positive control diet without forage based on ground flint corn without sodium bicarbonate containing 400g/kg of soybean hulls replacing ground corn, Per: period effect, Trat*Per: interaction between treatment and period.

[4]BWI: initial body weight; FBW: final body weigth; DMI: dry matter intake; BW: body weight; ADG: average daily gain; FE: feed eficiency.

Table 3.

Effect of adding increasing levels of sodium bicarbonate in diets without forage on ingestive behavior of feedlot lambs

Iten[4]	Treatments[1]				SEM[2]	Effect[3]				
	CONT	10SB	20SB	30SB		L	Q	SB*CONT	Per	Treat*Per
DMI, kg/d	1.69	1.223	1.549	1.309	0.04	0.39	<0.01	<0.0001	0.66	0.37
NDFC, g/d	513.27	101.36	101.82	102.19	21.39	0.97	0.99	<0.001	0.80	0.89
Ingesting										
Min/d	139.76	147.86	130.00	140.24	4.38	0.53	0.19	0.97	0.91	0.89
Min/g DM	0.09	0.12	0.08	0.11	0.004	0.09	<0.01	0.08	0.56	0.82
Min/g NDF	0.30	1.51	1.30	1.38	0.07	0.26	0.15	<0.001	0.88	0.76
Ruminating										
Min/d	174.05	147.86	105.71	114.76	6.59	0.04	0.06	<0.001	0.0006	0.41
Min/g DM	0.11	0.12	0.07	0.09	0.005	0.008	<0.01	0.15	0.01	0.51
Min/g NDF	0.36	1.48	1.08	1.15	0.07	0.03	0.07	<0.001	0.01	0.47
Chewing										
Min/d	313.81	295.71	235.71	255.00	8.64	0.07	0.04	<0.01	0.02	0.82
Min/g DM	0.20	0.25	0.15	0.20	0.007	0.01	<0.001	0.88	0.10	0.73
Min/g NDF	0.65	3.00	2.38	2.53	0.12	0.03	0.04	<0.001	0.16	0.47

Idleness, min/d	9.52	26.43	8.81	11.42	4.39	0.23	0.35	0.55	0.33	0.42
Water, min/d	982.14	913.81	952.38	930.48	39.1	0.86	0.72	0.53	0.0001	0.95

[1]CONT: positive control diet without forage containing soybeans hulls replacing ground flint corn in 400g/kg of DM; 10SB: diet without forage based on ground flint corn containing 10g/kg of SB; 20SB: diet without forage based on ground flint corn containing 20g/kg of SB; 30SB: diet without forage based on ground flint corn containing 30g/kg of SB.

[2]SEM: Standard error of the mean.

[3]L: linear effect, Q: quadratic effect, SB*CONT: diets without forage based on ground flint corn containing sodium bicarbonate vs positive control diet without forage based on ground flint corn without sodium bicarbonate containing 400g/kg of soybean hulls replacing ground corn, Per: period effect, Trat*Per: interaction between treatment and period.

[4]DMI= dry matter intake; NDFC= NDF consumption.

Table 4.

Effect of adding increasing levels of sodium bicarbonate in diets without forage on ruminal morphology of feedlot lambs

Itens[4]	Treatments[1]				SEM[2]	Effect[3]		
	CONT	10SB	20SB	30SB		L	Q	SB*CONT
Number of papillae	56.74	64.40	67.67	67.43	2.94	0.72	0.80	0.17
Area of papillae, cm^2	0.21	0.30	0.22	0.20	0.01	<0.01	0.46	0.32
ASA, cm^2	12.85	19.27	16.09	14.5	0.92	0.06	0.70	0.07
% papillae/ASA	92.16	94.53	93.25	92.56	0.40	0.08	0.75	0.16
Height, cm	0.58	0.64	0.55	0.53	0.02	0.01	0.29	0.75
Width, cm	0.19	0.24	0.21	0.20	0.01	0.09	0.85	0.12

[1]CONT: positive control diet without forage containing soybeans hulls replacing ground flint corn in 400g/kg of DM; 10SB: diet without forage based on ground flint corn containing 10g/kg of SB; 20SB: diet without forage based on ground flint corn containing 20g/kg of SB; 30SB: diet without forage based on ground flint corn containing 30g/kg of SB.

[2]SEM: Standard error of the mean.

[3]L: linear effect, Q: quadratic effect, SB*CONT: diets without forage based on ground flint corn containing sodium bicarbonate vs positive control diet without forage based on ground flint corn without sodium bicarbonate containing 400g/kg of soybean hulls replacing ground corn.

[4]ASA: absorptive surface área/cm^2 of wall; %papillae/ASA: percentage of papillae per absorptive surface area, Height: average height of papillae, Width: average width of papillae.

Table 5.

Effect of adding increasing levels of sodium bicarbonate in diets without forage on carcass characteristics of feedlot lambs

Iten[4]	Treatments[1]				SEM[2]	Effect[3]		
	CONT	10SB	20SB	30SB		L	Q	SB*CONT
SBW, kg	52.47	46.70	53.21	47.46	1.25	0.78	0.02	0.14
HCW, kg	28.16	25.77	29.36	25.47	0.76	0.86	0.02	0.36
CCW, kg	27.70	25.34	28.91	25.07	0.75	0.87	0.02	0.36
HCY, %	53.59	55.04	55.11	53.69	0.43	0.26	0.47	0.30
CCY, %	52.72	54.12	54.28	52.85	0.43	0.28	0.44	0.28
CL, %	1.64	1.67	1.52	1.56	0.04	0.30	0.26	0.54
BWT, mm	22.45	22.17	24.34	22.15	0.95	0.99	0.37	0.84
SF, mm	3.74	3.74	4.31	3.39	0.34	0.66	0.28	0.91
MS	1.00	1.00	1.00	1.14	0.03	0.17	0.42	0.57
PF, kg	0.58	0.57	0.67	0.59	0.05	0.87	0.51	0.83

LMA, cm^2	18.04	16.78	18.17	16.62	0.31	0.84	0.05	0.21
LCI, kg/cm	0.11	0.11	0.12	0.11	0.002	0.78	0.05	0.91
CCI, kg/cm	0.40	0.38	0.42	0.42	0.01	0.34	0.45	0.81

[1]CONT: positive control diet without forage containing soybeans hulls replacing ground flint corn in 400g/kg of DM; 10SB: diet without forage based on ground flint corn containing 10g/kg of SB; 20SB: diet without forage based on ground flint corn containing 20g/kg of SB; 30SB: diet without forage based on ground flint corn containing 30g/kg of SB.

[2]SEM: Standard error of the mean.

[3]L: linear effect, Q: quadratic effect, SB*CONT: diets without forage based on ground flint corn containing sodium bicarbonate vs positive control diet without forage based on ground flint corn without sodium bicarbonate containing 400g/kg of soybean hulls replacing ground corn.

[4]SBW: slaughter body weight; HCW: hot carcass weight; CCW: cold carcass weight; HCY: hot carcass yield; CCY: cold carcass yield; CL: chilling loss; BWT: body wall thickness; SF: subcutaneous fat thickness; MS: marbling score; PF: perirenal fat; LMA: longissimus muscle area; LCI: leg compactness index; CCI: carcass compactness index.

Table 6.

Effect of adding increasing levels of sodium bicarbonate in diets without forage on cut weights of feedlot lambs

Cuts[4]	Treatments[1]				SEM[2]	Effect[3]		
	CONT	10SB	20SB	30SB		L	Q	SB*CONT
Neck								
kg	0.97	0.88	1.06	0.92	0.03	0.59	0.01	0.73
% CCW	3.52	3.47	3.67	3.66	0.07	0.30	0.49	0.60
Shoulder								
kg	2.46	2.16	2.46	2.16		0.99	0.02	0.08
% CCW	8.91	8.54	8.59	8.63	0.10	0.70	0.96	0.09
Rib								
kg	3.62	3.38	3.85	3.27	0.12	0.67	0.03	0.60
% CCW	13.04	13.3	13.22	13.05	0.13	0.44	0.87	0.58
Loin								
kg	1.06	0.90	1.07	0.95	0.03	0.53	0.07	0.26
% CCW	3.84	3.57	3.68	3.81	0.07	0.25	0.94	0.36
Leg								
kg	4.15	3.84	4.33	3.77	0.09	0.74	0.01	0.35

% CCW	15.03	15.2	15.1	15.02	0.14	0.63	0.98	0.80
Skirt steak								
kg	0.84	0.77	0.88	0.74	0.03	0.70	0.09	0.56
% CCW	3.01	3.02	3.00	2.95	0.06	0.67	0.94	0.91
Tail								
kg	0.16	0.14	0.15	0.14	0.01	0.79	0.65	0.48
% CCW	0.55	0.57	0.54	0.55	0.03	0.85	0.83	0.98

[1]CONT: positive control diet without forage containing soybeans hulls replacing ground flint corn in 400g/kg of DM; 10SB: diet without forage based on ground flint corn containing 10g/kg of SB; 20SB: diet without forage based on ground flint corn containing 20g/kg of SB; 30SB: diet without forage based on ground flint corn containing 30g/kg of SB.

[2]SEM: Standard error of the mean.

[3]L: linear effect, Q: quadratic effect, SB*CONT: diets without forage based on ground flint corn containing sodium bicarbonate vs positive control diet without forage based on ground flint corn without sodium bicarbonate containing 400g/kg of soybean hulls replacing ground corn.

[4]%CCW: Cuts expressed as a percentage of cold carcass.