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Performance and carcass traits of steers fed corn silage treated with propionic acid doses

Desempenho e características de carcaça de novilhos alimentados com silagem de milho tratadas com doses de ácido propiônico

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Highlights

Better feed conversion with the use of propionic acid in silage ($p=0.0225$).
Increased dry matter digestibility with treated silages ($p=0.0469$).
Greater gain in subcutaneous fat thickness in carcasses ($p=0.0155$).

Abstract

The objective was to evaluate the weight gain performance, dry matter (DM) intake, apparent DM digestibility, and carcass ultrasound characteristics of beef steers fed corn silage treated with different doses of propionic acid. The experiment was conducted at the Animal Production Center (NUPRAN) of the State University of Central-West (UNICENTRO), in Guarapuava, state of Paraná, Brazil. The experimental design was completely randomized, consisting of three treatments and five repetitions, with animals fed as follows: T1 – diet with untreated corn silage (control); T2 – diet with corn silage treated with 0.03%

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propionic acid based on natural matter (NM); and T3 – diet with corn silage treated with 0.06% propionic acid (NM). All diets contained 45% corn silage and 55% concentrate. Using corn silage for animal feed, with the addition of propionic acid, regardless of the dose used, improved feed conversion (6.16; 6.00 kg kg^{-1}) and resulted in greater total weight gain (81.3 kg) at the end of the experiment compared to the control silage (7.00 kg kg^{-1}; 71.9 kg). Using propionic acid increased apparent DM digestibility (72.22%; 71.91%) compared to the control diet (69.15%), in addition to greater preservation of soluble carbohydrates in the treated silages and better carcass finishing. Animal behavior was also affected, with a reduction in feeding time and frequency. Consequently, animals fed treated silages spent more time ruminating (p=0.0007). Including 0.03 to 0.06% propionic acid in the diet resulted in greater final weight, improved feed conversion, greater carcass fat finishing, increased apparent DM digestibility, and better preservation of soluble carbohydrates. Furthermore, it altered the feeding behavior by reducing feeding time and frequency while increasing rumination time.
Key words: Chemical additive. Carcass traits. Dry matter intake. Feed conversion. Dry matter digestibility. Weight gain.

Resumo

Objetivou-se avaliar a performance de ganho de peso, consumo de matéria seca (MS), digestibilidade aparente da MS e ultrassonografia de carcaça de novilhos de corte, alimentados com silagem de milho tratada com diferentes doses de ácido propiônico. O experimento foi realizado no Núcleo de Produção Animal (NUPRAN) na Universidade Estadual do Centro-Oeste (UNICENTRO), Guarapuava, Paraná, Brasil. O delineamento experimental foi o inteiramente casualizado, constituído de três tratamentos e cinco repetições, sendo animais alimentados com: T1 – dieta com silagem de milho controle; T2: dieta com silagem de milho tratada com 0,03% de ácido propiônico na matéria natural (MN); e T3: dieta com silagem de milho tratada com 0,06% de ácido propiônico na MN, nas proporções de 45% de silagem de milho e 55% de concentrado. A utilização de silagem de milho para alimentação dos animais, com adição de ácido propiônico, independente da dosagem utilizada, melhorou a conversão alimentar (6,16; 6,00 kg kg^{-1}) e obteve maior ganho de peso total ao final do experimento (81,3kg), comparadas a silagem controle (7,00 kg kg^{-1}; 71,9 kg). O uso do ácido propiônico promoveu aumento da digestibilidade aparente da matéria seca (72,22; 71,91%) em comparação com a dieta controle (69,15%), além da maior conservação de carboidratos solúveis nas silagens tratadas, o que por consequência, gerou maior acabamento das carcaças. O comportamento animal também foi alterado, com redução no tempo e na frequência de cocho, resultando em um maior tempo dedicado à ruminação (p=0,0007) nos animais alimentados com silagens tratadas. A inclusão de 0,03 a 0,06% de ácido propiônico na dieta proporcionou maior peso final dos animais, melhor conversão alimentar, maior acabamento de gordura de carcaça, aumento na digestibilidade aparente da matéria seca e melhor conservação dos carboidratos solúveis. Além disso, modificou o comportamento alimentar, reduzindo o tempo e a frequência de alimentação e aumentando o tempo de ruminação.
Palavras-chave: Aditivo químico. Características da carcaça. Consumo de matéria seca. Conversão alimentar. Digestibilidade da matéria seca. Ganho de peso.

Introduction

The use of preserved feed is a common strategy in intensive livestock systems because it ensures that the animals' nutritional requirements are met and provides a consistent diet throughout the year. Corn silage preservation is optimized by anaerobic bacteria that transform soluble carbohydrates into organic acids, which reduces the pH and inhibits undesirable microorganisms (Velho et al., 2007; Bernardes & Rêgo, 2014; W. F. G. Ribas et al., 2021b).

However, the fermentation process involves several factors, from preparation to closing the silos and stabilizing the ensiled material. Poor execution can lead to losses during ensiling. Once the silo is opened, silage can become unstable due to the growth and proliferation of different microorganisms in aerobic environments. This results in nutrient consumption and an increase in pH, compromising the nutritional quality of the feed and consequently reducing animal performance (Borreani & Tabacco, 2010).

Using additives based on propionic acid (PA) has proven quite effective in maintaining silage quality. Although PA is produced naturally in small quantities in silage, adding more PA can help reduce the pH of the ensiled mass and create an environment that is unfavorable for the development of undesirable microorganisms. This process is essential for ensuring the quality and durability of the silage during storage (Arthur, 2019).

PA also stands out as an effective additive due to its antifungal properties. PA inhibits the growth of spoilage fungi and bacteria, preserving nutritional quality and improving aerobic stability during storage (Rutenberg et al., 2016). These characteristics ensure that the silage maintains its palatability and nutritional value over time, preventing deterioration that could reduce the productive potential of animals and increase production costs (Pino et al., 2018).

The objective of the present study was to evaluate the weight gain performance, dry matter intake, apparent DM digestibility, carcass characteristics, and ingestive behavior of beef steers in the pre-finishing phase that were fed corn silage treated with different doses of propionic acid (PA). We hypothesized that adding propionic acid to corn silage improves the digestibility and feed conversion of feedlot steers, resulting in greater weight gain, better carcass finishing, and greater acceptance of silages in the feed bunk.

Material and Methods

The experimental procedures were previously submitted to and approved by the Ethics Committee on Animal Research (CEUA/UNICENTRO) for execution under official letter no. 046/2023.

This study aimed to evaluate the weight gain performance, dry matter intake, apparent DM digestibility, carcass traits, and ingestive behavior of beef steers in the pre-finishing phase that were fed corn silage treated with different doses of PA: T1 – control; T2 – diet with corn silage treated with 300 mL t^{-1} PA (0.03% in NM); and T3 – diet with corn silage treated with 600 mL t^{-1} PA (0.06% in NM).

Experimental site

The experiment was conducted at the State University of Central-West (UNICENTRO), in Guarapuava, state of Paraná, Brazil (25°23′36″ S, 51°27′19″ W, at an altitude of 1,100 m). According to the Köppen classification, the region has a humid subtropical mesothermal climate (Cfb), with cool summers and moderate winters and no dry season.

The corn crop was planted in October 2022, using the early-cycle hybrid P 3565 PWU (Corteva Agriscience® company, Pioneer®) for grain and silage production. This hybrid has hard-textured grains and PowerCore® ULTRA technology. The material was harvested 140 days after plant emergence, at the initial hard grain phenological stage (R4 - R5).

The material harvested from the field in February 2023 was transported and deposited in a level, well-drained location. It was then manually compacted to obtain 170 kg of dry matter (DM) m^{3-1} in trench silos with the following dimensions: 1.0 m wide, 0.9 m high, and 8 m long. The silos were completely sealed and covered with 200-µm double-sided tarpaulin. Thus, 12 silos were made based on the evaluated treatments, each with an approximate capacity of 4,200 kg of original material.

Propionic acid (PA) was manually applied according to the evaluated doses during corn silage production. The additive was applied using a manual pressure sprayer to ensure uniform coverage of the material. To ensure homogeneous application, each 30-kg portion of chopped corn plants was arranged in thin layers, mixed manually after the additive was applied, and then placed in the silo. The layers were gradually and continuously compacted until the silo was completely filled and sealed. The average ensiling time for each experimental silo was approximately one hour.

The product used was Fungifree L5® from Safeeds Nutrição Animal Ltda. (Cascavel, Paraná, Brazil). It is classified as a preservative additive that prevents the growth of fungi and yeasts in feed and ingredients during storage. Its composition includes PA (550 g kg^{-1}), soy lecithin, sodium hydroxide (50 g kg^{-1}), polyoxyethylene (20) sorbitan monooleate (Polysorbate 80), and a vehicle with a pH between 2.0 and 2.5.

The planned evaluations in the experiment began 64 days after the silos were opened. The feed-out period of the experimental silos occurred over 51 days of feeding the animals in confinement, with an average daily removal of 15 cm from the silo face.

Animals

Thirty half-blood Angus Nellore steers (intact males) from the same herd were used. The animals had an average initial weight of 345.1 ± 2.2 kg, an average age of 11 ± 1 months, and had been previously dewormed. The steers were housed in 15 semi-covered feedlot pens, each measuring 15 m^2 (2.5 m × 6.0 m). Each pen had a concrete feeder measuring 2.30 m long, 0.60 m wide, and 0.35 m deep, as well as a metal waterer regulated by a float.

Animals were distributed into experimental units based on body weight (BW), ribeye area (REA), marbling score, and rump-cap fat thickness (RFT). These measurements were taken using an Aloka®

SSD-500 Vet ultrasound machine with a 17 cm, 3.5 MHz probe. The experimental design was completely randomized with three treatments and five repetitions. Each pen containing two animals was considered an experimental unit, and the average performance of the animals in each pen was used in the statistical analyses.

Evaluations

The experimental period lasted 61 days. There was a 10-day adaptation period with a control silage from the same crop and harvest time as the others. Then, there were 51 evaluation days, which were divided into three periods of 17 days each. The animals were fed twice a day, at 06h30 and 17h30. Voluntary feed intake was recorded daily by weighing the amount offered and the leftovers from the previous day. Daily intake adjustments were made to maintain 5% leftovers of the total dry matter (DM) provided.

The feed was provided as a total mixed ration (TMR). The diets consisted of 45% corn silage and 55% concentrate, on a dry matter basis, based on Valadares Filho et al. (2016), for crossbred animals aiming for gains of 1.5 kg day^{-1}.

The concentrate was produced at the commercial feed mill of the Cooperativa Agrária (Guarapuava, Paraná, Brazil), formulated with soybean meal, corn, corn germ, wheat bran, soybean hulls, malt rootlets, calcitic limestone, dicalcium phosphate, livestock urea, common salt, and a vitamin and mineral premix. It is presented as pellets. The concentrate presented average contents of 892.9 g kg^{-1} DM, 81.0 g kg^{-1} mineral matter (MM), 161.3 g kg^{-1} crude protein (CP), 39.2 g kg^{-1} ether extract (EE), 386.4 g kg^{-1} starch, 268.3 g kg^{-1} neutral detergent fiber (NDF), 96.0 g kg^{-1} acid detergent fiber (ADF), 13.6 g kg^{-1} lignin (LIG), 813.4 g kg^{-1} total digestible nutrients (TDN), 12.4 g kg^{-1} calcium (Ca) and 4.7 g kg^{-1} phosphorus (P). The premix contained the following guaranteed levels per kilogram of concentrate: 14,000 IU vitamin A, 1,800 IU vitamin D3, 75 IU vitamin E, 0.70 g sulfur (S), 0.12 g magnesium (Mg), 3.0 g sodium (Na), 1.0 mg cobalt (Co), 18 mg copper (Cu), 1.1 mg iodine (I), 29.0 mg manganese (Mn), 0.35 mg selenium (Se), 72.2 mg zinc (Zn), and 40 mg monensin sodium.

During the feedlot period, samples were collected every seven days to create composite samples of the diets and silages for determining their chemical compositions (Table 1). The samples were dried in a forced-air oven at 55 °C for 72 hours and ground in a Wiley mill using a 1 mm diameter sieve. Dry matter (DM), crude protein (CP), mineral matter (MM), and ether extract (EE) analyses were performed according to the Association of Official Analytical Chemists [AOAC] (1995) techniques. The neutral detergent fiber (NDF) and lignin contents were obtained using the method of Van Soest et al. (1991), which employs thermostable α-amylase. The acid detergent fiber (ADF) content was determined according to the method of Goering and Van Soest (1970). Total digestible nutrients (TDN) were estimated according to Weiss et al. (1992). Starch analysis was based on the hydrolysis of the starch present in the sample, as described by Hendrix (1993). Soluble carbohydrates were initially extracted by successive washes with 80% alcohol. Then, a colorimetric analysis of reducing sugars (glucose) was performed, and the results were converted into starch content.

Table 1
Chemical characterization of silages and experimental diets

Parameter	Doses of propionic acid		
	Control	0.03% (NM)	0.06% (NM)
Corn silage treated with PA doses			
Dry matter (g kg^{-1} NM)	290.2	291.1	289.9
Mineral matter (g kg^{-1} DM)	39.5	41.9	41.9
Crude protein (g kg^{-1} DM)	65.5	73.4	75.9
Ether extract (g kg^{-1} DM)	29.5	29.1	29.4
Starch (g kg^{-1} DM)	348.2	342.1	336.6
Neutral detergent fiber (g kg^{-1} DM)	464.6	460.9	465.4
Acid detergent fiber (g kg^{-1} DM)	314.6	308.7	306.0
Lignin (g kg^{-1} DM)	47.9	46.8	44.5
Total digestible nutrientes (g kg^{-1})	658.2	662.3	664.2
Silage particle size			
Top sieve >1.9 cm (%)	8.96	8.47	7.74
Medium sieve <0.78 cm, vegetative portion (%)	43.93	44.80	44.69
Medium sieve <0.78 cm, grain portion (%)	11.58	11.12	11.65
Lower sieve <0.78 cm (%)	35.53	35.61	35.95
Experimental diets			
Dry matter (g kg^{-1} NM)	621.7	622.1	621.6
Mineral matter (g kg^{-1} DM)	62.4	63.5	63.5
Crude protein (g kg^{-1} DM)	118.2	121.7	122.9
Ether extract (g kg^{-1} DM)	34.8	34.7	34.8
Starch (g kg^{-1} DM)	369.2	366.5	364.0
Neutral detergent fiber (g kg^{-1} DM)	356.7	355.0	357.0
Acid detergent fiber (g kg^{-1} DM)	194.4	191.7	190.5
Lignin (g kg^{-1} DM)	29.0	28.5	27.5
Total digestible nutrientes (g kg^{-1})	743.6	745.4	746.3

The animals were weighed at the beginning of the adaptation period and on days 0, 17, 34, and at the end of the experiment, after fasting for solids for 12 hours, to determine their average daily gain (ADG). Diets and leftovers were weighed daily to determine DM intake, expressed in kg day^{-1} (DMI) or as a percentage of body weight (DMI, BW%). The ADG and DMI data were then used to calculate the feed conversion ratio (FCR).

The analysis of ingestive behavior and apparent DM digestibility followed methodologies similar to those used by Heker et al. (2018), Neumann et al. (2020), and T. M. B. Ribas et al. (2021a). This analysis was carried out during the middle phase of the experiment for 96 consecutive hours, beginning at 12h00 on the first day and ending at 12h00 on the final evaluation day. Five previously trained observers conducted observations per shift for 96 hours, with shifts every six hours and readings taken at regular three-minute intervals. Data on ingestive behavior, represented by resting, rumination, drinking, and feeding activities, were expressed in hours day^{-1}. Frequencies of feeding, drinking, urinating, defecating, and non-ingestive oral behavior (NIO) activities, expressed as the number of times day^{-1}, were also determined. During the night, the environment remained under artificial lighting, a condition to which the animals had been subjected since their arrival at the feedlot.

During the analysis of ingestive behavior, the apparent DM digestibility (ADMD) of the diet was also determined. To do so, composite samples of the diets from each treatment were collected over the course of the experiment. Food samples were collected once a day for four consecutive days and stored in a freezer at -15 °C. After evaluation, the samples were thawed and homogenized to form a composite sample per pen and treatment.

The daily feed intake and leftovers over four consecutive days were measured, as well as the total amount of feces produced by the animals in each pen. During the ADMD trial, a homogeneous sample of the feces produced was collected and stored under refrigeration at six-hour intervals. The weight of the fecal sample collected at each six-hour interval was proportional to the total volume of feces produced during that interval. At the end of the evaluation, the homogenized samples were used to determine dry matter (DM) and fecal pH.

The DM of the leftovers and feces from each experimental unit was determined using the same procedures adopted in the diet analysis. The fecal pH was measured according to the methodology established by Cherney and Cherney (2003).

ADMD was calculated by the difference between the dry matter ingested and excreted. This value was then divided by the dry matter ingested and multiplied by 100 to express the result as a percentage using the following formula:

$$ADMD\ (\%) = [(\text{ingested DM} - \text{excreted DM}) / \text{ingested DM}] \times 100$$

During the experiment, the fecal score of each pen was analyzed daily, based on the methodology adapted from Looper et al. (2001) and Ferreira et al. (2013). These scores range from 1 to 5: 1 = watery feces, not very consistent; 2 = liquid feces, not very consistent, with small piles up to 2.5 cm; 3 = intermediate feces with concentric rings and pile between 3 and 4 cm (considered ideal); 4 = slightly liquid feces with concentric rings and a pile of more than 5 cm; and 5 = hardened or dry feces.

The qualitative score of the feed leftovers was evaluated daily and graded according to the proportion of silage to concentrate in the feed bunk. This was done through visual observation aided by an informative booklet with photos, classified on scales ranging from 1 to 5, being: 1 – 65% silage and 35% concentrate; 2 - 55% silage and 45% concentrate; 3 - 45% silage and 55% concentrate (ideal); 4 - 35% silage and 65% concentrate; and 5 - 25% silage and 75% concentrate.

At the end of the experimental period, assessments of the ribeye area (REA), marbling, ratio, subcutaneous fat thickness (EGS) of the *longissimus dorsi* muscle, and steak fat thickness (EGP) were performed using equipment consisting of an echo camera (Aloka® SSD-500 Vet) coupled to a 17 cm, 3.5 MHz probe. Measurements were taken between the 12th and 13th ribs, transversely to the *longissimus dorsi* muscle, following the recommendations of Herring et al. (1994). From the REA measurements, the ratio was calculated, which represents the relationship between its height and width. The images were interpreted by the laboratory responsible for data quality assurance (Designer Genes Technology) using the "BIA/DGT Brasil" software. Marbling was assessed by the presence of fat pads between the muscle fibers in the longissimus dorsi muscle, and scored using a scale ranging from 1 (nonexistent) to 5 (excessive), adapted from the system proposed by Müller (1987).

The ruminal degradation rate of the evaluated corn silages was estimated using the in situ technique, using nylon bags measuring 12 cm x 8 cm, with 50 µm pores containing 5 g of dry sample ground to 1 mm (Nocek, 1988), which were incubated in reverse chronological order at times 0, 2, 4, 6, 12, 24, 36, 48, 72, and 96 hours. Two male cattle with rumen cannulas were used for this purpose.

A first-order kinetic model was used to estimate the ruminal degradation parameters from the DM degradation rates at different incubation times, using non-linear regression with the Gauss-Newton method. The DM degradation parameters were estimated using the exponential equation proposed by Ørskov and McDonald (1979).

$$DegDM = a + b\ (1 - e - ct)$$

where: DegDM: fraction degraded at time "t" (%); "a": fraction that disappears quickly (t = 0); "b": potentially degradable fraction (%); "c": degradation rate (h^{-1}).

Effective degradability (ED) of DM was calculated using the Ørskov and McDonald (1979) equation:

$$EDDM = a + b \times [c / (c + k)]$$

Where "k" represents the ruminal passage rate, which is considered at 2%, 5%, and 8% h^{-1}, representing low, medium, and high concentrate intake, respectively.

The UNIVARIATE procedure was applied to identify outliers. Then, the data regarding performance, ADMD, and carcass traits were tested by ANOVA using the MIXED procedure (Statistical Analysis System Institute [SAS Institute], 1993), adopting a significance level of 5% ($P \leq 0.05$). Values from 5% to 10% ($P>0.05$ to $P\leq0.10$) were considered as a trend.

The experimental design was completely randomized with five repetitions. Data collected for each variable were analyzed using ANOVA and compared by Tukey's test at a 5% significance level, using SAS Institute (1993).

The analysis of each variable for the parameters related to animal performance and carcass traits followed this statistical model:

$$Yijk = \mu + \alpha i + \varepsilon ij$$

Where: Yijk = dependent variables; µ = overall mean of all observations; α_i = effect of the silage treatment of order "i", where 1 = control diet (no acid); 2 = diet with corn silage treated with 0.03% PA in NM; and 3 = diet with corn silage treated with 0.06% PA in NM, and ε_{ij} = residual random effect.

Results

As shown in Table 2, there were no differences in ADG (P = 0.1895). The values were 1.594 kg day^{-1} in animals fed silage treated with PA, regardless of the dose, and 1.410 kg day^{-1} in animals of the control group. Total dry matter intake and dry matter intake relative to body weight were not influenced by the addition of propionic acid (P > 0.05).

Table 2
Productive performance of steers in pre-feedlot fed diets containing corn silage treated or not with propionic acid

Parameter	Doses of propionic acid			Mean	SEM	Prob.
	Control	0.03% (NM)	0.06% (NM)			
Average daily gain (kg day^{-1})						
0 to 17 days	1.312	1.394	1.388	1.365	41.80	0.8898
0 to 34 days	1.450	1.591	1.571	1.537	69.05	0.6784
0 to 51 days	1.410	1.594	1.594	1.533	42.83	0.1895
Dry matter intake (kg day^{-1})						
0 to 17 days	9.17	8.96	9.18	9.11	0.17	0.8359
0 to 34 days	9.37	9.07	8.95	9.13	0.16	0.5815
0 to 51 days	9.49	9.19	8.98	9.22	0.16	0.4780
Dry matter intake by body weight (% body weight)						
0 to 17 days	2.56	2.53	2.57	2.55	0.04	0.8707
0 to 34 days	2.50	2.45	2.45	2.47	0.03	0.7359
0 to 51 days	2.44	2.38	2.36	2.39	0.03	0.4813
Feed conversion: DMI: ADG (kg kg^{-1})						
0 to 17 days	7.40	6.60	6.73	6.91	0.28	0.4504
0 to 34 days	7.03	6.27	6.16	6.49	0.15	0.1114
0 to 51 days	7.00 a	6.16 b	6.00 b	6.39	0.22	0.0225
Feed bunk score						
0 to 17 days	3.00	3.00	3.00	3.00	0.11	0.9251
0 to 34 days	3.02	2.94	2.82	2.93	0.09	0.9834
0 to 51 days	3.25	3.18	3.16	3.20	0.10	0.9886
Fecal score						
0 to 17 days	3.01	2.96	2.96	2.98	0.03	0.6204
0 to 34 days	3.02	2.96	3.01	3.00	0.03	0.1725
0 to 51 days	3.06	3.01	3.03	3.03	0.02	0.7393

Means followed by different letters in the same row differ from each other by Tukey's test at 5%.
SEM: Standard error of the mean; Prob.: Probability.

For FCR, animals fed silage treated with PA achieved better conversion (P<0.05) in the period from 0 to 51 days: 6.00 kg kg^{-1} for the 0.06% PA and 6.16 kg kg^{-1} for the 0.03% PA compared to the control with an FCR of 7.00 kg kg^{-1}.

No differences (P>0.05) were detected for feed bunk and fecal scores during the trial conducted with steers in the pre-feedlot phase.

Table 3 shows that fecal output (kg day^{-1}) in natural matter, DM, fecal score, and pH were not affected (P>0.05) by the different doses of PA used in the treatment of corn silages. Small numerical differences observed in fecal production and its dry matter content ratio promoted a significant difference when the feces were corrected for DM. The control group exhibited an average DM value of 17.16%, compared to 16.32% for the treatment with 0.03% PA. The 0.06% treatment did not differ significantly from either, presenting 16.71% DM.

Table 3
Fecal output on a natural or dry matter basis, fecal DM content, and apparent DM digestibility of diets of steers fed corn silage treated or not with different doses of propionic acid

Parameter	Doses of propionic acid			Mean	SEM	Prob.
	Control	0.03% (NM)	0.06% (NM)			
Feces (kg NM day^{-1})	16.82	15.86	15.14	15.94	0.44	0.3416
Fecal DM (%)	17.16 a	16.32 b	16.71 ab	16.73	0.11	0.0448
Feces (kg DM day^{-1})	2.88	2.59	2.52	2.66	0.07	0.1344
Fecal score	2.95	2.84	2.89	2.90	0.03	0.2940
Fecal pH	8.12	8.03	8.11	8.09	0.06	0.8141
ADMD (%)	69.15 b	72.22 a	71.95 a	71.11	0.46	0.0469

Means followed by different letters in the same row differ from each other by Tukey's test at 5%.
SEM: Standard error of the mean; Prob.: Probability.

For ADMD, the best results (P<0.05) were observed in the treatments with PA. The silage with 0.03% PA inclusion showed 72.22%, followed by 71.95% with 0.06% PA. The control treatment showed a lower ADMD at 69.15%.

The addition of PA to corn silage influenced the in situ dry matter degradation kinetics (P<0.05, Table 4). The "a" fraction exhibited greater degradation in silages treated with 0.03% and 0.06% PA (32.76% and 33.18%, respectively) compared to the control silage (30.57%). As for the degradation rate per hour ("c"), the silage treated with 0.03% exhibited the highest rate (0.0325%), while the silage treated with 0.06% showed the lowest (0.0200%). The control silage did not differ from these, with a rate of 0.0225%.

Table 4
In situ ruminal dry matter degradation kinetics of corn silage treated or not with doses of propionic acid

Parameter	Doses of propionic acid			Mean	SEM	Prob.
	Control	0.03% (NM)	0.06% (NM)			
a (% DM)	30.57 b	32.76 a	33.18 a	32.17	0.23	0.0059
b (% DM)	27.25	24.10	27.39	26.25	0.81	0.2960
c, hour^{-1}	0.0225 ab	0.0325 a	0.0200 b	0.03	0.01	0.0442
i (% DM)	42.19	43.13	39.42	41.58	0.80	0.2650
DP (% DM)	57.80	56.87	60.57	58.42	0.78	0.2650
DE, 2% hour^{-1}	43.61 b	46.79 a	45.92 a	45.44	0.24	0.0028
DE, 5% hour^{-1}	38.27 b	41.58 a	40.85 a	40.09	0.21	0.0003
DE, 8% hour^{-1}	36.06 b	39.22 a	38.06 a	37.84	0.20	0.0002

Means followed by different letters in the same row differ from each other by Tukey's test at 5%. The parameters are defined as follows: "a" is the highly degradable fraction; "b" is the potentially degradable fraction; "c" is the degradation rate per hour; "i" is the indigestible fraction. The abbreviations used are: PD (potential degradability); ED (effective degradability), considering passage rates of digesta at 2%, 5%, and 8% per hour, which represent, respectively, low, medium, and high concentrate intake; and SEM: Standard error of the mean.

Regarding fractions "b", "i", and potential degradation no differences were observed between treatments. For ED with estimated passage rates of 2%, 5%, and 8%, silages treated with PA showed greater degradation, regardless of dose, compared to control silage.

Table 5 lists the data regarding the average weights of animals fed silages treated or not with a dose of PA and their respective carcass traits, where animals fed silages treated with PA tended to gain more weight during confinement (81.3 kg) than the control group (71.9 kg), resulting in an additional gain of 9.4 kg with the PA treatment.

Table 5

Performance and carcass ultrasound of steers in the pre-feedlot phase receiving diets with silages treated or not with doses of propionic acid

Parameter	Doses of propionic acid			Mean	SEM	Prob.
	Control	0.03% (NM)	0.06% (NM)			
Initial weight (kg)	346.9	342.9	345.4	345.1	2.73	0.8355
Final weight (kg)	418.8	424.2	426.7	423.2	4.71	0.0890
Gain (kg)	71.9	81.3	81.3	78.1	0.81	0.0755
At the end:						
. REA	80.84	81.14	82.41	81.46	1.17	0.8461
. Ratio	0.55	0.54	0.53	0.54	0.01	0.8454
. Marbling	3.13	3.22	3.31	3.22	0.06	0.4798
. SFT (mm)	5.75	6.33	6.53	6.20	0.19	0.0658
. RFT (mm)	8.35 b	9.24 a	9.14 a	8.91	0.27	0.0355
Gain in pre-finishing:						
. REA	17.76	19.26	19.61	18.88	1.17	0.7960
. Ratio	0.04	0.04	0.05	0.04	0.01	0.9916
. Marbling	0.39	0.47	0.58	0.48	0.02	0.7391
. SFT (mm)	1.93 b	2.53 a	2.66 a	2.37	0.10	0.0155
. RFT (mm)	3.04 b	3.99 a	3.84 a	3.62	0.10	0.0217

Means followed by different letters in the same row differ from each other by Tukey's test at 5%, and values between 5% and 10% were considered a trend.
REA: Ribeye area; SFT: Subcutaneous fat thickness; RFT: Rump-cap fat thickness
SEM: Standard error of the mean; Prob.: Probability.

No differences were found in carcass traits, including ribeye area, ratio and marbling, between treatments at the end of the experiment. However, for subcutaneous (SFT) and rump-cap (RFT) fat thickness parameters, animals fed silages containing PA obtained higher results than the control treatment: 2.66 mm and 2.53 mm for 0.06% PA and 0.03% PA, respectively, compared to 1.93 mm for the control. Similar patterns emerged for RFT: treatments with 0.03% PA and 0.06% PA achieved gains of 3.99 mm and 3.84 mm, respectively, compared to 3.04 mm for the control treatment.

Table 6 lists ingestive behavior data related to feeding and drinking activities and the frequency of access to the feed bunk and drinking fountain, expressed in hours day^{-1} and number of times day^{-1}.

Animals fed the control silage diet spent more (P<0.05) time feeding (2.81 hours day^{-1}) and visited the feed bunk more frequently (16.6 times day^{-1}), compared to animals fed diets containing PA-treated silage (2.50 hours day^{-1} and 13.6 visits day^{-1}, on average).

In addition, animals fed silages with PA exhibited longer rumination times (P<0.05), with an average of 5.37 hours day^{-1}, compared to the 4.73 hours day^{-1} observed in the control group.

Table 6
Ingestive behavior of steers in the pre-feedlot phase receiving diets containing corn silage treated or not with doses of propionic acid

Parameter	Doses of propionic acid			Mean	SEM	Prob.
	Control	0.03% (NM)	0.06% (NM)			
Hours day^{-1}:						
Feeding	2.81 a	2.46 b	2.53 b	2.60	0.11	0.0215
Drinking	0.21 a	0.22 a	0.29 a	0.24	0.01	0.4884
Ruminating	4.73 b	5.38 a	5.36 a	5.16	0.11	0.0007
Idling	16.24	15.94	15.82	16.00	0.17	0.6091
Times day^{-1}:						
Feeding	16.6 a	13.6 b	13.6 b	14.6	0.62	0.0411
Drinking	4.8	6.0	6.2	5.7	0.28	0.3849
Defecation	6.8	7.3	7.4	7.2	0.38	0.7925
Urination	5.5	5.1	5.3	5.3	0.26	0.8667
NIOB	4.0	3.5	3.4	3.7	0.25	0.8525

Means followed by different letters in the same row differ from each other by Tukey's test at 5%. NIOB: Non-ingestive oral behavior; SEM: Standard error of the mean; Prob.: Probability.

Discussion

Using additives that inhibit undesirable fermentation when the silo is sealed and promote the aerobic stability of preserved feed results in lower nutrient loss when the feed is exposed to oxygen, thus preserving its nutritional value (Bernardes et al., 2013). When added to the ensiled mass at harvest time, propionic acid (PA) inhibits the development of aerobic microorganisms, mainly yeasts and fungi, from harvest to silo sealing, even in the absence of initial forage fermentation (Pedroso et al., 2007; Arthur, 2019).

Higher ADMD was observed in animals fed silages treated with PA, possibly due to greater preservation of soluble carbohydrates or crude protein. These processes result in better utilization of forage nutrients by animals, leading to greater feed digestibility (Rutenberg et al., 2016; Neumann et al., 2018). The higher ADMD may be related to the fact that feeds with high nutrient concentration, higher energy density, and high digestibility reduce dry matter intake, as described by Pino et al. (2018). This occurs because these feeds provide more energy and promote more efficient digestion, allowing animals to meet their nutritional requirements with lower intake and increasing feed efficiency while reducing production costs.

Propionic acid (PA) effectively controls secondary fermentation and improves the aerobic stability of preserved foods after exposure to O_2 (Kung et al., 2000). This allows for greater nutrient preservation and a higher concentration of digestible components. Consequently, there is better silage digestibility and greater feed efficiency in animals that consume the treated material, regardless of the dose, compared to those that receive untreated silage.

The low dry matter content (< 30%) during ensiling, combined with the anaerobic environment of the material, can favor the growth of microorganisms responsible for secondary fermentation, such as Clostridium bacteria. Adding propionic acid to silages modulates fermentation and limits the growth of proteolytic bacteria because PA reduces pH and inhibits microbial growth during the initial aerobic phase (Kung et al., 2018).

This process preserves more nitrogen, enabling more true protein to reach the rumen for efficient degradation (Muck et al., 2018). In the rumen, protein degradation produces ammonia nitrogen, which serves as a substrate for the growth of rumen microorganisms. This microbial growth increases fiber digestibility, resulting in greater efficiency in the use of dietary nutrients by animals (Kozloski, 2017).

Regarding degradation kinetics, the higher rate observed for fraction "a" — corresponding to the portion of the feed that disappears rapidly — in silages treated with PA may be associated with the rapid stabilization of the ensiled material. This early stabilization limits undesirable secondary fermentations within the silo, reducing losses of easily degradable substrates and minimizing energy consumption during fermentation. Furthermore, less aerobic deterioration after opening the silo contributes to preserving the silage since exposure to oxygen promotes the degradation of feed, promoting the development of molds, reducing dry matter, and decreasing digestibility (Muck, 2010).

Another factor related to the superior fermentative quality of silages treated with PA is the reduced frequency and duration of visits to the feed bunk observed in these animals. Although dry matter intake remained similar between treatments, this behavior indicates that animals receiving treated silage had shorter but more efficient meals, consuming the same amount of feed in less time. This pattern may reflect greater uniformity and stability of the silage.

The feed bunk scores recorded daily showed good homogeneity of leftovers between treatments, suggesting that there was no perceptible particle selection. This result reinforces the efficiency of the adopted feeding management. This result can be attributed to the standardized size and adequate proportion of the fiber fraction, as well as the uniform mixture of the forage and concentrate in the TMR. Thus, the shorter feed bunk time observed in animals fed treated silage does not appear to be related to dietary selection but rather to the feed's improved acceptance and stability, which reduces exploratory behavior and time spent at the feed bunk.

In a similar study, Almeida et al. (2023) evaluated the addition of ammonium dipropionate to the TMR of feedlot steers. They did not observe changes in ingestive behavior and associated this result with the composition and balance of the diet. This includes the forage-to-concentrate ratio, the digestibility of the constituents, the energy content, and the particle size.

Propionic acid inhibits undesirable microorganisms, reducing secondary fermentation and the production of compounds with an unpleasant odor, such as butyric acid, which is often associated with Clostridium activity (McDonald et al., 1991). Reducing these compounds improves the palatability and preservation of the silage, which may explain the greater feeding efficiency of animals that received treated silage (Allen, 2000). However, since the organic acid profile was not measured, this remains a hypothesis to be tested in future studies that include direct fermentative analysis of the silages.

Consequently, the shorter feeding time may have provided more time for other behavioral activities, especially rumination. Rumination plays a key role in ruminant digestion. According to Pazdiora et al. (2011), increased rumination time is beneficial because it promotes better particle fragmentation and increases the surface area of fiber exposed to microbial action, favoring digestion. Moreover, increased saliva production during rumination helps maintain an ideal rumen pH, reducing the risk of metabolic disorders and promoting better nutrient utilization and feed efficiency (Beauchemin, 2018).

The higher ADMD intake and better FCR observed in animals fed silages treated with PA were reflected in their improved performance by the end of the experiment. These results suggest that PA improves not only the efficiency of nutrient digestion but also optimizes the utilization of these nutrients by animals for metabolic and productive functions. With higher ADMD, animals can absorb more nutrients from the same amount of feed, resulting in better weight gain. Improved feed conversion indicates more efficient use of energy and nutrients in the diet, reducing waste and increasing productive return per unit of feed consumed (Fernandes et al., 2004). According to Kung et al. (1998), PA stabilizes fermentation and preserves the nutritional quality of silage. This ensures that animals receive a more consistent diet with less nutritional variation, contributing to more uniform performance over time.

The increased energy resulting from improved digestibility and conversion efficiency appears to be directed toward anabolic processes. This is reflected in greater weight gain and, primarily, in the deposition of subcutaneous fat, where a significant difference was observed between the treatments. The greater thickness of subcutaneous fat observed in animals that received silages treated with PA may be related to the greater preservation of soluble carbohydrates in the diet. Upon reaching the rumen, these are rapidly fermented into short-chain fatty acids and readily absorbed. They are subsequently converted into glucose by the liver. Similarly, when PA reaches the rumen, it is readily absorbed and becomes one of the precursors of glucose (Membrive, 2016).

This process increases energy availability in animals, enhancing weight gain and favoring subcutaneous fat deposition. This increase in fat deposition is a direct response to the greater metabolic efficiency provided by the improved quality and consequent digestibility of the silage, promoted by the action of PA (Rutenberg et al., 2016; Kung et al., 2018). In a similar experiment, Almeida et al. (2023) examined the effects of adding ammonium dipropionate (a buffered, PA-based salt) to the feed of feedlot steers. They observed that adding the salt resulted in better carcass gains and ADMD (74.57%). They also reported an increase in subcutaneous fat thickness (5.50 mm versus 4.94 mm without dipropionate).

According to Kozloski (2017) and Gonçalves et al. (2012), PA acts as a glucose precursor and stimulates insulin production when it enters the gluconeogenesis cycle. When an animal has a positive energy balance, insulin plays a crucial role by activating lipogenesis processes. This hormone promotes energy storage in the form of fat, favoring the deposition of adipose tissue, especially subcutaneous fat. Thus, PA improves the energy efficiency of animals and contributes to increased fat deposition when there is adequate energy availability in the diet (Pereira et al., 2024).

The study has limitations that should be considered when interpreting the results. The average compaction density of the silages (170 kg DM m^{-3}) was below ideal levels, which may have accentuated losses in the control treatment and overestimated the effect of PA. The small number of repetitions (five pens per treatment) limits the ability to detect differences in highly variable variables, such as weight gain. In addition, the absence of analyses of organic acids and microbiological parameters prevents confirmation of the proposed fermentative mechanisms.

Conclusion

The inclusion of 0.03 to 0.06% propionic acid in chopped corn plants during ensiling resulted in a tendency towards higher final animal weights, better feed conversion, and greater carcass fat deposition. These effects are related to the increased apparent dry matter digestibility and improved preservation of soluble carbohydrates in the treated silages. Furthermore, the additive altered ingestive behavior by reducing feeding time and frequency while increasing rumination time.

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