R. Bras. Zootec., 54:e20240024, 2025
https://doi.org/10.37496/rbz5420240024

Forage crops
Full-length research article

Revista Brasileira de Zootecnia

Brazilian Journal of Animal Science
e-ISSN 1806-9290
www.rbz.org.br

Effect of a new grain processor in harvesting on the final quality of corn silage

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Received: April 2, 2024
Accepted: November 25, 2024

How to cite: Sidor, F. S.; Plodoviski, D. C.; Souza, A. M.; Cristo, F. B.; Pereira, E. L. C.; Baldissera, E.; Cesar, P. V. P. and Neumann, M. 2025. Effect of a new grain processor in harvesting on the final quality of corn silage. Revista Brasileira de Zootecnia 54:e20240024.
https://doi.org/10.37496/rbz5420240024

Editors:
Gustavo José Braga
Luiz Felipe Ferraretto

ABSTRACT - The present study aimed to evaluate the effectiveness of the grain processing carried out by a device containing round and oblong holes attached to the inside of the forage harvester and evaluate its impact on the nutrient composition of corn silage, animal productivity, feeding behavior, apparent digestibility of the diet, and carcass traits of feedlot finished steers. The silages tested were: silage subjected to the grain processor (SGP) and silage not subjected to the grain processor (SNGP), which also made up the diet given to the animals. For animal assessment, we used 32 crossbred steers (half Angus, half Nellore), with an average age of 11±2 months and an initial average body weight of 350±9.06 kg. The experiment was a randomized block design, consisting of two treatments and eight repetitions each, represented by a pen with two animals. The SGP showed a greater accumulation of grains at the bottom of the particle separator system, that is, the processor promoted a reduction in particle size, which led to a 42% higher starch content in the lower layer. At the end of the 112 days of evaluation, the animals that received the diet composed of SGP achieved higher daily weight gain (1.627 kg/day) than those fed SNGP (1.427 kg/day), better feed efficiency, and higher carcass gain during the experimental period (116.3 vs 105.5 kg). The use of the grain processing system improves the use of the diet by the animals and makes a greater fraction of starch available, resulting in higher animal weight gain.

Keywords: feedlot cattle, fermentation process, kernel processing score, nutrient composition, starch

1. Introduction

Corn silage is the roughage most commonly used on Brazilian properties, supplied alone or in combination with other roughage to make up the animal diet (Ferraretto et al., 2018; Silvestre and Millen, 2021).

In Brazil, dairy production systems predominate in areas ranging from 2 to 20 ha, and for beef cattle farming, areas from 7 to 50 ha are intended for the cultivation of corn for silage. This leads to the predominant use of small tractor-driven harvesting machines, which, for the most part, do not have efficient grain processing systems like those found in large machines (Buriol et al., 2021).

Aiming to increase the energy content of the silage, plants are harvested at more advanced stages since this longer time the plant remains in the field favors the conversion of sugars into starch, which is deposited in the corn grain (Opsi et al., 2013). However, this aging makes the plant and its grains harder, which makes processing difficult (Khan et al., 2015).

The use of tools capable of breaking the grains of the mass to be ensiled and, at the same time, making the starch more available for rumen bacteria can be a key element in optimizing ruminant production (Silveira et al., 2013). Higher availability of energy in the diet can increase the metabolizable energy, i.e., a greater fraction of the energy consumed in the diet can be converted into carcass gain (Paulino et al., 2013).

In this context, the present study aimed to evaluate a grain processing system coupled to a rear-wheel drive forage harvester with a total cutting area, model JF C120 AT S4®. The evaluation focused on the physical characteristics and nutrient composition of the forage particles, as well as the performance, dry matter intake (DMI), and carcass traits of cattle fed in confinement with the resulting silages.

2. Material and methods

The ruminal degradation of dry matter (DM) of silages evaluated was estimated by the *in situ* technique in a steer with a rumen cannula inserted by rumenotomy previously approved by the Animal Research Ethics Committee (019/2023). To evaluate animal performance, the research project was previously submitted and approved by the ethics committee (004/2020).

The experiment was conducted in Guarapuava, Paraná, Brazil (25°22'55" S 51°29'48" W; 1,018 m). The climate of the Guarapuava region is Cfb, with an average annual rainfall of 1,944 mm, average annual minimum and maximum temperatures of 12.7 and 23.5 °C, respectively, and relative air humidity of 77.9%. The soil in the experimental area is classified, according to the Brazilian Soil Classification System, as Latossolo Bruno Alumínico (EMBRAPA, 2013). Upon corn planting, the soil presented the following chemical properties (0 to 20 cm layer): pH $CaCl_2$ 0.01M = 5.98; P-Mehlich-1 = 15.30 mg dm^{-3}; K = 0.43 cmolc dm^{-3}; OM = 23.73 g dm^{-3}; Al = 0.21 cmolc dm^{-3}; $H^{+}Al$ = 6.42 cmolc dm^{-3}; Ca = 6.33 cmolc dm^{-3}; Mg = 1.67 cmolc dm^{-3}; and base saturation (V%) = 56.75%.

The area where corn was planted has been used in recent years with annual pastures in the winter and corn crops in the summer, received fertilizers at each growing season following the Fertilization and Liming Manual for the state of Paraná (Pavinato, 2017).

Management before planting the corn crop was based on controlling weeds using glyphosate (commercial product Shadow®: 7.3 L/ha), combined with methomyl (commercial product Bazuka®: 1 L/ha) to control insect pests plus mineral oil (commercial product Assist®: 0.33 L/ha) as an adjuvant. Management after planting, with the same purpose, was conducted with the application of glyphosate (commercial product Shadow®: 5 L/ha) combined with pyrethrin (commercial product Turbo®: 0.1 L/ha) and mineral oil (commercial product Assist®: 0.33 L/ha). Sanitary management of the crop was also carried out using a fungicide based on pyraclostrobin + fluxapyroxad (commercial product Orkestra®: 0.25 L/ha).

Corn hybrid P3565 PWU (Corteva®; semi-hard grain texture, early cycle) was sown in a no-till system targeting a population of approximately 70 thousand plants/ha, with a basal fertilization of 410 kg/ha of N-P-K (8-20-20). When corn plants had five fully expanded leaves, urea topdressing was applied in the amount of 420 kg/ha (N-45%).

Corn was harvested between the dough (R4) and dent (R5) stages, with 35.30% of DM. The forages were harvested 20 cm from the ground and chopped to a theoretical cutting length of 12 mm using a JF C120 AT S4 forage harvester. The machine is tractor-driven and equipped with two pick-up drums, with high-speed discs and knives on each drum; transmission is via crown and pinion with an armored box containing four internal rollers, of which two are pick-up rollers, one smooth and one movable, with an adjustable rotor with 15 knives in a “C” profile. It also has six launchers and an articulated platform containing gears with 24 theoretical cutting length settings (2 to 36 mm). Sharpening is carried out using a rectangular stone; the machine comprises a fixed rotor counter knife with two lives, two cleaners per rotor, and a folding outlet spout made of cross-link polyethylene with internal protection.

The platform box is lubricated with lithium-based grease; the rotor and rollers are driven by a cardan, spout, and jet break adjusted by a hydraulic system. The machine requires 540 revolutions per minute (RPM) at the power take-off and power of 65 to 95 hp (JF MÁQUINAS AGRICOLAS®).

The evaluated grain processing system was coupled to the forage harvester, composed of two curved plates, one smooth (conventional) and the other with round and oblong holes (tested), made of special high-strength steel (JF MÁQUINAS AGRICOLAS® sells the machine with these two curved plates; the operator decides which to use).

Later, the forages (subjected to the grain processor or not) were transported from the field and deposited in a previously leveled and well-drained place in trench silos measuring 3.5 m wide, 10 m long, and 1.2 m high, completely sealed, and protected with 200 µm double-sided plastic tarpaulin.

Upon silage making, eight whole plant samples with 20 plants each (original material) were collected in a homogeneous and representative way to characterize the crop; all were used to determine the plant height, the first ear height, and the number of dry leaves per plant. Then, 10 plants from each sample were weighed and separated into the structural components stem, leaves, bracts plus cob, and grains. These samples were weighed, pre-dried in a forced-air oven at 55 °C for 72 h, and weighed again to determine the partial DM content, according to AOAC (1984). This procedure allowed estimating the productive potential of ensilable DM (kg/ha), as well as the physical structure of the plant and the DM content of the plant and its structural components for the agronomic characterization of the crop.

The experimental design for chemical assessment of silage and animal performance evaluations was randomized blocks, consisting of two treatments (SGP – silage produced using a grain processor; and SNGP – silage produced without the use of a grain processor) and eight repetitions. In the animal evaluation, each repetition was represented by a pen with two animals, thus 32 crossbred steers (half Angus, half Nellore), with an average age of 11±2 months and an average initial body weight (BW) of 350±9.06 kg, were used.

During the silo feed-out, the temperature of silages subjected or not to grain processing was measured daily at nine points in each silo (three points at the bottom, three points in the middle, and three points at the top), at 06:00 and 17:00 h, as well as the ambient temperature, using a digital thermometer with a metal rod, timer, and current reading range between −50 and 250 °C (INCOTERM®). Temperature readings in the silage were taken at a depth of 7 cm in the structured mass on the face of the silos.

During the animal feeding period (112 days), homogeneous samples of silage from the silo feed-out face were collected twice a week to measure pH using a digital potentiometer ECNAL Tec-5®, with a scale ranging from 0 to 25 °C, according to the methodology of Cherney and Cherney (2003). Silage samples were weighed, pre-dried in a forced air oven at 55 °C for 72 h, and weighed again to determine the partial DM content, according to AOAC (1984).

In sequence, these samples were ground to 1 mm. After pre-drying and grinding, samples were analyzed for total DM in an oven at 105 °C; crude protein, using the micro Kjeldahl method; ether extract and mineral matter, according to Silva and Queiroz (2009); neutral detergent fiber (NDF), using thermostable α-amylase (Termamyl 120L, Novozymes Latin America Ltda.) according to Van Soest et al. (1991); and acid detergent fiber and lignin, according to Goering and Van Soest (1970). The starch analysis was carried out following the Hendrix method (1993), which involves the hydrolysis of the starch in the sample after the extraction of soluble carbohydrates through successive washing with 80% alcohol, followed by a colorimetric analysis of the reducing sugars (glucose), and the result converted to the amount of starch present.

The content of total digestible nutrients was calculated according to equations proposed by Weiss et al. (1992). To determine P and Ca levels, analyses were carried out according to Tedesco et al. (1995).

In the physical analysis of silages, we adopted the methodology adapted from Kononoff and Heinrichs (2003) to determine particle size, using a system of sieves and manual agitation to separate particles larger than 19 mm, particles between 19.00 and 7.80 mm, between 7.80 and 4.75 mm, and smaller than 4.75 mm. These sieves were made up of a metal aluminum box and three acrylic sieves, with dimensions of 32 × 32 × 22 cm (width × length × height) and a distance of 7 cm between sieves; the capacity of the metal box is to accommodate a 500-g sample.

Two separation methods were used. In the first, a wet sample was dried after particle separation; in the other method, the sample was dried before separation. For these two methods, the sample particle separation parameter was obtained on a wet basis, on a dry basis, and on a previously dried basis.

After shaking, the grains in the two intermediate classes (19.00-7.80 mm and 7.80-4.75 mm) were quantified and classified as unprocessed. After counting and qualifying the grains, they were dried in a forced-air oven at 55 °C to obtain the partial DM of the processed and unprocessed grains.

To evaluate the Kernel Processing Score (KPS), silage samples were previously dried in a forced-air oven at 55 °C for 72 h and manually shaken in a system of three sieves to separate particles larger than 19.00 mm, particles between 19.00 and 7.80 mm, particles between 7.80 and 4.75 mm, and particles smaller than 4.75 mm. To determine the KPS, all material retained above the 4.75 mm sieve (19.00, 7.80, and 4.75 mm sieves) was subjected to chemical analysis to determine the starch content. The same procedure was adopted for the material at the bottom of the system (<4.75 mm) following the methodology adapted from Mertens (2005). From this point, it was possible to determine how much starch was deposited at the bottom of the sieve set and qualify grain processing.

The ruminal DM degradation of silages was estimated by the *in situ* technique using nylon bags measuring 12 × 8 cm, 40-60 µm mesh size, containing 5 g dry sample of each material ground to 1 mm, for subsequent incubation in the rumen (Nocek, 1988). The incubation times were 12, 24, 36, and 48 h in the rumen of a Jersey castrated male bovine with a ruminal cannula implanted by rumenotomy. The feeding of this animal was based on corn silage and mineral supplements to meet its daily requirements.

The kinetic parameters for DM were estimated as proposed by Ørskov and McDonald (1979).

To assess animal performance, 32 crossbred steers, half Angus, half Nellore from the same herd, with an average initial weight of 350±9.06 kg and an average initial age of 11±2 months were dewormed and housed in 16 semi-covered feedlot pens of 15 m^2 area, equipped with a concrete feeder and waterer regulated by an automatic float. Animals were distributed into the experimental units considering their BW, rib eye area (REA), rump fat thickness, ratio, and marbling, measured by ultrasound (Aloka® SSD-500 Vet) consisting of an echo camera coupled to a 17 cm and 3.5 MHz probe.

To evaluate animal performance, eight repetitions were adopted in each treatment, in which each repetition consisted of a pen with two animals. The finishing period of the animals in the feedlot was 128 d, with 16 d for adaptation to the diets and experimental facilities and, sequentially, four evaluation periods of 28 days.

Animals were fed *ad libitum* twice a day, at 06:00 and 17:00 h. Voluntary feed intake was recorded daily by weighing the quantity offered and the leftovers from the previous day, considering daily intake adjustments, to keep leftovers at 5% DM.

The diets consisted of corn silages subjected to grain processing or not (SGP and SNGP, respectively) in a constant ratio of 40% roughage and 60% concentrate on a DM basis. The concentrate was prepared in a commercial feed factory, formulated based on soybean meal (6.00%), wheat bran (10.00%), malt radicle (22.00%), ground corn grain (7.87%), ground oat grain (8.0%), ground barley grain (28.00%), corn germ (12.00%), calcitic limestone (3.10%), common salt (0.60%), livestock urea (1.63%), and vitamin-mineral premix (0.80%), supplied as pellets. These isoproteic diets were formulated based on the NRC (2016) to provide the animals with an average daily weight gain (ADG) of 1.700 kg/day. Table 1 lists the nutrient composition of the used feeds and the mean values of the experimental diet on a total DM basis.

Table 1 - Chemical composition of corn silages and experimental diets (with and without grain processing) used to feed animals, on a total dry matter basis

Parameter (% DM)	Corn silage	
	With processor	Without processor
Dry matter (% NM)	34.95	34.22
Mineral matter	2.64	2.51
Crude protein	6.88	6.22
Ether extract	2.53	2.15
Neutral detergent fiber	44.37	45.24
Acid detergent fiber	25.90	26.76
Lignin	3.80	3.81
Starch	33.85	31.36
Non-fiber carbohydrates	43.58	43.88
Total digestible nutrients	69.71	69.11
Ca	0.14	0.13
P	0.24	0.25
Parameter (% DM)	Experimental diet	
	With processor	Without processor
Dry matter (% NM)	69.16	68.87
Mineral matter	4.87	4.82
Crude protein	14.87	14.61
Ether extract	2.24	2.09
Neutral detergent fiber	36.63	36.98
Acid detergent fiber	18.21	18.55
Lignin	4.32	4.32
Starch	36.29	35.30
Non-fiber carbohydrates	41.38	41.50
Total digestible nutrients	75.09	74.85
Ca	1.06	1.05
P	0.44	0.45

Premix guarantee level per kg of concentrate: vitamin A, 16,000 IU; vitamin D3, 2000 IU; vitamin E, 25 IU; S, 0.36 g; Mg, 0.74 g; Na, 3.6 g; Co, 0.52 mg; Cu, 22.01 mg; F, 18.00 mg; I, 1.07 mg; Mn, 72.80 mg; Se, 0.64 mg; Zn, 95.20 mg.

In addition to adjusting intake, the qualitative score of trough leftovers in each pen was evaluated daily through visual observation. Scores were graded using scales ranging from 1 to 5, in which 1 = 60% silage and 40% concentrate; 2 = 50% silage and 50% concentrate; 3 = 40% silage and 60% concentrate; 4 = 30% silage and 70% concentrate; and 5 = 20% silage and 80% concentrate, with score 3 considered ideal.

During the experiment, the fecal score of each pen was also graded daily through visual observation. Feces were graded using scores ranging from 1 to 5, based on the methodology adapted from Looper et al. (2001) and Ferreira et al. (2013), with 1 = liquid feces, without consistency; 2 = runny feces, with few ripples, without shape definition; 3 = pasty feces with 1-1.5 cm high piles, with 2 to 4 concentric rings; 4 = soft feces with 5-7.5 cm high piles; 5 = hardened feces with more than 7.6 cm high piles. Score 3 is considered ideal.

The qualitative assessments of trough score and feces score were performed by six previously trained evaluators, who took turns to perform this assessment throughout the experimental period.

Performance was assessed every 28 days, sequentially, totaling four assessment moments. These evaluations were carried out after a 10-h solid fasting to weigh the animals individually. The variables evaluated were BW; average DMI, expressed in kg/animal/day (kg/day); average DMI, expressed as a percentage of BW (ADMI, % BW); average daily weight gain (ADG, kg/day); and feed efficiency (FE, kg/kg).

Average dry matter intake (kg/day) was measured through the difference between the daily amount of feed provided and the amount of leftovers from the previous day. Average dry matter intake (% BW) was obtained by the ratio of ADMI (kg/day) to the average BW for the period, multiplied by 100:

$$\text{ADMI (\% BW)} = \frac{\text{ADMI (kg/day)}}{\text{BW}} \times 100 \quad (1)$$

Average daily weight gain was calculated by the difference between the final (BWf) and initial (BWi) BW of the experimental period divided by the days evaluated:

$$\text{ADG} = \frac{\text{BWf} - \text{BWi}}{28} \quad (2)$$

Feed efficiency was obtained by the ratio of ADG to ADMI:

$$\text{FE} = \frac{\text{ADG}}{\text{ADMI (kg/day)}} \quad (3)$$

The animal feeding behavior was evaluated in the middle phase of the experiment (between the second and third moments of animal evaluation) over a continuous period of 48 h, starting at noon on the first day and ending at noon on the third assessment day. Observations were registered by seven observers per shift for 48 h, taking turns every 6 h, with readings taken at regular intervals of 3 min.

Data on feeding behavior, represented by activities of idling, ruminating, drinking, and feeding, were expressed in h/day. The frequency of occurrence of feeding, drinking, urinating, and defecating activities expressed in number of times per day was also observed, following the same methodology. During night observation, the environment was maintained under artificial lighting.

The digestibility analysis was based on the determination of the apparent digestibility of the diet, which was carried out while finishing the animals in the feedlot. For this, composite samples of the diets of each treatment were taken during the experimental period.

Feed collections were carried out once a day, following the four consecutive day collection methodology, and stored in a freezer. After the end of the evaluation, samples were thawed, homogenized to form a composite sample per pen and treatment, and stored at −15 °C. Together, the daily intake of feed and leftovers for two consecutive days (48 h) was measured.

During the apparent digestibility test, the total feces produced every six hours was collected; thereafter, a homogeneous sample of 0.5 kg of this total was collected and stored under refrigeration. After two consecutive days of collection, these were mixed and homogenized to obtain a composite sample of each pen for laboratory analysis.

To determine the fecal output/day, the total feces produced during each six hours were added together.

Diet and fecal samples were dried in a forced air oven at 55 °C to constant weight and corrected for total DM at 105 °C to determine DM content. The DM and NDF of leftovers and feces from each experimental unit were determined using the same procedures adopted in the diet analysis.

The apparent digestibility coefficient (AD) of DM and NDF of the experimental diets was determined according to the following formula:

$$\text{AD (\%)} = \frac{\text{g nutrient ingested} - \text{g nutrient excreted}}{\text{g nutrient ingested}} \times 100 \quad (4)$$

All assessments regarding feeding behavior and digestibility were carried out according to the methodology developed by Michels et al. (2018).

At the beginning of the experimental period and prior to slaughtering the animals, REA and subcutaneous fat thickness, rump fat, ratio, and marbling were assessed using a set of equipment consisting of an echo camera (Aloka® SSD-500 Vet) coupled to a 17 cm probe, 3.5 MHz. Measurements were taken in the region between the 12th and 13th ribs over 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 height and width. Images were interpreted by the laboratory responsible for ensuring data quality (Designer Genes Technology) using the BIA/DGT Brasil software. Marbling was assessed through the existence of fat pads between muscle fibers in *longissimus dorsi* and scored using increasing indices ranging from 1 (non-existent) to 9 (excessive) adapted from the system proposed by Muller (1987).

At the end of feedlot, animals were subjected to 10 h of solid fasting for the last weighing relative to the last evaluation period, and after that, they were fed and weighed before being transported to the slaughterhouse, to obtain their farm weight.

Carcass gain during the feedlot period (CG, expressed in kg) was obtained by the difference between the hot carcass weight at slaughter and the initial BW (BWi) of the animals under a theoretical carcass yield of 50%. Based on the period of 112 feedlot days, the average carcass gain (ACG, expressed in kg/day) was also calculated, which is obtained by the ratio of CG to BW, as well as the efficiency of transformation of the DM consumed into carcass (expressed in kg DM kg/carcass) and the efficiency of transformation of weight gain into carcass, which is obtained by the ratio of ACG to ADG (ACG:ADG, expressed in %). For the calculations, hot carcass weight was considered.

Five development measurements were taken on the carcasses: carcass length, which is the distance between the medial cranial edge of the pubic bone and the medial cranial edge of the first rib; leg length, which is the distance between the medial cranial edge of the pubic bone and the tibiotarsal joint; arm length, which is the distance between the olecranon tuberosity and the radiocarpal joint; arm perimeter, obtained in the median region of the arm by circling it with a measuring tape; round thickness, measured using a compass, perpendicular to the carcass length, taking the largest distance between the section that separates the two half carcasses and the lateral muscles of the thigh; and subcutaneous fat thickness (*longissimus dorsi*, forequarter, rib, and hindquarter), according to the methodologies suggested by Muller (1987).

Data were subjected to the Shapiro-Wilk and Bartlett tests to check the assumptions of normality and homogeneity of variance, respectively. Once these assumptions were met, the F-test was applied at a 5% probability of error, through Analysis of Variance (ANOVA) in the statistical program SAS (Statistical Analysis System, 1993).

The analysis of each variable followed the statistical model:

$$Yij = \bar{x} + Pi + Bj + Eij, \quad (5)$$

in which Yij = dependent variables; $\bar{x}$ = overall mean of all observations; Pi = effect of grain processor of order i, in which 1 = silage subjected to the processor, and 2 = silage not subjected to the processor; Bj = effect of block of order j, with 1 = first, 2 = second, 3 = third, 4 = fourth, 5 = fifth, 6 = sixth, 7 = seventh, and 8 = eighth; and Eij = residual random effect.

3. Results

The productive agronomic data of the corn plant upon ensiling characterized the crop with mean values of plant height of 2.18 m, ear height of 1.13 m, high stay green with 0.87 dry leaves per plant, production of 20,132 kg/ha DM, and physical structural participation, on a DM basis of 20.4% stem, 13.4% leaves, 20.7% bracts plus cob, and 45.5% grains. Regarding DM contents, mean values were 32.79% for the whole plant, 28.70% in the plant without grains, 22.94% in the stem, 37.76% in the leaves, 37.26% in the bracts plus cob, and 54.05% in the grains.

The corn plants harvested and subjected or not to the grain processor resulted in silages with similar nutrient composition (Table 1), with mean values of 34.59% DM, 2.58% mineral matter, 6.55% crude protein, 2.34% ether extract, 44.81% NDF, 26.33% acid detergent fiber, 3.81% lignin, and 32.61% starch.

In the overall mean, the stability of SGP during the period of use for animal feeding showed lower pH and temperature ($P<0.05$) in the upper layer of the silo (3.88 and 22.12 °C versus 4.01 and 24.44 °C, respectively) than SNGP. There were no variations ($P>0.05$) in pH and temperature in the middle layer (3.82 and 20.11 °C versus 3.84 and 20.92 °C), as well as at the bottom (3.71 and 20.22 °C versus 3.79 and 20.52 °C) of SGP or SNGP, respectively.

The data regarding the separation of silage particles into different classes (Table 2), on a wet basis, showed a statistical difference ($P<0.05$), in which the SGP had lower particle retention on the 7.8 mm sieve and a higher deposition above 4.75 mm.

Considering the stratification, on a dry basis and the dry sample, the lowest deposition on the 7.8 mm sieve was not observed; however, the pattern of greater deposition on the 4.75 mm sieve was maintained in the SGP treatment. There was a greater deposition of grains for SGP for the three types of segregation (Table 2), with values of total grains of 11.78 and 15.06%, 27.42 and 34.87%, 16.39 and 21.74%, and superiority for grain processing of 3.28, 7.45, and 5.35 percentage points, respectively, for this parameter.

Table 2 - Separation of corn silage particles according to size, with and without a grain processor

Parameter	Particle separation		SEM	Prob.
	With processor	Without processor		
Stratification (% wet basis)[1]				
> 19 mm	4.01	4.53	0.533	0.3775
> 7.8 mm	59.08	63.08	1.404	0.0195
> 4.75 mm	23.76	23.30	0.939	0.6556
< 4.75 mm	13.16	9.10	0.844	0.0006
Grains > 7.8 mm	8.13	11.66	0.465	0.0001
Grains > 4.75 mm	3.65	3.41	0.153	0.1618
TG > 4.75 mm	11.78	15.06	0.529	0.0001
Stratification (% dry basis)[2]				
> 19 mm	4.37	5.04	0.586	0.3049
> 7.8 mm	56.05	57.59	1.296	0.2841
> 4.75 mm	22.40	23.83	1.002	0.2030
< 4.75 mm	17.19	13.54	0.696	0.0003
Grains > 7.8 mm	18.61	28.01	1.462	0.0001
Grains > 4.75 mm	8.82	6.86	0.643	0.0138
TG > 4.75 mm	27.42	34.87	1.857	0.0024
Stratification (% dry sample)[3]				
> 19 mm	1.68	1.74	0.361	0.9026
> 7.8 mm	31.82	29.74	1.154	0.1670
> 4.75 mm	32.09	38.78	0.767	0.0001
< 4.75 mm	34.41	29.74	1.324	0.0152
Grains > 7.8 mm	6.87	8.14	0.509	0.0495
Grains > 4.75 mm	9.51	13.60	0.426	0.0001
TG > 4.75 mm	16.39	21.74	0.573	0.0001
Stratification of starch (% dry basis)				
> 4.75 mm	18.38	21.86	0.413	0.0001
< 4.75 mm	13.91	9.71	0.690	0.0005
Kernel Processing Score				
% starch < 4.75 mm	42.95	30.67	1.222	0.0001

TG - total grains; SEM - standard error of the mean.
[1] Fresh sample.
[2] Dry sample after particle separation.
[3] Sample previously dried at 55 °C.
Mean values, in the same row, with probability <0.05 are significantly different from each other by F-test at 5%.

The grain processor proved effective when considering the data specifically related to grains for the three methods evaluated. The total value of grains larger than 4.75 mm was higher (P<0.05) in the unprocessed silage. This indicates that these grains were better processed and reached the bottom of the sieve system.

As for the starch analysis of particles retained on the 4.75 mm sieve and those smaller than 4.75 mm, there was a greater deposition of starch (P<0.05) in the class smaller than 4.75 mm of SGP. Such a result points to a greater grain disruption (4.20 percentage points) in particles smaller than 4.75 mm.

For the KPS parameter, the SGP was superior, with 42.95% against 30.67% of the SNGP, i.e., a 40.03% higher grain processing.

Regarding the ruminal DM degradability (Table 3), there was a statistical difference (P<0.05) between incubation times of 12 and 24 h. For 12 h, the treatment subjected to grain processing reached higher degradability than the treatment without grain processing, with values of 42.40 and 37.36%, respectively, culminating in an increase of 13.49%. This pattern remained constant over the 24 h, with values of 49.95% for the SGP and 46.97% for SNGP, again demonstrating an increase of 6.34% in ruminal degradability. Evaluating the times of 36 and 48 h, a similar effect was found between the two treatments in their degradability curves, with mean values of 58.23% for 36 h and 66.86% for 48 h.

As for the *in situ* NDF degradability, there was no change (P>0.05) resulting from the use or not of the grain processor for any of the incubation periods tested. For the ruminal kinetics (Table 3) referring to fraction a, the SGP had a greater value (P<0.05; 34.43%) than the SNGP (28.48%), thus, increasing by 11.76% the soluble fraction of corn silage. Regarding fraction b, a statistical difference was observed (P<0.05); however, the SGP showed a lower fraction (40.84%) than the SNGP (59.50%). Observing the kd attribute, no significant difference was detected, in which the mean value was 0.029%/h. The same pattern was found for fraction c and PD parameter, with mean values of 23.37 and 75.90%, respectively. The same also occurred for effective degradability at passage rates of 2, 5, and 8%/h, presenting mean values of 31.75, 23.57, and 19.07%, respectively.

Table 3 - *In situ* degradability of dry matter and neutral detergent fiber in 12, 24, 36, and 48 h of incubation, and ruminal kinetics of corn silage, with and without a grain process

Parameter	Silage		SEM	Prob.
Incubation time	With processor	Without processor		
In situ degradability of dry matter				
12 h	42.40	37.36	0.822	0.0450
24 h	49.95	46.97	0.908	0.0200
36 h	59.05	57.41	0.795	0.0771
48 h	66.81	66.91	0.740	0.9229
In situ degradability of neutral detergent fiber				
12 h	68.56	66.10	3.209	0.6254
24 h	65.32	65.59	1.438	0.9037
36 h	73.48	74.98	0.789	0.2703
48 h	79.11	76.90	0.778	0.1389
Ruminal kinetics				
a (%)	34.43	28.48	0.306	0.0418
b (%)	40.84	59.50	0.213	0.0380
kd (%/h)	0.026	0.032	0.001	0.3424
c (%)	24.73	22.02	2.521	0.3448
PD (%)	79.55	72.28	0.207	0.0745
ED 2%/h	30.34	33.17	1.179	0.5518
ED 5%/h	21.65	25.49	0.994	0.6157
ED 8%/h	17.18	20.96	0.822	0.6393

a - soluble fraction; b - potentially degradable fraction of the insoluble fraction; kd - degradation rate of fraction b; c - indigestible fraction; PD - potential degradability; ED - effective degradability; SEM - standard error of the mean.
Mean values, in the same row, with probability <0.05 are significantly different from each other by F-test at 5%.

In general, animals fed SGP from the beginning to the end of the feedlot period had higher ADG and better FE, presenting a superiority of 14 and 11%, respectively, to animals on the diet with SNGP (Table 4). Also, DMI, expressed in kg/day or % BW did not change (P>0.05).

Animals that received SGP exhibited no improvement (P>0.05) in the efficiency of transforming the DM ingested into weight gain in the periods from 0 to 28 days, from 0 to 56, and from 0 to 84 days (Table 4). However, evaluating the total feedlot period (0 to 112 days), FE was higher (P<0.05) by 11.11% for animals on SGP. When evaluating the trough score and fecal score, there were no variations (P>0.05) due to the use of the SGP during the feedlot of the animals.

There was no influence of the processing of silage grains (P>0.05) regarding the efficiency of transforming weight gain into carcass, with a mean value of 69.14% (Table 5).

Animals fed corn silage subjected to grain processing included in their diet had higher average daily carcass gains (1.107 versus 0.986 kg/day) and, consequently, higher carcass gains in the total feedlot period (116.3 versus 103.5 kg), in addition to better efficiency of transformation of the DM consumed into carcasses (8.69 versus 9.49 kg DM kg carcass gain) compared with SNGP (Table 5). In this way, a

Table 4 - Average daily weight gain (ADG), dry matter intake expressed in kg/day (DMID) or per 100 kg body weight (DMIB), feed efficiency (FE), and qualitative score of trough and feces of feedlot finished steers fed corn silage subjected or not to a grain processor

Parameter	Experimental diet		SEM	Prob.
	With processor	Without processor		
ADG (kg/day)				
0 to 28 days	1.688	1.473	0.0680	0.0415
0 to 56 days	1.599	1.480	0.0396	0.0398
0 to 84 days	1.619	1.461	0.0327	0.0402
0 to 112 days	1.627	1.427	0.0512	0.0471
DMID (kg/day)				
0 to 28 days	9.05	8.73	0.420	0.6140
0 to 56 days	9.36	9.07	0.350	0.5747
0 to 84 days	9.50	9.22	0.338	0.5695
0 to 112 days	9.59	9.26	0.315	0.4818
DMIB (% body weight)				
0 to 28 days	2.28	2.23	0.075	0.7090
0 to 56 days	2.24	2.21	0.052	0.6837
0 to 84 days	2.16	2.14	0.044	0.7731
0 to 112 days	2.10	2.07	0.036	0.6604
FE (ADG:DMID; kg/kg)				
0 to 28 days	0.188	0.167	0.0058	0.0579
0 to 56 days	0.172	0.163	0.0085	0.4711
0 to 84 days	0.171	0.158	0.0070	0.0825
0 to 112 days	0.170	0.153	0.0051	0.0436
Trough score				
0 to 28 days	3.18	3.34	0.103	0.3086
0 to 56 days	3.14	3.28	0.086	0.2740
0 to 84 days	3.11	3.32	0.096	0.1697
0 to 112 days	3.14	3.30	0.076	0.1615
Fecal score				
0 to 28 days	2.96	3.04	0.029	0.0682
0 to 56 days	2.92	2.96	0.031	0.3589
0 to 84 days	2.99	3.02	0.021	0.3207
0 to 112 days	2.99	3.01	0.011	0.4512

SEM - standard error of the mean.
Mean values, in the same row, with probability <0.05 are significantly different from each other by F-test at 5%.

statistical difference (P<0.05) was detected for BW at slaughter and hot carcass weight, with higher values in animals fed SGP (543.1 kg and 302.4 kg, respectively) than SNGP (519.4 kg and 288.3 kg, respectively).

Fecal output (kg/day) in both DM and natural matter and the DM content of feces did not change with the two experimental diets (Table 5). As for DMD, it improved (P<0.05) when the animals fed SGP (74.84%) compared with the control diet (72.53%).

As for the feeding behavior, the times spent drinking water, ruminating, and idling were not changed (P>0.05) by corn silage processing. In turn, a difference was detected (P<0.05) for the time animals remained feeding. When evaluating the feeding behavior, expressed in the number of times/day, there was no significant difference (P>0.05) between treatments.

Both at slaughter and in gain during the feedlot period, REA, ratio, marbling, subcutaneous fat thickness, and rump fat thickness values were not altered by the use of the grain processor (Table 6). Likewise, the grain processor used in the production of corn silage did not promote changes (P>0.05) in the degree of carcass finishing, expressed in measurements of fat thickness on the *longissimus dorsi*, in the forequarter, rib, and hindquarter compared with the control diet.

Regarding the parameters of carcass yield, carcass length, round thickness, arm length, and arm perimeter, there was no significant difference (P>0.05) between treatments, with mean values of 55.59%, 128.9 cm, 27.6 cm, 38.7 cm, and 40.6 cm, respectively.

When evaluating the weights of vital organs (Table 6), expressed as % BW, there was also no significant difference (P>0.05) between treatments.

Table 5 - Carcass performance and digestive and ingestive behavior of feedlot finished steers fed corn silage subjected or not to a grain process

Parameter	Experimental diet		SEM	Prob.
	With processor	Without processor		
Carcass performance				
CG (kg)	116.3	103.5	4.461	0.0433
ACG (kg/day)	1.107	0.986	0.043	0.0430
ACG/ADG (%)	68.56	69.72	1.398	0.5706
ETC	8.69	9.49	0.297	0.0273
Digestive behavior				
FWNM (kg/day)	13.55	13.83	0.410	0.5065
FDM (%)	17.76	18.05	0.228	0.2220
FWDM (kg/day)	2.40	2.50	0.076	0.2189
DMD (%)	74.84	72.53	0.641	0.0075
NDFD (%)	85.74	84.98	0.341	0.1565
Feeding behavior (h/day)				
Feeding	2.48	2.15	0.106	0.0048
Drinking	0.27	0.23	0.040	0.2044
Ruminating	5.14	5.50	0.316	0.2718
Idling	16.14	16.16	0.347	0.9560
Feeding behavior (times/day)				
Feeding	16.40	15.50	0.910	0.3153
Drinking	5.90	5.30	0.320	0.2805
Defecating	5.90	5.00	0.496	0.0705
Urinating	4.30	4.80	0.653	0.4503

CG - carcass gain in the total period; ACG - average carcass gain; ACG/ADG - efficiency of transformation of weight gain into carcass; ETC - efficiency of transformation of dry matter consumed into carcass; FWNM - fecal weight in natural matter; FDM - fecal dry matter; FWDM - fecal weight in dry matter; DMD - apparent dry matter digestibility; NDFD - apparent neutral detergent fiber digestibility; SEM - standard error of the mean. Mean values, in the same row, with probability <0.05 are significantly different from each other by F-test at 5%.

Table 6 - Values at slaughter and gain during the feedlot period of the rib eye area (REA), ratio, marbling, subcutaneous fat thickness (SFT), rump fat thickness (RFT), quantitative traits of the carcass, and vital organs of feedlot finished steers fed corn silage subjected or not to a grain processor

Parameter	Experimental diet		SEM	Prob.
	With processor	Without processor		
Ultrasound at slaughter				
REA	88.42	84.70	2.151	0.2415
Ratio	0.56	0.55	0.009	0.5056
Marbling	3.59	3.53	0.130	0.7385
SFT	8.00	7.32	0.512	0.3649
RFT	11.78	10.84	0.619	0.3011
Gain in the finishing period				
REA	20.39	18.85	1.312	0.4201
Ratio	0.079	0.083	0.005	0.7029
Marbling	0.49	0.47	0.057	0.8740
SFT	3.08	2.67	0.157	0.4287
RFT	5.59	5.18	0.250	0.5216
Fat thickness (mm)				
Longissimus dorsi	5.56	4.85	0.224	0.2591
Forequarter	4.19	3.69	0.245	0.3876
Rib	6.19	5.38	0.243	0.2404
Hindquarter	6.31	5.50	0.291	0.2880
Quantitative traits (cm)				
Carcass length	128.9	128.8	1.171	0.9855
Round thickness	28.0	27.2	0.408	0.2219
Arm length	38.7	38.8	0.577	0.8946
Arm perimeter	40.9	40.2	0.336	0.1995
Vital organs (% body weight)				
Heart	0.33	0.35	0.007	0.1689
Liver	1.16	1.15	0.017	0.9613
Lings	0.90	0.92	0.021	0.2699
Kidneys	0.20	0.20	0.004	0.1334

SEM - standard error of the mean.
Mean values, in the same row, with probability <0.05 are significantly different from each other by F-test at 5%.

4. Discussion

Results found for particle separation (Table 2) corroborate Saylor et al. (2021), who observed that the processing of grains in corn silage did not change the particle size of the vegetative portion of the whole plant, with an influence only on the grain portion.

Evaluating starch stratification (Table 2), the greater accumulation of starch at the bottom of the system confirmed the ability of the processor to efficiently reduce grain particles in corn silage.

The grain processor receives the chopped material thrown by the forage harvester through the high-speed rotor. It hits the holes in the concave plate and causes the particles to rupture, resulting in greater availability of starch in the SGP.

For the KPS parameter, our findings are in line with Mertens (2005) to arrive at the KPS result, which takes into account the starch content that passed through the 4.75 mm sieve so that better processing will result in a higher KPS value for silage. The same was confirmed by Zwald et al. (2008), who reported a strong relationship between the stratified starch content smaller than 4.75 mm and the degree of processing of corn silage.

Analyzing the *in situ* degradability (Table 3), this outstanding degradability for the grain processor at 12 and 24 h is because the processor removes the physical barrier formed by the protein matrix surrounding the starch granules of the grains, accelerating the degradation process at this first stage (Hoffman et al., 2011).

Another important point is that grain processing provides greater adhesion of the ruminal microbiota, while the intact pericarp makes it difficult for bacteria to adhere to the grain and degrade it (McAllister et al., 1994).

Marafon et al. (2015) observed similar behavior with the use of the grain processor, in which regardless of the harvest time, the hybrids subjected to the grain processor showed higher DM degradability.

For the *in situ* NDF degradability, the lack of difference (P>0.05) between treatments is probably due to the direct relationship between fiber degradability and NDF hydrolysis during storage as explained by Young et al. (2012), for whom adequate grain processing should not affect this parameter. This is elucidated in the similar content of NDF between the two experimental diets (Table 1), making it clear that the grain processor did not influence the fiber portion of the silage.

The results for ruminal kinetics are supported by Neumann et al. (2021), who evaluated ruminal degradation kinetics of various energy sources and concluded that corn grain presents a slower starch degradation due to the protein matrix covering starch granules. Therefore, the grain processing tested here was effective in increasing the soluble portion of corn silage, corroborating Goes et al. (2011), who concluded that feeds with smaller particles show greater solubilization in the rumen. Considering that fraction b is directly related to the soluble portion, it is evident that silage subjected to a processor contains a lower participation of this fraction.

In animal performance (Table 4), higher ADG values can be explained by pericarp rupture, starch exposure, and partial gelatinization, in which the mass of grains properly processed and exposed in silage may be influenced during initial ensiling when the temperature rises. Hydrogen bonds between starch granules partially break between 40 and 60 °C (Rooney and Pflugfelder, 1996; Souza and Andrade, 2000). These data are confirmed by particle separation (Table 2), in which the influence of the processor on the smaller grain particle size became clear.

The similar DMI between treatments can be because the grain processor did not change fiber diameter, only reduced the grain size. These results agree with Factori et al. (2012), who studied whole corn plant silage and concluded that the change in the size of fiber particles directly influences DMI. This evidences the importance of maintaining the ideal fiber size, as explained by Passini et al. (2002), who demonstrated that highly processed particles increase the ruminal passage rate and reduce effective digestion.

In line with what has been reported, the lack of difference in DMI (Table 4) can be elucidated by the similar passage rate of both treatments (Table 3), in which the grain processor did not cause damage to the vegetative portion, which was also proven by Gomes et al. (2012). These authors argue that the processing of the fiber portion of the feed has a direct impact on rumen filling, as well as on the passage rate of this material, directly affecting the DMI and the passage rate through the gastrointestinal tract.

The best FE found is in line with the study carried out by Marafon et al. (2015), who evaluated corn silages subjected or not to grain processing at two different harvest times, resulting in improvements of 10.49% in feed conversion in the group of animals fed silage subjected to the processor. The best FE is inferred to be the result of the higher ADG of animals receiving silage subjected to the grain processor related to the stability in DMI.

For trough score data, the lack of difference indicates no dietary selectivity of the animals that could be related to its expression or absence in the results obtained.

When evaluating the fecal score, the lack of difference indicates that there were no gastrointestinal disorders resulting from the experimental diets, since the fecal scores were considered within the range established as normal.

Results found for carcass were similar to those of Neumann et al. (2018), who reported that higher ADG (Table 4) related to higher apparent DM digestibility (Table 5) had a positive effect on the carcass parameters evaluated. As a consequence, data from CG, ACG, and efficiency of transformation of the DM consumed into carcass showed improvements in percentage gains, with values of 12.36, 12.27, and 8.42%, respectively, in the silage not subjected to grain processing. There was no interference from silage grain processing (P>0.05) regarding the efficiency of transformation of weight gain into carcass, with a mean value of 69.14%.

Freitas et al. (2021) investigated the influence of dry-rolled corn grain compared to whole corn grain without pericarp on carcass traits. Their study presented similar data for slaughter BW and hot carcass weight, in which greater grain processing resulted in higher values. This is because processing corn increases the growth rate of animals compared with unprocessed corn, as it increases the net energy content of the diet.

The higher DM degradability and unchanged fecal production is justified by the higher supply of starch available for ruminal fermentation. This is probably not related to dietary NDF since it did not present a statistical difference in apparent digestibility (P>0.05) between the treatments tested.

These factors indicate that the animals evaluated maintained similar DMI regardless of using the grain processor, and the DMD was higher (P<0.05) for the grain processor, thus increasing production efficiency. This is because the tested treatment provided less loss of nutrients through excretion in feces (Mendes and Campos, 2016).

Feeding behavior data, evaluated in hour per day, can be related to the higher energy density caused by the change in the proportions of short-chain fatty acids (SCFA), leading to a greater supply of propionic acid, regulating the animal intake by satiation due to energy supply (Ellis et al., 2012). In this way, the animal tends to remain longer consuming feed in smaller quantities.

The results of feeding behavior, considering the frequency of each activity per day, may be linked to what has been previously explained regarding similar NDF content (Table 1) and similar DMI between the diets (Table 4). By correlating the two variables, a similar feed intake frequency behavior is expected between treatments.

The lack of statistical difference between data related to carcass ultrasound characteristics and the degree of carcass finishing are inferred to be related to the genetics and sexual class of the animals rather than the diet (Ítavo et al., 2014). Another inherent factor that may explain this lack of difference in fat deposition despite the higher ADG found is the predisposition of non-castrated male cattle to mainly present the deposition of lean tissue (musculature) as a physiological characteristic (Paulino et al., 2008).

The lack of difference in the vital organ weight is because the grain processor, despite providing fast fermenting starch, did not cause damage to the animals' organs. According to Neto et al. (2014), the higher energy density in the diet can result in metabolic disorders, leading to organ overload and, consequently, morphological changes.

5. Conclusions

Corn silage prepared by using the grain processor shows an improved KPS and better ruminal degradation of fraction a, which results in greater animal weight gain, better feed efficiency, and better efficiency in transforming ingested dry matter into weight gain.

Author contributions

Conceptualization: Neumann, M. **Data curation:** Neumann, M. **Formal analysis:** Sidor, F. S. and Neumann, M. **Investigation:** Sidor, F. S.; Plodoviski, D. C.; Souza, A. M.; Cristo, F. B.; Pereira, E. L. C.; Baldissera, E. and Cesar, P. V. P. **Methodology:** Sidor, F. S. and Neumann, M. **Project administration:** Sidor, F. S. **Supervision:** Sidor, F. S. and Plodoviski, D. C. **Validation:** Neumann, M. **Visualization**: Sidor, F. S. and Neumann, M. **Writing – original draft:** Cristo, F. B. **Writing – review & editing**: Sidor, F. S.; Souza, A. M.; Baldissera, E. and Neumann, M.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

Special thanks to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for granting a master's scholarship.

References

AOAC - Association of Official Analytical Chemists. 1984. Official methods of analysis. 14th ed. AOAC, Arlington, VA.

Buriol, L. R.; Torteli, S. R.; Gallina, G.; Battiston, J. and Lajús, C. R. 2021. Perfil granulométrico e digestibilidade do amido da silagem de milho submetida a diferentes processamentos. Brazilian Journal of Development 7:39680-39710. https://doi.org/10.34117/bjdv7n4-433

Cherney, J. H. and Cherney, D. J. R. 2003. Assessing silage quality. p.141-198. In: Silage science and technology. Buxton, D. R.; Muck, R. E. and Harrison, J. H., eds. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI. https://doi.org/10.2134/agronmonogr42.c4

Ellis, J.; Dijkstra, J.; Bannink, A.; Kebreab, E.; Hook, S. E.; Archibeque, S. and France, J. 2012. Quantifying the effect of monensin dose on the rumen volatile fatty acid profile in high-grain-fed beef cattle. Journal of Animal Science 90:2717-2726. https://doi.org/10.2527/jas.2011-3966

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. 2013. Sistema brasileiro de classificação de solos. 3.ed. Embrapa Solos, Rio de Janeiro.

Factori, M. A.; Passini, C. T.; Meirelles, P. R. L.; Vieira Junior, L. C.; Marcelo, E. T.; Silva, M. G. B. and Pereira, A. S. 2012. Silagem de planta inteira de milho: pontos importantes a serem considerados. Pubvet 6:1368. https://doi.org/10.22256/pubvet.v6n17.1368

Ferraretto, L. F.; Shaver, R. D. and Luck, B. D. 2018. Silage review: Recent advances and future technologies for whole-plant and fractionated corn silage harvesting. Journal of Dairy Science 101:3937-3951. https://doi.org/10.3168/jds.2017-13728

Ferreira, L. S.; Bittar, C. M. M.; Silva, J. T.; Soares, M. C.; Oltramari, C. E.; Nápoles, G. G. O. and Paula, M. R. 2013. Desempenho e parâmetros sanguíneos de bezerros leiteiros que receberam sucedâneo lácteo ou silagem de colostro. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 65:1357-1366. https://doi.org/10.1590/S0102-09352013000500013

Freitas, T. B.; Felix, T. L.; Clark, C.; Fluharty, F. L. and Relling, A. E. 2021. E. Effect of feeding dry-rolled corn or whole shelled corn during the finishing phase on growth performance and carcass characteristics. Translational Animal Science 5:txaa228. https://doi.org/10.1093/tas/txaa228

Goering, H. K. and Van Soest, P. J. 1970. Forage fiber analysis (apparatus, reagents, procedures, and some applications). Agriculture Handbook No. 379. ARS-USDA, Washington, D.C.

Goes, R. H. T.; Souza, K. A.; Nogueira, K. A. G.; Pereira, D. F.; Oliveira, E. R. and Brabes, K. C. S. 2011. Degradabilidade ruminal da matéria seca e proteína bruta, e tempo de colonização microbiana de oleaginosas, utilizadas na alimentação de ovinos. Acta Scientiarum. Animal Sciences 33:373-378. https://doi.org/10.4025/actascianimsci.v33i4.11388

Gomes, S. P.; Borges, A. L. C. C.; Borges, I.; Macedo Júnior, G. L.; Silva, A. G. M. and Pancoti, C. G. 2012. Efeito do tamanho de partícula do volumoso e da freqüência de alimentação sobre o consumo e a digestibilidade em ovinos. Revista Brasileira de Saúde e Produção Animal 13:137-149.

Hendrix, D. L. 1993. Rapid extraction and analysis of nonstructural carbohydrates in plant tissues. Crop Science 33:1306-1311. https://doi.org/10.2135/cropsci1993.0011183X003300060037x

Herring, W. O.; Miller, D. C.; Bertrand, J. K. and Benyshek, L. L. 1994. Evaluation of machine, technician, and interpreter effects on ultrasonic measures of backfat and longissimus muscle area in beef cattle. Journal of Animal Science 72:2216-2226. https://doi.org/10.2527/1994.7292216x

Hoffman, P. C.; Esser, N. M.; Shaver, R. D.; Coblentz, W. K.; Scott, M. P.; Bodnar, A. L.; Schmidt, R. J. and Charley, R. C. 2011. Influence of ensiling time and inoculation on alteration of the starch-protein matrix in high-moisture corn. Journal of Dairy Science 94:2465-2474. https://doi.org/10.3168/jds.2010-3562

Ítavo, L. C. V.; Dias, A. M.; Schio, A. R.; Mateus, R. G.; Silva, F. F.; Ítavo, C. C. B. F.; Nogueira, E. and Leal, E. S. 2014. Fontes de amido no concentrado de bovinos superprecoces de diferentes classes sexuais. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 66:1129-1138. https://doi.org/10.1590/1678-6514

Khan, N. A.; Yu, P.; Ali, M.; Cone, J. W. and Hendriks, W. H. 2015. Nutritive value of maize silage in relation to dairy cow performance and milk quality. Journal of the Science of Food and Agriculture 95:238-252. https://doi.org/10.1002/jsfa.6703

Kononoff, P. J. and Heinrichs, A. J. 2003. The effect of corn silage particle size and cottonseed hulls on cows in early lactation. Journal of Dairy Science 86:2438-2451. https://doi.org/10.3168/jds.S0022-0302(03)73838-7

Looper, M. L.; Stokes, S. R.; Waldner, D. N. and Jordan, E. R. 2001. Managing milk composition: Evaluating herd potential. Guide D-104. Cooperative Extension Service, College of Agriculture and Home Economics, New Mexico State University, Las Cruces.

Marafon, F.; Neumann, M.; Ribas, T. M. B.; Reinehr, L. L.; Poczynek, M.; Bueno, A. V. and Fianco, B. 2015. Análise do efeito da colheita da planta de milho em diferentes estádios reprodutivos e do processamento dos grãos sobre a qualidade da silagem. Semina: Ciências Agrárias 36:3257-3268. https://doi.org/10.5433/1679-0359.2015v36n5p3257

McAllister, T. A.; Bae, H. D.; Jones, G. A. and Cheng, K. J. 1994. Microbial attachment and feed digestion in the rumen. Journal of Animal Science 72:3004-3018. https://doi.org/10.2527/1994.72113004x

Mendes, E. D. M. and Campos, M. M. 2016. Eficiência alimentar em bovino de corte. Informe Agropecuário 37:28-38.

Mertens, D. R. 2005. Particle size, fragmentation index, and effective fiber: Tools for evaluating the physical attributes of corn silages. p.211-220. In: Proceedings Four-State Dairy Nutrition and Management Conference. MWPS-4SD18. Dubuque, IA.

Michels, A.; Neumann, M.; Leao, G. F. M.; Reck, A. M.; Bertagnon, H. G.; Lopes, L. S.; Souza, A. M.; Santos, L. C. and Stadler Júnior, E. S. 2018. Isoquinoline alkaloids supplementation on performance and carcass traits of feedlot bulls. Asian-Australasian Journal of Animal Sciences 31:1474-1480.

Muller, L. 1987. Normas para avaliação de carcaças e concurso de carcaças de novilhos. 2.ed. Universidade Federal de Santa Maria, Santa Maria. 31p.

NRC - National Research Council. 2016. Nutrient requirements of beef cattle. 8th rev. ed. National Academy Press, Washington, DC. https://doi.org/10.17226/19014

Neto, J. A. S.; Oliveira, V. S.; Santos, A. C. P. and Valença, R. L. 2014. Distúrbios metabólicos em ruminantes – Uma revisão. Revista Brasileira de Higiene e Sanidade Animal 8:157-186. https://doi.org/10.5935/1981-2965.20140141

Neumann, M.; Horst, E. H.; Bueno, A. V. I.; Venancio, B. J.; Santos, L. C.; Stadler Júnior, E. S. and Leão, G. F. M. 2018. Desempenho de novilhos confinados alimentados com silagens de diferentes híbridos de milho. Revista de Ciências Agrárias 41:548-556. https://doi.org/10.19084/RCA17126

Neumann, M.; Santos, L. C.; Askel, E. J.; Venancio, B. J.; Pontarolo, G. B.; Cristo, F. B.; Plodoviski, D. C. and Silva, E. P. 2021. Ruminal kinetics and degradability of energetic feedstuffs used in diets for ruminants. Ciência Animal Brasileira 22:e-68993. https://doi.org/10.1590/1809-6891v22e-68993

Nocek, J. E. 1988. In situ and other methods to estimate ruminal protein and energy digestibility: a review. Journal of Dairy Science 71:2051-2069. https://doi.org/10.3168/jds.S0022-0302(88)79781-7

Opsi, F.; Fortina, R.; Borreani, G.; Tabacco, E. and López, S. 2013. Influence of cultivar, sowing date and maturity at harvest on yield, digestibility, rumen fermentation kinetics, and estimated feeding value of maize silage. The Journal of Agricultural Science 151:740-753. https://doi.org/10.1017/S0021859612000925

Ørskov, E. R. and McDonald, I. 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. The Journal of Agricultural Science 92:499-503. https://doi.org/10.1017/S0021859600063048

Passini, R.; Silveira, A. C.; Titto, E. A. L.; Rodrigues, P. H. M.; Arrigoni, M. B.; Costa, C. and Chardulo, L. A. L. 2002. Silagem de grãos úmidos de milho e de sorgo e níveis protéicos sobre desempenho e características da carcaça de novilhos superprecoces. Acta Scientiarum. Animal Sciences 24:1133-1140. https://doi.org/10.4025/actascianimsci.v24i0.2600

Paulino, P. V. R.; Oliveira, T. S.; Gionbeli, M. P. and Gallo, S. B. 2013. Dietas sem forragem para terminação de animais ruminantes. Revista Científica de Produção Animal 15:161-172.

Paulino, P. V. R.; Valadares Filho, S. C.; Detmann, E.; Valadares, R. F. D.; Fonseca, M. A.; Véras, R. M. L. and Oliveira, D. M. 2008. Desempenho produtivo de bovinos Nelore de diferentes classes sexuais alimentados com dietas contendo dois níveis de oferta de concentrado. Revista Brasileira de Zootecnia 37:1079-1087. https://doi.org/10.1590/S1516-35982008000600019

Pavinato, P. S. 2017. Manual de adubação e calagem para o Estado do Paraná. SBCS/NEPAR, Curitiba.

Rooney, L. and Pflugfelder, R. 1986. Factors affecting starch digestibility with special emphasis on sorghum and corn. Journal of Animal Science 63:1607-1623. https://doi.org/10.2527/jas1986.6351607x

Saylor, B. A.; McCary, C. L.; Diepersloot, E. C.; Heinzen Jr., C.; Pupo, M. R.; Gusmão, J. O.; Ghizzi, L. G.; Sultana, H. and Ferraretto, L. F. 2021. Effect of forage processor roll gap width and storage length on fermentation profile, nutrient composition, kernel processing score, and starch disappearance of whole-plant maize silage harvested at three different maturities. Agriculture 11:574. https://doi.org/10.3390/agriculture11070574

Silva, D. J. and Queiroz, A. C. 2009. Análise de alimentos: métodos químicos e biológicos. 3.ed. reimpressão. Universidade Federal de Viçosa, Viçosa, MG.

Silvestre, A. M. and Millen, D. D. 2021. The 2019 Brazilian survey on nutritional practices provided by feedlot cattle consulting nutritionists. Revista Brasileira de Zootecnia 50:e20200189. https://doi.org/10.37496/rbz5020200189

Silveira, J. P. F.; Toseti, L. B.; Lo Tierzo, V.; Melo, V. F. P.; Persichetti Junior, P.; Silveira, T. F.; Bergamaschine, A. F.; Costa, C. and Meirelles, P. R. L. 2013. Consumo e digestibilidade total da silagem de milho processada mecanicamente. Boletim de Indústria Animal 70:53-58.

Souza, R. C. R. and Andrade, C. T. 2000. Investigação dos processos de gelatinização e extrusão de amido de milho. Polímeros: Ciência e Tecnologia 10:24-30. https://doi.org/10.1590/S0104-14282000000100006

Tedesco, M. J.; Gianello, C.; Bissani, C. A.; Bohnen, H. and Volhweiss, S. J. 1995. Análises de solo, plantas e outros materiais. 2.ed. Universidade Federal do Rio Grande do Sul, Porto Alegre.

Van Soest, P. V.; Robertson, J. B. and Lewis, B. A. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74:3583-3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Weiss, W. P.; Conrad, H. R. and St. Pierre, N. R. 1992. A theoretically-based model for predicting total digestible nutrient values of forages and concentrates. Animal Feed Science and Technology 39:95-110. https://doi.org/10.1016/0377-8401(92)90034-4

Young, K. M.; Lim, J. M.; Der Bedrosian, M. C. and Kung Jr., L. 2012. Effect of exogenous protease enzymes on the fermentation and nutritive value of corn silage. Journal of Dairy Science 95:6687-6694. https://doi.org/10.3168/jds.2012-5628

Zwald, A.; Dorshorst, A. E.; Hoffman, P. C.; Bauman, L. M. and Bertram, M. G. 2008. A near-infrared reflectance spectroscopy technique to predict particle size of starch within corn silage. Journal of Dairy Science 91:2071-2076. https://doi.org/10.3168/jds.2007-0832