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Substitution of dry corn grain by rehydrated and ensiled corn grain, finely or coarsely ground, on performance of young bulls finished in feedlot

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ABSTRACT - We investigated the effects of corn grain, finely or coarsely ground, rehydrated and ensiled to 35% moisture in substitution of dry corn grain on performance of beef cattle in the feedlot. Forty non-castrated young Angus crossbred bulls with average age of 13±1.4 months and average initial body weight (BW) of 374±14 kg. The experiment was conducted in blocks by weight, and bulls were randomly assigned into four groups of five animals each in a 2 × 2 factorial scheme. The factors evaluated were particle size (finely and coarsely ground) and two grain sources (dry ground corn and rehydrated corn grain silage). The treatments were diets containing dry corn grain, finely ground (DCF; 1.86 mm); dry corn grain, coarsely ground (DCC; 3.53 mm); rehydrated and ensiled corn grain, finely ground (RCF; 1.86 mm); and rehydrated and ensiled corn grain, coarsely ground (RCC; 3.53 mm). Initial BW, final BW, average daily gain (ADG), feed efficiency, and intake of dry matter (DMI), acid detergent fiber, and metabolizable energy were not affected by treatment. Ensiling corn grain decreased DMI by 10.3% (11.6 vs. 10.4 kg/d for dry and ensiled, respectively) and increased feed efficiency by 13.3% (0.13 vs. 0.15 kg/d for dry and ensiled, respectively), but there was no effect of particle size, grain source, and their interaction on ADG. Effects of particle size and grain source were observed for fecal starch and total tract starch digestion, with evidence that treatments containing rehydrated corn diets showed greater efficiency in the utilization of dietary starch. Animals fed RCF diets showed lower fecal starch losses of 37, 55, and 75% when compared with treatments RCC, DCF, and DCC, respectively. Our results suggested that ensiled rehydrated corn grain improves feed efficiency in substitution of dry corn grain. The finely and coarsely ground of rehydrated and ensiled corn grain increases the digestibility of starch for finishing cattle in feedlot.

Keywords: corn grain, feed efficiency, feedlot, processing, reconstituted corn

1. Introduction

Corn is the main source of energy used to feed confined cattle. In Brazil, flint corn is the predominant type used (Oliveira and Millen, 2014; Pinto and Millen, 2019) and is known to have a lower degradability rate and, therefore, lower energy availability (Philippeau and Michalet-Doreau, 1997; Correa et al., 2002;

Stock and Erickson, 2006). Grain processing practices aimed at modifying its physical structure and increasing starch availability are necessary (Ferraretto et al., 2015; González García et al., 2018; Silva et al., 2019).

Thus, processing is critical and can range from coarser grinding to more efficient and optimizing methods such as ensiling grains harvested with high moisture content or rehydrating grain with moisture content reconstitution (Macken et al., 2006; Ferraretto et al., 2014; Silva et al., 2018). Reducing particle size enhances energy availability, increases surface area for microbial colonization, and starch digestibility, consequently improving animal performance (McAllister et al., 2006; Owens and Soderlund, 2006; Zinn et al., 2007; Ferraretto et al., 2015; Arcari et al., 2016). Reducing particle size, however, can reduce chewing and rumination, as well as increase passage rate (Cozannet et al., 2018; González García et al., 2018).

Rehydrated and ensiled corn grain is an alternative to minimize some common problems in production systems that use corn as an energy source for beef cattle. This technology allows reducing and/or eliminating costs with fees and discounts, taxes, transportation, freight, and storage, as well as reducing losses from insect and rodent attacks, which is very common in dry corn storage (Macken et al., 2006; Silva et al., 2018; Paschoaloto et al., 2019). In addition, there are possibilities of buying grains during periods of lower prices, especially in the harvest season, with economic appeal, providing a reduction in cattle production costs (Arcari et al., 2016).

Ensiling rehydrated corn grain is a strategy to improve starch digestibility (Owens et al., 1986; Benton et al., 2005). During the storage period, the action of proteolytic bacteria and kernel proteases break down the protein matrix (Junges et al., 2017), increasing the availability of starch to animal digestion (Zinn et al., 2007; Hoffman et al., 2011; Ferraretto et al., 2015).

In recent meta-analyses about the effect of ensiling on the feeding value of flint corn grain for feedlot beef cattle, Jacovaci et al. (2021) found that the inclusion of ensiled corn in diets increased total tract digestibility of DM by 4.59% and starch by 3.33%, decreased DM intake by 14.1%, and increased feed efficiency by 18.3% but did not affect average daily gain (ADG). However, these benefits of grain ensiling are based on three major factors (Gomes et al., 2020): moisture content (Owens et al., 1997), particle size (Rémond et al., 2004), and length of storage time (Hoffman et al., 2011).

We hypothesized that mean particle size (MPS) and ensiling process of corn grain could increase animal performance by increasing the digestibility of starch, feed efficiency, and average daily gain (ADG) to allow a complete substitution of cracked dry corn grain. The objective was to evaluate the performance of young bulls fed finishing diets composed of rehydrated and ensiled corn grain, finely or coarsely ground, in substitution of dry corn grain, finely or coarsely ground.

2. Material and Methods

All procedures were approved by the Animal Use Ethics Committee (CEUA) under protocol number 029/2018.

2.1. Ensiling and processing

Shelled corn was purchased in the local market, with average vitreousness of 76%, determined by the method of Dombrink-Kurtzman and Bietz (1993), and dry matter (DM) content of 88%. Corn was ground in a hammer mill with 2-mm sieve for finely ground and 6-mm sieve for coarsely ground (Nogueira DPM 2 -7.5 HP, São João da Boa Vista, Brazil). Corn kernels were rehydrated with water, aiming to achieve 35% final moisture, and inoculated with microbial additive containing *Lactobacillus plantarum* MA 18/5U (3×10^{10} cfu/g) and *Propionibacterium acidipropionici* MA 26/4U (3×10^{10} cfu/g) (Biomax Milho, Lallemand, Saint-Simon, France). After rehydration, the material was ensiled in lined trench silos, compacted with a tractor, aiming at a density of 1000 kg/m^3 (Table 1), and sealed with polyethylene plastic film of 200 μm for 40 days. The dry corn finely and coarsely ground was stored in grain silos during the experiment.

Table 1 - Density and percentage of dry matter (DM) of rehydrated corn grain silage finely ground (RCF) and rehydrated corn grain silage coarsely ground (RCC) at the silo opening

Parameter	RCF	RCC
Compaction density (kg/m^3)	1,117	1,040
DM upon opening (%)	63.5	62.4

2.2. Experimental design, treatments, and feeding trial

Forty non-castrated young Angus crossbred bulls with average age of 13±1.4 months and average initial weight of 374±14 kg were used. All experimental animals were subjected to a 14-d adaptation period prior to the beginning of the experiment. All young bulls were previously fed corn silage on the farm of origin. Young bulls were transitioned to the finishing diet over a 14-d period following arrival, including starter Step-1 (fed d 1–7) and Step-2 (fed d 8–14).

The young bulls were blocked by weight and randomly assigned into four groups with five animals each in a 2 × 2 factorial scheme. Animals were housed in collective pens (two animals/pen), with 18 m^2 total area with 8 m^2 being covered. The factors evaluated were MPS (finely and coarsely ground) and two grain sources (dry ground corn and rehydrated corn grain silage). The treatments were diets containing dry corn grain, finely ground (DCF; 1.86 mm); dry corn grain, coarsely ground (DCC; 3.53 mm); rehydrated and ensiled corn grain, finely ground (RCF; 1.86 mm); and rehydrated and ensiled corn grain, coarsely ground (RCC; 3.53 mm).

Animals were fed twice a day (06.00 and 17.00 h), being offered 50% diet in the morning and 50% in the afternoon, allowing 5% of daily orts, ensuring *ad libitum* intake. The feed orts were quantified daily for the evaluation of DM (DMI) and nutrient intake by the animals, besides adjusting the diet to be provided.

The experimental period lasted 84 d, divided into three stages of 28 d. Animals were weighed for performance evaluation (ADG) at the beginning and end of each growth stage, after undergoing 12 h of solid fasting.

2.3. Laboratory analysis

The experimental diets were formulated according to the requirements estimated by NRC (2000) (Table 2). Weekly samples of each diet ingredients and orts were collected and frozen to form a composite sample per period. These samples were dried in a forced-air oven for 72 h at 55 °C and ground through a 1-mm mesh screen (Wiley mill, Arthur H. Thomas Co., Philadelphia, PA).

Subsamples were analyzed for DM and ash according to the Association of Official Analytical Chemists (AOAC, 2012; methods 934.01 and 942.05, respectively). Crude protein (CP) was determined by Micro Kjeldahl steam distiller (AOAC, 2012; method 984.13); diet neutral detergent fiber (NDF), acid detergent fiber (ADF), and lignin were analyzed with sodium sulfite and heat-stable α-amylase (Ankom A200I Fiber Analyzer, NKOM Technology, Macedon, NY, USA) according to Van Soest et al. (1991); and starch content was determined by an enzymatic method (AOAC, 2012; method 996.11).

Fecal grab samples were collected from each young bull twice at 08.00 and 20.00 h during the last 3 d of each period. Following the same processing and chemical evaluation procedures performed with the abovementioned samples. The total tract starch digestion (TTSD) was calculated according to Zinn et al. (2007):

$$\text{TTSD (\%)} = 99.9 - [0.413 \times \text{FS}] - [0.0131 \times \text{FS}^2],$$

in which FS = fecal starch.

Table 2 - Ingredients and nutrient composition of experimental diets with dry corn grain finely (DCF) or coarsely ground (DCC) and reconstituted corn grain silage finely ground (RCF) or reconstituted corn grain silage coarsely ground (RCC)

Item	Treatment			
	DCF	DCC	RCF	RCC
Ingredient (% of diet DM)				
DCF	38	-	-	-
DCC	-	38	-	-
RCF	-	-	38	-
RCC	-	-	-	38
Soybean meal	6	6	6	6
Wheat bran	3	3	3	3
Urea	1	1	1	1
Mineral supplement[1]	2	2	2	2
Corn silage (whole plant)	50	50	50	50
Dry matter (% as fed)	50.22	50.07	45.51	43.72
Nutrients (% as fed)				
Ash	4.43	4.21	4.05	3.61
Crude protein	12.08	12.41	12.27	12.08
Neutral detergent fiber	32.95	34.31	32.85	33.46
Acid detergent fiber	14.31	16.95	14.10	16.82
Hemicellulose	18.64	17.36	18.75	16.64
Dietary starch	45.01	43.56	45.57	45.22
Total digestible nutrients (%)[2]	77.82	75.97	75.87	75.37
Metabolizable energy (Mcal/kg)[3]	3.03	2.84	3.09	2.95

[1] Mineral supplement was composed of 240 g/kg Ca; 10 g/kg Mg; 50 g/kg Na; 90 g/kg K; 25 g/kg S; 380 mg/kg Cu; 1,800 mg/kg Zn; 1,200 mg/kg Mn; 13 mg/kg Se; 14 mg/kg Co; 28 mg/kg I; 190,000 IU/kg vitamin A; 14,000 IU/kg vitamin D3; 120 IU/kg vitamin E; and 1,250 mg/kg monensin.
[2] Estimated according to Weiss et al. (1992).
[3] Estimated according to NRC (2000).

The metabolizable energy (ME) of the diet (Mcal/kg), also in samples of DCF, DCC, RCF, RCC, and whole corn plant silage, was estimated according to the equation proposed by NRC (2000). From the derived estimates of net energy required for maintenance and gain, the NEm and NEg values of the diet were obtained using the quadratic formula proposed by Zinn and Shen (1998).

$$x = (-b - \sqrt{b^2 - 4ac})/2c,$$

in which x = diet NEm (Mcal/kg); a = −0.41ME; b = 0.877ME + 0.41DMI + EG; c = −0.877DMI; and NEg = 0.877NEm − 0.41.

2.4. Statistical analyses

Statistical analyses were performed using PROC MIXED of SAS (Statistical Analysis System, version 9.3). Data were analyzed as a randomized block design using the following model:

$$Y_{ijk} = \mu + B_i + PS_j + SG_k + PS_jSG_k + e_{ijk},$$

in which μ = overall mean, B_i = random effect of block (i = 1 to 4), PS_j = fixed effect of mean particle size (j = finely or coarsely ground), SG_k = fixed effect of source grain (k = dry or rehydrated), PS_jSG_k = interaction between PS and SG, and e_{ijk} = residual error. When significance was observed, an F test was used to identify differences at P<0.10.

3. Results

In the present study, there were no interaction effects for parameters initial BW, final BW, ADG, feed efficiency, DMI, ADF intake, and ME of diets (Table 3). Statistical differences (P<0.01) were found for feed efficiency and DMI, when comparing diets containing dry ground corn and rehydrated corn grain silage, respectively. Diets with rehydrated and ensiled corn decreased the DMI (10.3%). Compared with diets containing dry corn, diets balanced with ensiled corn increased feed efficiency without affecting ADG.

The NEm value of the diets was similar for rehydrated and dry corn treatments. However, the NEg for RCC increased values of the diet by 1.4% (RCF), 4.1%(DCF), and 10.9% (DCC).

For ADF intake, differences were found for the influence of MPS (P = 0.04) and grain source (P<0.01). There was a higher intake of ADF for animals fed dry corn and corn grain coarsely ground when compared with finely ground and rehydrated corn. In contrast, no significant differences (P = 0.48) were detected in ME intake when comparing grain source and particle size.

The ensiling process provided a 10.2% reduction in protein intake when compared with the use of ground corn, regardless of the particle size used. There was also an interaction effect of grain source on this trait showing higher protein intake in diets with dry corn over treatments with rehydrated corn, with no particle size effect.

Interaction effects between particle size and grain source were found for the variables daily intake of NEm, NEg, CP, NDF, and starch and for fecal starch and TTSD (Table 4). For variables CP and NDF (kg/d), higher intake values were found for animals fed dry corn in the diet.

Table 3 - Effects of interactions of particle size (PART) and grain source (dry or rehydrated and ensiled) of corn on performance and nutrient intake

Item	Particle size		Source		SEM	P-value		
	FG	CG	DC	RC		PART (P)	Source (S)	P×S
Animal performance								
Initial BW (kg)	374.2	374.3	374.5	374.0	3.14	0.98	0.92	0.75
Final BW (kg)	503.9	504.9	505.0	503.7	1.01	0.99	0.46	0.75
ADG (kg)	1.52	1.54	1.53	1.53	0.05	0.80	0.92	0.17
Feed efficiency	0.14	0.14	0.13	0.15	0.41	0.65	<0.01	0.12
Nutrient intake								
DM (kg/day)	10.8	11.2	11.6	10.4	0.14	0.28	<0.01	0.97
ADF (kg/day)	0.59	0.70	0.75	0.54	<0.01	0.04	<0.01	0.62
ME (Mcal/day)	34.3	31.6	34.0	32.0	1.61	0.41	0.48	0.81

BW - body weight; ADG - average daily gain; DM - dry matter; ADF - acid detergent fiber; ME - metabolizable energy.
Particle size: FG - finely ground corn; CG - coarsely ground corn. Source: DC - dry corn grain; RC - rehydrated and ensiled corn grain.

Table 4 - Effects of particle size (PART; finely or coarsely ground) and grain source (dry or rehydrated and ensiled) of corn on nutrient intake, fecal starch, and TTSD of cattle fed the evaluated diets

Item	Treatment[1]				SEM	P-value		
	DCF	DCC	RCF	RCC		PART (P)	Source (S)	P×S
Nutrient intake								
Dietary NEm (Mcal/kg)	2.06a	1.90b	1.99ab	2.05a	0.16	2.88	0.20	0.08
Dietary NEg (Mcal/kg)	1.40a	1.30b	1.44a	1.46a	0.12	2.92	0.20	0.09
CP (kg/day)	1.38ab	1.46a	1.27b	1.28b	0.01	0.94	0.04	0.05
NDF (kg/day)	2.89ab	3.09a	2.64bc	2.52c	0.07	<0.01	0.79	0.04
Starch (kg/day)	3.21a	3.15ab	3.15ab	3.08b	0.49	0.07	0.13	0.08
Fecal starch (%)	5.70b	10.52a	2.54c	4.01bc	0.08	<0.01	<0.01	<0.01
TTSD	97.1b	94.1c	98.8a	98.1ab	0.14	<0.01	<0.01	<0.01

[1] DCF - dry corn grain finely ground; DCC - dry corn grain coarsely ground; RCF - rehydrated corn grain silage finely ground; RCC - rehydrated corn grain silage coarsely ground.
CP - crude protein; NEm and NEg - net energy for maintenance and gain of corn (Zinn and Shen, 1998); TTSD - total tract starch digestion (Zinn et al., 2007); NDF - neutral detergent fiber; SEM - standard error of the mean.

For starch intake (kg/day), differences were found between experimental diets, and there was influence of particle size (PART) and interactions for this parameter. Animals fed diets containing RCC had the lowest daily starch intake, being 4% lower than DCF.

Particle size and grain source effects were observed for fecal starch (P<0.01) and TTSD (P<0.01), with evidence that animals fed rehydrated corn diets showed greater efficiency on utilization of dietary starch. Our results about TTSD indicated that feeding beef cattle with rehydrated and ensiled corn increased total digestibility of corn starch. Animals fed RCF showed lower fecal starch losses of 37, 55, and 75% when compared with treatments RCC, DCF, and DCC, respectively.

4. Discussion

The decrease of DMI observed in diets with rehydrated and ensiled corn did not influence ADG. These results provided an increase of 13.3% in feed efficiency of animals fed rehydrated corn in replacement of dry corn. Similar to the results found in this trial, Jacovaci et al. (2021) observed that the replacement of dry corn with rehydrated corn also did not affect the ADG, but there was a reduction in the DMI of 14.1% and an improvement in feed efficiency of 18.3%.

The inclusion of rehydrated and ensiled corn in diets for finishing cattle can increase feed efficiency by an average of 14% as a result of an average reduction of 12% in feed intake (Tonroy et al., 1974; Benton et al., 2005; Caetano et al., 2015; Caetano et al., 2019; Paschoaloto et al., 2019; Salvo et al., 2020). However, these benefits and results of using grain ensiling are based on major factors: moisture and nutritional content, particle size, quality of the ensiling process, and length of storage time (Owens et al., 1997; Rémond et al., 2004; Hoffman et al., 2011; Silva et al., 2018; Gomes et al., 2020; Salvo et al., 2020).

The action of proteolytic bacteria and kernel proteases break down the protein matrix during the storage period (Junges et al., 2017). Thus, there is an increase in the availability and digestibility of starch in both the rumen and the small intestine (Owens et al., 1986; Owens et al., 1997; Hoffman et al., 2011).

The greater availability and fermentability of starch are associated with hypophagia (Oba and Allen, 2003). The explanation may be related to higher energy availability (NEm and NEg) and the "Hepatic Oxidation Theory", defended by Allen et al. (2009). According to the authors, with higher starch fermentability, there is an increase in the production of short-chain fatty acids (SCFA) per unit of rumen-fermented organic matter, resulting in changes in the ruminal fermentation pattern, which leads to an increase in the molar proportion of propionate, which has a DMI suppression effect.

A potential explanation for increase in the production of SCFA is that the starch in corn experiences different degrees of exposure to enzymatic attack in the rumen (Beauchemin et al., 1994; Huntington, 1997), which indicates that rehydrated and ensiled corn is a more efficient processing method than grinding corn for beef cattle in feedlot.

The averages of NEg values of corn grain silage were markedly higher, 7% higher than dry flint corn (finely or coarsely ground). Ensiled corn in finishing diets increased starch and DM digestibility and had higher energy contents than diets based on dry corn. Previous studies have suggested that NEg of dry ground flint corn is lower than tabular values in nutritional models (e.g., NRC, 1996; NASEM, 2016) and the ensiling corn grain may increase the NEg to 1.72 Mcal/kg DM (Zinn et al., 2011).

The percentage of fecal starch was influenced by the treatments, in which the highest starch content in the feces was verified when the animals were fed dry corn ground to larger particles, demonstrating that when the corn was rehydrated and ensiled, it provided better utilization of this nutrient. Similar to the present study, Cozannet et al. (2018) showed an increase in the energy of corn-based diets and a reduction in fecal starch content of bulls fed rehydrated and ensiled corn grain (Salvo et al., 2020).

In the same way, Ferraretto et al. (2015) stated that the rehydration of ground corn increased starch digestibility, especially when ensiled, suggesting that these procedures may be viable alternatives under favorable climatic conditions for harvesting and storage. The increase in grain starch digestion was expected because according to Watson (1987), the breakage of corneous endosperm occurs along the cell walls as a result of the strength of the protein matrix.

Another important point to highlight is that the finely ground dry corn grain also improved digestibility by decreasing fecal starch and increasing TTSD when compared with dry coarsely ground corn grain in the diet of young bulls finished in feedlot.

Starch digestibility is inversely proportional to the MPS for dry (Rémond et al., 2004) and rehydrated and high-moisture corn (Ferraretto et al., 2014). In the present trial, a higher percentage of fecal starch was verified for the treatments that contained MPS of 3.53 mm. On the other hand, Gomes et al. (2020) reported that flint corn presents divergent data when compared with dent corn.

The increase of TTSD observed in this trial may have occurred as a result of greater degradation of some zein protein in the starch-protein matrix of rehydrated and ensiled corn, improving greater solubilization of protein matrix and consequently, increasing starch granule surface area for bacterial attachment in the rumen (Huntington et al., 2006; Hoffman et al., 2011; Ferraretto et al., 2015).

Diets containing rehydrated and ensiled finely ground corn grain had higher NEg level accompanied by lower fecal starch loss. This may be an indication that the use in diets for finishing beef cattle requires supply adjustments, because although there may be a decrease in DMI, there was no influence on ADG.

5. Conclusions

Our results suggested that ensiled rehydrated corn grain improves feed efficiency, and the finely and coarsely ground rehydrated and ensiled corn grains increase the digestibility of starch in substitution of dry corn grain. The fine grinding of dry grain can also be a valid strategy in diet of finishing of young bulls in feedlot.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: M.R.H. Silva and C.C. Jobim. Data curation: M.R.H. Silva. Formal analysis: M.R.H. Silva, C.C. Jobim and M.P. Osmari. Funding acquisition: M.R.H. Silva and M. Neumann. Investigation: M.R.H. Silva, C.C. Jobim and M. Neumann. Methodology: M.R.H. Silva, C.C. Jobim and M. Neumann. Project administration: M.R.H. Silva. Resources: M.R.H. Silva. Supervision: C.C. Jobim and M. Neumann. Validation: M.R.H. Silva and C.C. Jobim. Visualization: M.R.H. Silva and M. Neumann. Writing-original draft: M.R.H. Silva and M.P. Osmari. Writing-review & editing: M.R.H. Silva, C.C. Jobim, M. Neumann and M.P. Osmari.

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