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The effect of corn grain micronization on diet digestibility and blood biochemical parameters in weaned Holstein calves

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Abstract

Aim of study: To evaluate corn grain micronization for calves fed a grower diet.

Area of study: Padinska Skela – Belgrade, Serbia.

Material and methods: Thirty weaned Holstein dairy calves (65–74 days of age) were randomly assigned to one of two treatments with growers containing micronized (MCG) or untreated corn grain (UCG). The experimental period lasted for 60 days.

Main results: The values of total tract apparent digestibility of dry matter (DM), organic matter (OM), crude protein (CP), and nonfiber carbohydrates (NFC) were higher for calves fed MCG versus those within the UCG treatment by 3.9% ($p<0.05$), 7.0% ($p<0.01$), 7.1% ($p<0.01$) and 7.5% ($p<0.05$), respectively, for the days 25–30 of the experimental period. In addition, the values of digestibility of OM, CP, and NFC were higher by 4.9% ($p<0.05$), 5.7% ($p<0.05$), and 6.0% ($p<0.05$), respectively, for the days 55–60 of the experimental period. The density of metabolizable energy, net energy for maintenance and gain in consumed dietary DM was higher ($p<0.001$) by 4.7, 5.5, and 7.2%, respectively for calves fed on the grower containing micronized corn grain (MCG), during the first digestibility period, and by 3.0, 3.6, and 4.6%, respectively, during the second digestibility period. Energy intake was lower ($p<0.05$) during the second digestibility period, for calves fed a diet with micronized corn. Blood urea N was affected ($p<0.001$) by dietary treatments. Lower values (10.2%) were observed for calves fed the grower containing MCG.

Research highlights: The micronization of corn grain is a useful tool for optimizing weaned calf production due to the improvement in the digestibility and energy content of the ration.

Additional key words: calf; grains; grower diets; feed efficiency; heat-processing.

Abbreviation used: ADF (acid detergent fiber); BW (body weight); CP (crude protein); DE (digestible energy); DM (dry matter); DMI (dry matter intake); EE (ether extract); MCG (micronized corn grain); ME (metabolizable energy); NDF (neutral detergent fiber); NEg (net energy for gain); NEL (net energy for lactation); NEm (net energy for maintenance); NFC (nonfiber carbohydrates); OM (organic matter); RUP (rumen undegradable protein); UCG (untreated corn grain).

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Introduction

Corn grain is commonly used as a starch source in calves' diets. The starch granules of corn are completely embedded in a protein matrix, reducing the starch availability since this matrix is impermeable to water and enzymes (Sadeghi et al., 2012). Cereal grains may be processed to increase their digestibility, by affecting the rate and extent of starch and protein degradation in the rumen and their intestinal digestion (Yu et al., 2010).

The rate and extent of ruminal fermentation vary widely with grain source and cereal processing methods (Huntington, 1997). Increasing starch availability is the primary goal of corn grain heat-processing. Processing methods have been shown to improve nutrient digestibility and shift the rate and site of grain digestion (Chrenkova et al., 2018). Extrusion increases starch degradation in the rumen, while pressure toasting decreases degradation and increases rumen bypass starch (Yu et al., 2002). Steam-flaking has been found to increase the amount of starch fermented in the rumen and enhance starch digestion in the small intestine (Firkins et al., 2001).

Micronization is the term that refers to a high-temperature, short-time heat processing of grains using near-infrared (NIR) rays. This affects the constituent molecules to vibrate, which leads to intermolecular friction, resulting in rapid heating of the material that causes the gelatinization of starch (Deepa & Hebbar, 2014). Micronization has many advantages compared to other heating methods because infrared energy heats the grains directly, which enables achieving a high efficiency level. Increasing the starch availability and altering the site of digestion of protein from the rumen to the intestine is the primary goal of grain processing. This may result in an improved supply of amino acids to animal metabolism (Safaei & Yang, 2017). Heat processing improves the efficiency of fermentative utilization by modifying the protein matrix of the endosperm and the starch structure (gelatinization and dextrination), thus enabling a better utilization by microbial enzymatic digestion (Alvarado et al., 2009). According to Yu et al. (2010), micronization significantly reduced protein degradability (74 vs. 63%), but increased starch degradability (87 vs. 93%) of the oat in dairy total mixed rations. Deepa & Hebbar (2014) reported that micronization increased the rapidly digestible starch content (7.1 to 7.7%) determined in vitro, which may be attributed mainly to the gelatinization of starch. On the other hand, Sadeghi et al. (2012), in the experiment with rams, found that the micronization of corn grain decreased the potentially degradable fraction and ruminal degradation rate of starch. McAllister & Sultana (2011), in a study with steers, also detected that micronized wheat markedly reduced the rate and extent of ruminal disappearances of dry matter (DM), starch and protein, suggesting the increased resistance of protein to microbial digestion in the rumen.

However, scientific research to evaluate the dietary effects of micronized cereal grains on feed consumption, nutrient digestibilities and metabolic response in dairy calves is limited. This study was conducted to evaluate the effects of micronized corn grain as a dietary starch source on total tract nutrient digestibility and blood biochemical parameters in weaned Holstein calves.

Material and methods

The experiment was carried out at a commercial dairy cattle farm (PKB Corporation Padinska Skela), Serbia. The study was conducted according to the Animal Welfare Act (41/2009, Official Gazette). Experimental procedures complied with adopted standards by the Ethics Committee on Animal Experimentation of the Faculty of Agriculture.

Experimental design, treatments, and management

Thirty weaned Holstein dairy calves (20 male and 10 female) with initially 72±1.9 kg of body weight (BW) and 65 to 74 days of age were randomly assigned to one of two experimental grower diets (15 calves per treatment). From day 4 to weaning, all calves were fed 6 L/day of prepared milk replacer, while starter and high-quality alfalfa hay were fed ad libitum. Calves were weaned at 60 days of age. Ground corn and micronized corn (ground through a 2-mm mesh) were used to formulate two iso-starch, isonitrogenous, and isoenergetic pelleted calf growers with all other components. The experiment was designed as one factorial arrangement with two treatments – a grower that included untreated corn grain (UCG) and a grower that included micronized corn grain (MCG). Calves were housed in group pens (3 calves/pen), wherein each experimental treatment consisted of five pens with 2 male calves and 1 female calf. Pens were bedded with long wheat straw, which was renewed every 24 h. The experimental period lasted for 60 days.

The corn grain (dent corn hybrid Maksim, Institute PKB Agroekonomik, Padinska Skela) was conditioned before micronization to reach a 25% moisture content, and thereafter was subjected to micronization for 45 s at 120°C (Infra-Red Micronizer, Micronizing Company U.K. Ltd). The micronized grains were flaked by a heavy-duty flaking mill (a 0.8 mm gap between rolls) and cooled in a counter flow-cooler. The micronizer capacity was 1200 kg/h. Micronized material was ground by a hammer mill before mixing with the other components. Table 1 shows the chemical composition of heat-treated and untreated corn grain used to formulate calf growers.

Calves were fed the concentrate mixtures (20% crude protein - CP on a DM basis) for ad libitum intake (orts did not exceed 10%). The pellets were 20 mm in length and 4 mm in diameter. The ingredient composition of calf mixtures is presented in Table 2. Calves were allowed free access to unchopped high-quality alfalfa hay from feeding

Table 1. Chemical composition of micronized (MCG) and untreated (UCG) corn grains included in calf growers, and the alfalfa hay used in diets.

Ingredient	MCG	UCG	Alfalfa hay
DM, %	89.6	87.9	83.0
CP, % DM	8.22	8.49	20.15
EE, % DM	3.62	3.47	2.09
NDF, % DM	11.0	11.2	44.0
ADF, % DM	2.58	2.76	32.02
NFC, % DM	76.1	75.6	27.1
Ash, % DM	1.10	1.16	8.72
Ca, % DM	0.05	0.05	1.91
P, % DM	0.32	0.34	0.34

DM: dry matter. CP: crude protein. EE: ether extract. NDF: neutral detergent fiber. ADF: acid detergent fiber. NFC: nonfiber carbohydrates.

buckets and water from a drinker in each pen. Growers and alfalfa hay were offered to calves once a day at 07:00 h.

Digestibility trial

Apparent total tract digestibility of the nutrients was measured using acid-insoluble ash as a suitable internal marker (Van Keulen & Young, 1977; Huhtanen et al., 1994). During the two periods (days 25–30 and days 55–60 of the experiment), fecal grab samples were collected from the pen floor, composited by pen, and then frozen at −20°C until further analysis. Samples were mostly collected between 07:00 and 9:00 h, and care was taken not to sample non-fecal material. Feeds were offered for minimal refusals (about 3%) during the collection periods. Offered feeds and orts were measured and stored, composited, and subsampled for analysis. During both digestibility periods, new bedding was added only twice to minimize the straw consumption by calves.

Apparent nutrient digestibility in the total tract was calculated from concentrations of the marker and nutrients in the consumed diet (grower and alfalfa hay) and feces using the following equation: Apparent digestibility = $100-[(M_d/M_f)\times(N_f/N_d)]\times100$, where M_d = concentration of the marker in the consumed diet, M_f = concentration of the marker in the feces, N_f = concentration of the nutrient in the feces, and N_d = concentration of the nutrient in the consumed diet.

Body weight (BW) was recorded before the morning meal at days 30 and 60 of the experimental period.

Analytical procedures

Composites of feed, fecal, and ort samples were analyzed in the Laboratory of Animal Nutrition at the Faculty of Agriculture, University of Belgrade. Composite fecal samples were thawed at room temperature and dried in a forced-air oven at 55°C (approximately 48 h). Samples of growers, alfalfa hay, orts, and feces were ground to pass a 1 mm screen on a small-sample mill (Kinematica PX-MFC 90D). Ground samples of feeds and feces were analyzed according to the Official Methods (AOAC, 2002). The analytical DM content of samples was determined by drying at 105°C for 16 h (method 967.03). Ash was determined by combustion at 600°C for 2 h (method 942.05). The CP content was determined by the Kjeldahl method (method 2001.11) using K_2SO_4/Cu catalyst-Kjeltabs S 3.5 using a Kjeltec Auto 1030 Analyzer-Tecator System. Ether extract (EE) content was determined by extraction using diethyl-ether in the Soxhlet apparatus (method 920.39). The neutral detergent fiber (NDF) content was determined according Method 2002.04, using heat-stable α-amylase (A3306 Sigma Chemical Co., St Louis, MO, USA), without using sodium sulfite and without correcting ash content. The acid detergent fiber (ADF) was determined without correcting ash content (Method 973.18).

The acid-insoluble ash content of concentrate mixtures, alfalfa hay, and feces was determined according to Van Keulen & Young (1977) using 2 M HCl.

Blood biochemical parameters

On day 60 of the experimental period, blood samples (20 mL) were collected from each calf between 10:00 and 12:00 h using a jugular catheter into a vacutainer tube and placed on ice. The samples were centrifuged at 3000×g for 15 min at 4°C, and the obtained plasma subsamples were analyzed for glucose, total protein, and urea nitrogen using commercial kits (ThermoFisher Scientific: EIAGLUC, A53227, and EIABUN, respectively) and the semi-automatic biochemical analyzer RT-1904C (Rayto Life and Analytical Sciences Co. Ltd) in the laboratory for diagnostic analysis of PKB Corporation – Centre for livestock production, Padinska Skela.

Table 2. Composition and nutritive value of calf growers containing micronized (MCG) or untreated (UCG) corn grains.

	MCG	UCG
Ingredients (%)		
Corn, ground	-	59.0
Corn-micronized, ground	59.0	-
Whole soybean, extruded	22.0	22.0
Sunflower meal	15.0	15.0
Calcium carbonate	1.0	1.0
Calcium diphosphate	1.0	1.0
NaCl	0.5	0.5
Minazel[1]	0.5	0.5
Vitamin and mineral mix[2]	1.0	1.0
Chemical composition		
Dry matter (DM), %	91.4	90.3
Crude protein, % DM	19.7	20.1
Ether extract, % DM	6.53	6.41
NDF, % DM	23.0	23.6
ADF, % DM	12.5	13.0
NFC, % DM	47.4	46.7
Ash, % DM	5.40	5.52
Ca, % DM	0.82	0.84
P, % DM	0.71	0.68

[1]Mineral adsorbent of mycotoxins, based on natural zeolite, clinoptilolite. [2]Mixture of vitamins and trace elements, 1 kg contains: vitamin A – 1000000 IU, vitamin D – 150000 IU, vitamin E – 2000 mg, thiamin – 100 mg, Riboflavin – 200 mg, niacin – 1000 mg, calcium D-pantothenate – 500 mg, cyanocobalamin – 1 mg, Mg – 60 g, S – 2000 mg, Fe – 5000 mg, Cu – 1000 mg, Zn – 5000 mg, Mn – 3000 mg, J – 60 mg, Se – 10 mg, and Co – 20 mg. NDF: neutral detergent fiber. ADF: acid detergent fiber. NFC: nonfiber carbohydrates.

Energy utilization

Digestible energy (DE) values of calves' diets were estimated according to Weiss (1999) using determined apparent total tract digestibility of CP, nonfiber carbohydrates (NFC), NDF, and EE. Levels of dietary metabolizable energy (ME) as well as net energy for maintenance (NE_m) and net energy for gain (NE_g) were calculated according to Galyean et al. (2016).

Statistical analysis

The Student's t-Test using the JASP v.0.15 (JASP Team, 2021) was conducted to assess the effects of corn grain micronization on total tract nutrient digestibility and blood metabolites in calves. The Shapiro-Wilk's test was used to test the assumption of the normal distribution of analyzed data. Overall differences between treatment means were considered to be significant at $p<0.05$ and trend at $p<0.1$. The parameters of descriptive statistics were also determined.

Results

Over both digestion measurement periods, calves on the UCG treatment consumed more grower than MCG calves ($p<0.05$), whereas alfalfa hay intake did not vary (Table 3). The total DM, OM, and CP intakes were higher ($p<0.001$) for calves on the UCG treatment. Greater intakes ($p<0.01$ to 0.05) of NDF ($p<0.01$), ADF, and NFC

Table 3. Effects of corn grain heat processing on the nutrients intake of weaned Holstein calves; calves fed a grower containing micronized (MCG) or untreated (UCG) corn grains and alfalfa hay.

Item	MCG	SEM	UCG	SEM	p-values	MCG	SEM	UCG	SEM	p-values
	Days 25–30 of the exp. period					Days 55–60 of the exp. period				
Average BW, kg[1]	91.5	1.01	88.3	0.99	0.053	123	1	122	1	0.354
Intake, g DM/day[2]										
Grower	2173	30	2327	32	0.020	2846	29	3027	38	0.014
Alfalfa hay	431	25	417	23	0.736	438	33	417	23	0.660
DM	2603	5	2744	19	<0.001	3284	8	3444	15	<0.001
OM	2448	6	2579	18	<0.001	3092	7	3241	15	<0.001
CP	515	1	553	4	<0.001	649	2	694	3	<0.001
NDF	635	4	670	6	0.006	779	8	818	2	0.006
ADF	410	4	435	5	0.012	496	7	526	3	0.013
NFC	1147	7	1199	11	0.011	1469	5	1526.0	11	0.007

BW: body weight. DM: dry matter. OM: organic matter. CP: crude protein. NDF: neutral detergent fiber. ADF: acid detergent fiber. NFC: nonfiber carbohydrate. The assumption that the data are normally distributed was met. [1] n=15. [2] n=5.

were also observed for the UCG calves during the first and second digestibility periods. On the other hand, calves fed the MCG grower tended to have greater average BW than UCG calves.

Total tract apparent digestibility measurements during the 4th week of the experimental period are shown in Table 4 (left). The digestibility of OM and CP was greater for calves fed MCG versus UCG treatment ($p<0.01$), as well as the digestibility of DM and NFC ($p<0.05$). Total tract digestibilities of NDF, ADF, and ether extract were not affected.

Apparent digestibility coefficients for days 55 to 60 of the experimental period are shown in Table 4 (right). Calves fed a diet with MCG had greater digestibility coefficients for OM, CP, and NFC ($p<0.05$) compared with calves fed a UCG diet. As in the first collection period, the digestibility of NDF, ADF, and EE was not affected by corn grain micronization, with a difference for the NDF digestibility value that tended to be lower for the group fed MCG grower.

During both digestion measurement periods, the content of ME, $NE_{m,}$ and NE_g (MJ/kg consumed DM) was affected by using the heat-treated corn grain in grower feed (Table 5). The energy values (ME, $NE_{m,}$ and NE_g) of consumed dietary DM were greater for MCG versus UCG diet ($p<0.001$), while energy intake was almost equal for both treatments in the first collection period or lower ($p<0.05$) during the second digestibility period, for calves fed a micronized corn diet.

Table 4. Effects of corn grain heat processing on total tract apparent digestibility in weaned Holstein calves that fed a grower containing micronized (MCG) or untreated (UCG) corn grains and alfalfa hay.

Digestibility, %	MCG	SEM	UCG	SEM	p-values	MCG	SEM	UCG	SEM	p-values
	Days 25–30 of the exp. period					Days 55–60 of the exp. period				
DM	79.02	1.4	76.09	1.4	0.034	79.73	1.8	77.25	1.0	0.075
OM	81.62	2.2	76.28	1.8	0.008	81.91	1.9	78.06	1.4	0.020
CP	75.30	1.7	70.32	1.7	0.003	76.25	2.2	72.14	1.7	0.031
EE	85.95	1.2	86.36	1.7	0.766	85.77	3.4	87.36	2.2	0.549
NDF	55.67	2.1	58.23	1.7	0.155	55.08	2.1	58.92	2.2	0.062
ADF	49.59	1.6	50.76	1.5	0.416	49.39	1.5	51.18	2.0	0.281
NFC	88.80	2.5	82.59	3.7	0.043	89.57	2.0	84.50	2.6	0.025

DM: dry matter. OM: organic matter. CP: crude protein. EE: ether extract. NDF: neutral detergent fiber. ADF: acid detergent fiber. NFC: nonfiber carbohydrate. The assumption that the data are normally distributed was met. n=5.

Table 5. Effects of corn grain heat processing on the energy density of consumed DM and energy intake in weaned Holstein calves that fed a grower containing micronized (MCG) or untreated (UCG) corn grains and alfalfa hay.

Energy values	MCG	SEM	UCG	SEM	p-values	MCG	SEM	UCG	SEM	p-values
	Days 25–30 of the exp. period					Days 55–60 of the exp. period				
ME (MJ/kg consumed DM)	12.79	0.025	12.22	0.019	<0.001	12.94	0.025	12.56	0.017	<0.001
NEm (MJ/kg consumed DM)	8.03	0.018	7.61	0.013	<0.001	8.14	0.017	7.86	0.011	<0.001
NEg (MJ/kg consumed DM)	5.35	0.016	4.99	0.012	<0.001	5.44	0.015	5.20	0.009	<0.001
Intake of ME (MJ/day)	33.48	0.120	33.85	0.250	0.286	42.68	0.086	43.54	0.236	0.022

The assumption that the data are normally distributed was met. n=5.

The measured blood biochemical parameters are shown in Table 6. No significant differences were observed for blood total protein or glucose in both treatments. On the other hand, calves on MCG had lower blood urea concentrations than UCG ($p<0.001$).

Discussion

The primary reason for heat processing of corn grain is to enhance feeding value by the impact on nutritional and digestive characteristics. The grower dry matter intake (DMI) was decreased (5.1 and 4.7%, $p<0.05$) when MCGs were included. This is likely due to the increased rate and extent of ruminal fermentation and higher total tract digestibility and utilization of the consumed diet. It could be also related to lower ruminal pH. Steam-flaking of corn lowered ruminal pH and reduced DMI in feedlot cattle (Zinn et al., 2002; Corona et al., 2005). Similar results were obtained for steam-flaked oat (Tosta, 2019) and barley (López-Soto et al., 2014) used in the ration for lactating dairy cows, where the decrease in DMI was attributed mainly to lower ruminal pH of cows fed more extensively processed grains.

Weaned Holstein calves fed the grower containing MCG had significantly greater apparent digestibility coefficients for DM, OM, CP, and NFC (3.9, 7.0, 7.1, and 7.5%, or 3.2, 4.9, 5.7, and 6.0%, respectively) compared to the grower containing UCG. Increased digestibility has been also noted in earlier studies with heat-treated grains. Likewise, steam-flaked corn-based diets for beef cattle had greater DM digestibility (Leibovich et al., 2009) and greater digestibility of OM and starch (Corona et al., 2006) than dry-rolled corn-based diets. Heat processing results in a greater proportion of dietary starch fermented in the rumen, enhances the extent of starch digestion in the small intestine, and increases total starch digestibility (Firkins et al., 2001). Grain processing increases starch availability for microbial enzymatic digestion, thereby improving cattle performance (Bengochea et al., 2005). In addition, this increased digestibility is caused by the disruption of the protein matrix surrounding the starch granules in the grain endosperm and the disorganization and gelatinization of the starch granules (Theurer et al., 1999). It is also reported that increasing starch flow to the small intestine in ruminants may be accompanied by decreased total tract digestion because starch that escapes fermentation is more resistant to enzymatic digestion (Harmon et al., 2004).

A more effective utilization of ammonia for microbial protein synthesis due to a more extensive ruminal degradation of starch, as well as increasing the rumen undegradable protein (RUP) content and degradation in the small intestine could be the basis for greater total tract apparent digestibility of CP. The higher rate of ruminal starch fermentation decreases the extent of OM digestion in the large intestine; thus, decreased fecal N loss should be expected. An observed tendency of increased BW for calves fed the grower containing MCG could result from obtaining greater total tract CP digestibility and possibly higher N retention in body tissues. The more extensive ruminal degradation of processed grain carbohydrates is positively correlated to the utilization of ammonia for microbial protein synthesis (Chibisa et al., 2015). The steam-flaking of grains increased the flow of microbial protein to the duodenum in dairy cows (Theurer et al., 1999; Firkins et al., 2001). Steam-flaking increases urea cycling to the gut and microbial protein flow to the small intestine. Chrenkova et al. (2018) reported that steam-flaked wheat, maize, and barley, showed higher RUP and lower rumen degradable protein. Rahman et al. (2016) noticed that the microwave irradiation of oat grains numerically increased the RUP degradation in the small intestine. The feeds' heat treatment without moisture can increase the intestinal digestion of RUP while decreasing the degradation rate in the rumen, which depends on the heat intensity and the duration of the process (Sadeghi & Shawrang, 2007). The results of the study by Tosta (2019) also showed that steam-flaked oat in the ration for dairy cows decreased the soluble true protein fraction whereas rumen undegradable protein was significantly higher. In a study using feedlot cattle, Corona et al. (2005) reported that the digestibility of CP was greater by 7.0% for steam-flaked maize than for dry maize. Heat-treated corn has also consistently been proven to increase post-ruminal protein digestion (Barajas & Zinn, 1998).

Table 6. Blood measurements of weaned Holstein calves fed a ration with a grower containing micronized (MCG) or untreated (UCG) corn grains, at day 60 of the experimental period.

Item	MCG	SEM	UCG	SEM	p-values
Total protein, g/dL	6.54	0.05	6.38	0.08	0.137
Glucose, mg/dL	75.5	0.4	74.4	0.6	0.185
Urea, mg/dL	16.9	0.3	18.8	0.2	<0.001

The assumption that the data are normally distributed was met. n=5.

Results of the current study indicate decreasing NDF and ADF digestibility (4.4 and 2.3% or 6.5 and 3.5%, respectively) with using MCGs in the grower for calves, which is likely due to the increased rate and extent of starch fermentation and lower ruminal pH. This is consistent with the findings of Owens & Soderlund (2006) where NDF digestibility of a diet for feedlot cattle with heat-processed corn is lower compared with a diet containing dry-rolled corn, concluding that the rate of ruminal digestion of NDF can be reduced by a low ruminal pH.

Results related to the concentration of metabolizable energy (ME), net energy for maintenance (NE_m), and net energy for gain (NE_g) in consumed dietary DM were significantly higher ($p<0.001$) by 4.7, 5.5, and 7.2%, respectively, during the first digestion measurement period for calves on the grower containing MCGs when compared to UCGs. There were also found significant differences ($p<0.001$) for energy density in dietary DM during the second digestibility period, and these values were higher by 3.0, 3.6, and 4.6%, respectively, for ME, NEm, and NEg, for calves fed the grower containing MCGs. The significantly lower ($p<0.05$) ME intake (2.0%) was also determined for calves on micronized corn diet during this period. Calves fed the micronized corn diet showed a greater energy density in consumed dietary DM as a result of greater total tract DM and OM digestion. The larger improvements in available energy values of heat-treated corn were noted in earlier studies. Steam-flaking increased the NE_m and NE_g of corn for feedlot cattle (Barajas & Zinn, 1998; Zinn et al., 2002; Corona et al., 2005). According to Theurer et al. (1999), the steam-flaked corn and sorghum increased net energy for lactation (NE_L), and Tosta (2019) also reports greater values for available energy (ME and NE_L) of the heat-processed oat grain.

Plasma total protein and glucose did not significantly respond to dietary treatments. However, a slight increase in blood glucose concentration of calves fed heat-treated corn (4.1%) may indicate an enhanced ruminal propionate concentration due to a higher rate of starch degradation, causing more extensive gluconeogenesis in the liver. Corona et al. (2005) in a study with feedlot cattle showed that steam-flaking of corn decreased the ruminal molar proportion of acetate (7%) and the ruminal acetate to propionate molar ratio (41%) while increasing the ruminal molar proportion of propionate (24%). It is important to emphasize that probably a greater extent of ruminal starch degradation of micronized corn and consequently its decreased duodenal flow did not negatively affect blood glucose concentration. Blood urea was significantly affected by dietary treatments ($p<0.001$), with lower values (10.2%) for calves fed the grower containing MCG. The excess ammonia nitrogen that is not used for microbial protein synthesis in the rumen is absorbed into the portal blood and subsequently converted to urea in the liver (NRC, 2001). On the other hand, obtained results suggest that micronized corn provided more fermentable starch in the rumen, thus possibly improving bacterial capture of the nitrogen, and also decreasing the soluble true protein fraction. These observations are consistent with the findings of Tòthi (2003), where toasting and subsequently pelleting increased the starch degradability while decreased the rumen protein degradability of corn and according to that decreased the NH_3-N level in the rumen of dairy cows.

In summary, the micronization of corn grains improved characteristics of dietary dry matter, crude protein and nonfiber carbohydrates digestion in weaned Holstein calves fed a grower diet. Increased metabolizable and net energy densities of micronized corn-based diets may improve calves' performances by enabling sufficient energy with less feed intake. Obtained results suggest that heat processing of corn grain improved dietary protein utilization efficiency. In general, it could be concluded that the micronization of corn grain may be considered a valuable tool for optimizing weaned calf production.

Authors' contributions

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Supervision: B. Stojanovic.
Validation: Not applicable.
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