IGOR GOMES FÁVERO

EFFECTS OF REPLACEMENT OF FEED GRADE UREA WITH POST-RUMINAL RELEASE UREA AND ITS INTERACTIONS WITH CORN GRAIN PROCESSING METHODS (GROUND VS. RECONSTITUTED AND ENSILED) ON FINISHING PERFORMANCE OF NELLORE CATTLE

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Completion of undergraduate work presented to the Federal University of Lavras, as part of the requirements of the Animal Science Department, to graduate.

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LAVRAS, MG - BRAZIL

2023

For God and Miracolus Medal about all for the blessings bestowed…

For my dad Nadir Fávero and mom Maria Otília Gomes Fávero for my creation and love in my whole life…

For aunt Teresinha about all affection and love…

I dedicate

ACKNOWLEDGMENT

Firstly, to God and Our Lady of Aparecida for giving me strength and the will to be better at every moment of my undergraduate life.

To my mother Maria Otília, to my father Nadir. To my grandparents Maria Borges, Orlando, Maria Fávero and Jovino. To my aunts Teresinha and Vera Luce. To my uncle Geraldo and Olair. My cousins Alice, Aline, Carol, Cláucio, Danilo, Paola and Victor.

To the Federal University of Lavras and all the professors who were part of my training.

To my girlfriend Tamiris Anibal for all the good times and companionship.

To my friends from Monte Sião for all the moments, especially Diogo, Evandro and Leonardo.

To my friends Alexandre, David, Fábio, Giancarlo, Guilherme, Marco Aurélio, Luis Ricardo, Tamyres, Lucas for all the companionship in graduation and beyond.

To all my friends I made in graduate school.

To the Brazilian Beef Cattle Team – NEPEC for all the professional and personal growth it made me acquire, especially Antônio, Aurélio, Carolina, Enrico, Gabriel, Gabriela, Gustavo, Javier, José Maria, Júlia, Lorena, Lucca.

To the Beef Cattle Sector and its professors Dr. Erick Darlisson Batista, Dr. Daniel Rume Casagrande, Dr. Thiago Fernandes Bernardes, Dr. Jhones Onorino Sarturi, Dr. Priscilla Dutra Teixeira and Dr. Mateus Pies Giobelli for all the guidance and trust.

To my friends and brothers from the Team Roping André Lasmar, André Romaniello, Dawson, Lucas Figueira, Lucas Freire, Maurício, Odilon, Weliton, Vitor for all the good moments.

To my brothers I made at Texas Tech University: Jeffrey Manahan, Kauê Nardi, Kaliu Silva and Michael Looney for companionship during the internship at United States.

To my brother from Biofarma: Andrés Lacherre, Federico Franceschini, Josué Colussi, Juan Bollati and Leandro Soave for all the knowledge passed on to me and companionship during the internship period at Argentina.

Biofarma Agropecuaria and Texas Tech University for the opportunity and to trust in me.

I will be forever grateful to everyone who was part of every moment of my graduation. Thank y'all!

ABSTRACT

The effects of flint corn processing methods [fine ground corn or reconstituted corn grain silage] were evaluated at two sources of urea [feed-grade urea and post ruminal release urea] to determine impact on feedlot growth performance, carcass characteristics, and diet energy content of finishing Nellore bulls. Eighty Nellore bulls (26-mo age; initial body weight [BW] = 388 ± 45.7 kg) were randomly allocated into 28 pens (7 pens/treatment; 6 pens with 3 bulls + 1 pen with 2 bulls). Treatments were applied as follows: 1) fine ground corn (FGC) with feed-grade urea (U) diet (FGC+U); 2) reconstituted corn grain silage (RSC) with U (RSC+U); 3) FGC with post-ruminal release urea (PRU; FGC+PRU), and 4) RSC with PRU (RSC+PRU). Data were analyzed using the MIXED procedure of SAS 9.4. Bulls fed PRU had greater carcass-adjusted ADG ($P = 0.02$) and carcass-adjusted G:F ($P < 0.001$) compared to bulls fed U. Bulls fed RCS-diets presented higher carcass ADG ($P = 0.01$), carcass-adjusted G:F ($P < 0.001$), HCW ($P = 0.01$) and carcass G:F efficiency ($P <0.01$) compared with bulls fed FGC-based diets. Dietary NE intakes were greater ($P \leq 0.03$) for bulls fed RCS compared with bulls fed FGC. Observed NEm and NEg values (Mcal/kg) were greater ($P < 0.001$) for RCS- than for FGC-based diets. The observed NE: expected NE ratios were greater ($P < 0.001$) for RCS- than FGC-based diets Post-ruminal release urea increased carcass-adjusted ADG ($P < 0.01$) and, improved carcass-adjusted G:F ($P < 0.03$) of bulls compared with those fed U-diets. Bulls fed PRU-diets improved final BW ($P < 0.01$) and HCW ($P = 0.04$) compared to bulls fed U-diets, respectively. There was a tendency of US effect on carcass-gain efficiency ($P = 0.07$), which was greater in bulls fed PRU than U. Rump muscle length was longer in bulls fed PRU than U ($P = 0.02$). Bulls fed PRU had greater observed NEm and NEg than bulls fed U ($P = 0.04$). PRU-diets resulted in higher observed NEm and NEg values (Mcal/kg) than U-based diets ($P = 0.04$). In summary, reconstituted corn grain silage markedly improved flint corn energy value, NE of diets, animal growth performance, and feed efficiency compared with fine grinding corn, independently of the urea source. With regard to source of urea, observed NE content of the diet, carcass-adjusted gain and G:F (live- and carcass-adjusted) improved as feed-grade urea was replaced by post-ruminal release urea. When cattle are finished on diets based on flint corn like the ones used in this study, independent of the processing method post-ruminal release urea seems to be the optimal source of supplemental NNP.

Keywords: Feedlot; Beef cattle; Finishing phase.

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SUMARY

INTRODUCTION

From 2011 to 2021, Brazil has increased the beef production more than all the other countries and is the world largest beef exporter (ABIEC, 2022). Along with this, the percentage of feedlot animals slaughtered in relation to the total number of slaughtered heads increased from 12.6 to 17.2% in the last 3 years, corresponding approximately 5% (ABIEC, 2019; 2022).

Consulting nutritionists from the feedlots in Brazil, Silvestre and Millen et al. (2021) reported approximately 97% of the feedlots include more than 71% of concentrate in finishing diets. The main component of concentrate in finishing diet is corn due to its high energy content coming from the starch. However, flint corn is the most common grain used in Brazilian feedlots (Bernardes and Castro, 2019; Oliveira and Millen, 2014; Pinto and Millen, 2018) and this grain is characterized by lower digestibility compared with dent corn (Corona et al., 2006; Correa et al., 2002). The starch present in the corn kernel can have different availability and digestion by the animal depending on the type and grade of kernel processing since it can influence the action of proteolytic bacteria and kernel proteases break down of the protein matrix (Junges et al., 2017) and increase starch availability (Hoffman et al., 2011).

Although fine grinding corn (**FGC**) is still the primary corn processing method adopted by most Brazilian feedlots (Millen et al., 2009; Oliveira and Millen, 2014; Pinto and Millen, 2018), there is an interest in using ensiling methods to maximize starch digestion (Bernardes and Castro, 2019). In corn, the starch–protein matrix is composed mainly of hydrophobic zein proteins, classified as prolamins (Zinn et al., 2002). Thus, even when corn grain is milled, the starch–protein matrix may be a physicochemical impairment to starch digestion by rumen microorganisms (Owens et al., 1986; Hoffman et al., 2011; McAllister et al., 1990). In this scenario, as a process to improve starch digestibility is high-moisture harvesting and storage corn (**HMC**) and reconstituted corn grain silage (**RCS**; Owens et al., 1986; Benton et al., 2005) that represents, approximately, 17% of primary grain-processing method and a half of secondary grain-processing method (Silvestre and Millen et al., 2021) used in Brazil. In addition to the impact of corn processing on ruminal starch availability, nitrogen (**N**) availability in the rumen and its interaction with starch could be an issue for optimized ruminal fermentation and microbial protein yield in ruminants (Casper et al., 1999).

Since the mid-1950s, researchers have explored urea as a low-cost N source to replace a portion of the true protein sources (e.g., soybean meal), decreasing feed cost and maintaining animal performance (Sinclair et al., 2012). In the ruminal environment, dietary urea is rapidly hydrolyzed by the action of urease upon entry into the rumen, resulting in a rapid peak in rumen ammonia N (**RAN**) concentrations within the first hour after consumption, which may exceed the capacity of rumen bacteria to assimilate it into amino acids (Huber and Kung, 1981). However, RAN that is not utilized for microbial synthesis is absorbed across the gastrointestinal tract, with increasing RAN resulting in increased rate of absorption (Huntington, 1986). Increased blood ammonia concentrations alter hepatic metabolism by increasing ureagenesis and may also affect glucose metabolism in the liver and peripheral tissues (Spires and Clark, 1979; Fernandez et al., 1990; Huntington et al., 2006). In such case, this rapid release of ammonia may result in inefficient N utilization in the rumen.

A potential way to minimize excess ammonia reaching the liver is to increase microbial utilization of RAN by modulating its appearance in the rumen. To achieve this goal, slow-release non-protein N (**NPN**) compounds, which have been fed to ruminants, include isobutylidene diurea, acetylurea, biuret, starea, tung- and linseed-oil-coated urea and formaldehyde treated urea (Mudd, 1977; Tamminga and van Hellemond, 1977; Miller, 1979; Owens et al., 1980;). These compounds have not been as advantageous as urea because a substantial part of the NPN in them may leave the rumen without being converted to RAN, reducing its incorporation into microbial protein, and also because the ammonia formation from these compounds in the rumen, though slower than urea, was still too fast to optimize microbial protein production by rumen bacteria (Owens and Zinn, 1988; Henning et al., 1993).

On the other hand, a diet providing relatively more N from sources digested postruminally is expected to result in a lower average RAN over time compared with a diet providing N sources that are predominantly fermented in the rumen (Atkinson et al., 2007b; Wickersham et al., 2009a). However, postruminally digested and absorbed dietary N can contribute to ruminal N balance as recycled urea-N. In this sense, a postruminally delivered urea may serve as a more efficient N source for microbial protein synthesis compared with ruminally released urea by promoting lower RAN concentrations at the same or at a greater level of urea-N intake (Egan and Moir, 1965; Weston and Hogan, 1967; Fujihara and Tasaki, 1975). Additionally, urea derivatives that resist ruminal degradation (e.g., biuret, isobutylidene diurea) have been shown to mitigate peaks of RAN concentration upon consumption when compared with traditional urea (Komatsu and Sakaki, 1971; Veen and Bakker, 1977; Smith, 1986). Recently studies comparing ruminal pulse dose representing rumen degradable urea intake and continuous abomasal infusion representing rumen-undegradable urea (Carvalho et al., 2020; Oliveira et al., 2020; Nichols et al., 2021) demonstrated that continuous infusion of urea into the abomasum provided RAN in a more suitable form for ruminal microbial growth and increased the urea-N recycled and incorporated in microbial protein.

In this sense, as highlighted by Calsamiglia et al. (2010), a better understanding of urea-N recycling and the efficiency of N uptake in the rumen should allow the development of nutritional strategies to improve the N efficiency of utilization in ruminants. Therefore, dietary manipulation, such as increasing amounts of fermentable carbohydrates in the rumen (Kennedy and Milligan, 1980) or grain processing (e.g. steam flaking, HMC, and RCS) can change the site of starch digestion from the small intestine to the rumen (Theurer et al., 2002). In that case, there is a potentially increase on the transfer of N-urea to the rumen by the ruminal epithelium (Samson Hailemariam et al., 2021), improving the efficiency of microbial protein synthesis (urea-N recycling). However, there is no information available in the literature related to the replacement of U with PRU and how this replacement associated with changes in the dietary content of fermentable carbohydrates in the rumen through the corn grain processing method can influence the performance of beef cattle.

Based on the above information, we hypothesized that corn grain processing method interact with urea source and a greater performance could be observed in RCS-based diets associated with PRU due to a greater recycling of N-urea to the rumen, increase its utilization to produce microbial protein, reducing its excretion in the urine and, consequently, promoting a greater efficiency of N utilization. To test this hypothesis, effects of flint corn processing methods [finelly ground corn (**FGC**; 1.77 mm average particle size) or reconstituted corn grain silage (**RCS;** 2.15 mm average particle size)] were evaluated with two sources of urea [feed-grade urea (**U**) and postruminal release urea (**PRU**)] to determine impact on feedlot growth performance, carcass characteristics, and diet energy content of finishing Nellore bulls.

MATERIAL AND METHODS

The trial was conducted at the Experimental Feedlot of the Department of Animal Science (DZO), College of Animal Science and Veterinary Medicine (FZMV), Federal University of Lavras in Lavras, Minas Gerais, Brazil. All experimental protocols and activities in this trial were approved by the Ethics Committee on Animal Use of the Federal University of Lavras (protocol number 038/20).

Preparation of whole-plant corn silage and reconstituted and ensiled corn

A corn hybrid (Pioneer® 30S40) was planted in a field and harvested in February 2020. The field was harvested with a DM content of 38% as whole plant corn Shredlage®. The

Shredlage was harvested using a self-propelled forage harvester equipped with a silage harvester head set for a 22-mm theoretical length. The Shredlage was stored in a bunker silo (length × width × height of 42 × 5 × 1.5 m) allowed to ferment for about 12 weeks to use. Flint corn was acquired from the same source (Lag Lavras Armazens Gerais, Lavras, Minas Gerais, Brazil), at an approximately 13% moisture content (87% DM) and stored in metal bins until their use. Prior to the beginning of the experiment, a total of 40,000 kg of corn grain were ground using a stationary mill Nogueira TN-8 (Nogueira Máquinas Agrícolas, São João da Boa Vista, SP). Water was added with 2 kg/ton of a blend of organic acids on a fresh weight basis until the DM decreased to approximately 65%. The blend of organic acids (Fylax® Forte HC, Selko, Trouw Nutrition Brazil) was diluted with 1.6 kg of tap water and applied by spraying onto the ground kernels during mixing. After about 10 min of mixing, reconstituted grains were ensiled in bunker reinforced concrete silos (1.0 m inside diameter × 1.0 m long × 8.0 cm wall thickness) with a mean density of 1,000 kg of fresh material/m^3.

Experimental design, animals, and housing

Eighty Nellore bulls (26-mo age, 388 ± 45.7 kg initial body weigh [**BW**], mean ± SD) were weighed and blocked by initial BW from light to heavy, and allocated into 1 of 28 pens (24 pens of 3 bulls and 4 pens of 2 bulls). Cattle within BW blocks were randomly allocated into pens (7 pens/treatment; 6 pens with 3 bulls + 1 pen with 2 bulls) with 4 m wide × 10 m deep; 4 m of linear concrete bunk space) and a common automatic water fountain was shared between 2 adjacent pens. At the arrival to the feedlot, before step-up diets, bulls were fed a diet containing (DM basis) 80% corn silage, 17% ground corn, 1.6% soybean meal, 0.4% urea, and 1.0% mineral mixture. Prior to the onset of the experiment, bulls were dewormed (Treo® Ace; Zoetis, Brazil) and vaccinated against rabies (Rai-Vet; Laboratório Bio-Vet S/A, Vargem Grande Paulista, São Paulo, Brazil), respiratory diseases and Leptospirosis (CattleMaster® 4+L5; Zoetis), and prophylaxis of botulism and other diseases of ruminants (StarVac®; Labovet Produtos Veterinários Ltda, Feira de Santana, Bahia, Brazil). After a period of 21 d for adaptation to the facilities, bulls were then gradually adapted to the experimental diets over 14-d using 3 step-up diets (6-d for step 1 and 4-d for step 2 and 3), each with an incremental increase in 22.3% of the final diet (from 33 to 55.3 to 77.6, respectively) until reaching the proportion of 72% of concentrate and 28% of corn silage per dietary DM. The experimental period lasted 100 d, 14 d for diet adaptation period (referred as adaptation period) and 86 d of finishing diet feeding period (referred as feedlot period).

Dietary treatments

Experimental treatment diets (Table 1) consisted of 1) fine ground corn (**FGC**) with feed-grade urea (**U**) diet (**FGC+U**); 2) rehydrated and ensiled corn (**RCS**) with U (**RCS+U**); 3) FGC with post-ruminal release urea (**PRU; FGC+PRU**), and 4) RCS with PRU (**RCS+PRU**). The corn Shredlage® inclusion was 28.0% (DM basis) and remainder of the diets consisted of 63% corn (ground or rehydrated and ensiled), 6.3% soybean meal from a single lot, 0.1% ammonium sulphate and 3.0% of a mineral, vitamin, and monensin supplement (Table 1). The same flint corn was used in both diets, differing due to the processing (ground or reconstituded and ensiling). A commercial PRU product (N4C4®, SIPENA SAS, St Malo, France) was supplemented at 1.35% DM in the diets, for bulls to consume approximately 140 g daily of N4C4®, a blended, controlled release urea product in a palm oil coating to protect against ruminal fermentation. Post-ruminal release urea contained 82% urea on DM basis (230% CP, 72.8% ruminal protection, and 92.9% digestibility), which has 18% less N than urea due to the vegetable oil (palm oil) coating of PRU. The FGC+U treatment was used as a standard diet commonly used in Brazilian feedlots, providing recommendations of primary source of grain and roughage, additive utilized; processing method and inclusion level of grains, CP concentration, urea recommended level, and forage: concentrate ratio. In that case, it was considered the inventory of nutritional practices adopted by nutritionists in Brazilian feedlots (Silvestre and Millen, 2021). All the diets were formulated to provide sufficient energy, protein, minerals, and vitamins to provide NASEM (2016) requirements for Nellore steers in the finishing phase, with an estimated ADG of 1.5 kg/d. The feedlot mineral premix contained, per kilogram, 120 g Ca (minimum), 30 g P, 80 g Na, 50 g K, 68 g Mg, 25 g S, 1,220 mg Zn, 330 mg Cu, 950 mg Mn, 20 mg Co, 24 mg I, 6 mg Se, 67,000 IU vitamin A, 9,500 IU vitamin D3, 950 IU/kg vitamin E and 650 mg/kg monensin to the diet DM (equivalent to 20 mg/kg of diet DM).

Feeding management and measurements

Total mixed rations were manually mixed, offered *ad libitum* twice daily 0800 and 1600 h. Bulls had free choice access to feed and fresh water. Based on DMI of the previous 3-days, the amount of fresh feed offered to each pen was adjusted so that refused feed should not exceed 5% of daily intake. Samples of all ingredients in each concentrate batch and corn silage and RCS were collected daily throughout the study while one sample of the refusals from each pen were collected twice a week before 0730 h. A composed weekly representative sample was obtained and partially dried in a forced-air oven (55°C for 72h). Weekly DM contents of corn silage and RCS were used to adjust the ingredient proportions of the diets if DM deviated by >3% from average. Weekly samples were grounded in a knife mill with a 1-mm screen. Laboratory DM of samples were determined by drying at 105°C for 16 h. Dry matter intake of each pen was determined as the difference between the amount of feed offered each day and refused at the end of each week, corrected for DM content of TMR and refusals.

Samples analyses

Corn vitreousness (86.0 ± 3.37 g/100 g) was determined by dissecting 100 dry corn kernels to obtain vitreous and floury endosperm fractions (Dombrink-Kurtzman and Bietz, 1993). Mean particle sizes of FGC 1.77 ± 0.110 mm (n=2) and HMC 2.15 ± 0.025 mm (n=2) were valuated using methods adapted from Yu et al. (1998).

Samples of silage, feedstuffs, leftovers, and feces were ground in a knife mill to pass through a 2-mm screen. After that, half of each ground sample was ground again to pass through a 1-mm screen. Samples of each material ground through 1-mm sieves (silage, feedstuffs, leftovers, and feces) were analyzed according to the standard analytical procedures of the Brazilian National Institute of Science and Technology in Animal Science (INCT-CA; Detmann et al., 2012) for DM (dried overnight at 105°C; method INCT-CA no. G-003/1), ash (complete combustion in a muffle furnace at 600°C for 4 h; method INCT-CA no. M-001/1), N (Kjeldahl procedure; method INCT-CA no. N-001/1), NDF corrected for ash and protein (NDFap; using a heat-stable α-amylase, omitting sodium sulfite and correcting for residual ash and protein; method INCT-CA no. F-002/1). From samples processed through a 2-mm sieve, iNDF content was determined as the residual NDF remaining after 288 h of ruminal in situ incubation using F57 filter bags (Ankom Technology Corp., Macedon, NY), according to Valente et al. (2011).

To describe diet particle size diet samples were collected weekly and separated using the Penn State Particle Separator, in which sieves were stacked in the following order: 19.0-mm sieve on top, 8.0-mm sieve second, 4-mm sieve, and then a plastic pan fitted to the bottom of the last sieve. The sieve set was placed on a flat surface, and approximately 400 g of diet sample was spread out on the top sieve. The sieve set was shifted horizontally on the flat surface 5 times, rotated one-fourth turn, and shifted 5 times again, according to Kononoff et al. (2003) and Gentry et al. (2016).

Animal performance

Once the bulls were allocated to their respective treatment groups, they were reweighed individually (non-fasted) at the end (d 100; after a 16-h solid-feed fasting) of the feed period between 0700 and 1000 h and before delivery of fresh feed. Shrunk BW at d 0 of feedlot period was estimated by using a non-linear equation developed for Zebu cattle to account for gut fill ($0.88 \times BW^{1,0175}$; Valadares Filho et al., 2016). Average daily gain (ADG) was calculated as the difference between the initial, intermediate, and final shrunk BW divided by the number of days of each period or overall, G:F ratio was calculated as ADG divided by DMI for each period and overall.

At the end of the trial, bulls were transported to a commercial abattoir (Supremo Carnes, Campo Belo, MG, Brazil) for harvesting. Pre-harvest handling was conducted in accordance with good animal welfare practices, and slaughtering procedures followed strict guidelines stablished and regulated by the Sanitary and Industrial Inspection Regulation for Animal Origin Products in Brazil (Brazil, 1997). Dressing percentage was calculated based on the final carcass weight and BW ratio after fasting. Net energy contents of the diets were calculated from growth performance and DMI based as described by Zinn et al. (2002). The metabolizable energy (ME) was calculated using the following equations: Digestible energy (DE) = TDN × 0.04409; and ME = 0.82 × DE (NASEM, 2016). The net energy for maintenance (Em) required was calculated using the following equation $Em = 0.077 \times BW^{0.75}$ (where BW is the mean body weight; Lofgreen and Garrett, 1968) and multiplied by a correction factor of 0.9 for *Bos indicus* breeds (NASEM, 2016). The net energy required for gain (Eg) was calculated using the following equation $Eg = (0.0493 \times BW^{0.75}) \times ADG^{1.097}$ (NRC, 1984) to estimate net energy for maintenance (NEm) and net energy for gain (NEg) of the diets. Net energy of maintenance (NEm, Mcal/kg) of the diets was calculated from the quadratic formula, $x = (–b \pm \sqrt{}\ (b^2 – 4ac))/2a$, where a = –0.877 DMI, b = 0.877 Em + 0.41 DMI + Eg, and c = –0.41 Em (Zinn and Shen, 1998) and net energy of gain (NEg, Mcal/kg) was calculated as 0.877 NEm – 0.41.

On d 99 of feedlot period, measurements of the *longissimus thoracis* muscle area (LMA), back fat thickness (BFT), and rump fat thickness (RFT) were scanned by the right side using an Aloka 183 500-V machine (Corometrics Medical Systems, Wallingford, CT) with a linear probe (3.5-MHz, 17.2-cm linear array transducer). The LMA was measured on a transversal section in the 12th and 13th ribs, BFT was measured on a longitudinal section in the 12th rib, ¾ the length ventrally over the longissimus muscle. The RFT was taken at the junction of the *biceps femoris* and *gluteus medius* between the ischium and ileus and parallel to the vertebral column. The images analysis was performed using the BioSoft Toolbox® II for Beef software (Biotronics Inc., Ames, IA, USA). Ultrasound images were collected and analyzed by a trained technician.

Statistical analyses

Prior to all statistical analyses, the data were checked for normality and homoscedasticity. Data transformations were not necessary. Additionally, outliers were checked. One bull (RCS+UC) was removed from the study within the first 6 week due for reasons unrelated to treatment (Phlegmon infection) and the corresponding data was removed prior to statistical analysis. All statistical analyses were conducted using the MIXED procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC). Pen was the experimental unit (all the bulls within a pen belong to the same treatment group) and bulls as replicates. The model was fitted with individual animal data and included the fixed effects of CPM, US, and the CPM × US interaction as well and a random effect of pen nested within treatment (St-Pierre, 2007). In addition to overall growth performance, ADG and G:F were analyzed using a carcass-adjusted final BW calculated by dividing the HCW by the common dressing percentage of 55.63% (the mean dressing percentage over all replicates included on the study) to account for possible differences in gut-fill during weigh-out and allow for more accurate evaluation of cattle growth. The IBW was used as a covariate for growth performance variables when was deemed significant at $P < 0.10$. When significant CPM × US interactions were detected ($P \leq 0.10$), pairwise comparisons of the simple effect means were conducted with the PDIFF option of the MIXED procedure of SAS.

The mean DMI of each pen was calculated during adaptation on d 1 to 6 (step 1), d 7 to 10 (step 2), and d 11 to 14 (step 3), and then weekly (12 weeks in total). Data collected for each pen for each week period were analyzed as a mixed linear model with treatment, period (as a repeated measure) and the treatment × period as fixed effects and pen as the experimental unit. The variance components were used as the covariance structure and pen within treatment × period as subject for the repeated measures. The restricted maximum likelihood method was used for estimating variance components and the Kenward-Roger option was used to adjust the degrees of freedom. The variance and covariance error structures that were investigated included compound symmetry, heterogeneous compound symmetry, and autoregressive. The error structure with the lowest Akaike information criteria fit statistic was selected for the model. Data are reported as least square means and differences among treatments were determined using orthogonal contrasts for corn processing, urea source, and interactions effects. For the repeated measures model, the SLICE option was used when the treatment × period interaction was significant to partition and test the simple main effects. Differences were considered significant at $P \leq 0.05$ and trends were discussed at $0.05 < P < 0.10$.

RESULTS

Effects of corn grain processing × urea source level were not detected ($P \geq 0.27$) for any feedlot growth performance, dietary NE concentration, and carcass traits. Although a CPM × US interaction was not observed, a treatment × time interaction was verified on DMI ($P < 0.01$; Fig. 1).

Effects of corn processing × urea source

There was a treatment × week ($P < 0.01$; Fig. 1) interaction for pooled DMI data; in wk 3, bulls fed FGC+PRU had greater DMI than RCS+U ($P = 0.05$), and tendency were verified at wk 4 and 7 between these treatments ($P = 0.09$, 0.06). At step 3 and wk 6, DMI tended to be lower in cattle fed RCS+U ($P = 0.10$ and P = 0.06, respectively) than those fed FGC+PRU. At these respective weeks, DMI was not different from that of bulls fed the other treatments ($P \geq 0.12$).

Effects of corn grain processing

Treatment means for feedlot performance are presented in Table 2. As designed, initial BW was not different among treatments ($P \geq 0.95$). Corn grain processing method did not affect DMI ($P = 0.41$), however bulls fed RCS-based diets had 9.5% greater carcass-adjusted ADG ($P = 0.02$) and 12.4% greater carcass-adjusted G:F ($P < 0.001$) compared to bulls fed FGC-based diets (Table 2). Corn grain processing method did not affect dressing and ultrasound measurements ($P \geq 0.26$), however bulls fed RCS-diets presented higher HCW (326 vs. 316 kg; $P = 0.01$) and carcass gain:feed efficiency (101 vs. 92 g/kg DMI; $P < 0.01$) compared with bulls fed FGC-based diets.

Dietary NE intakes, which were calculated from growth performance measurements (BW, ADG, and DMI), were greater ($P \leq 0.03$) for bulls fed RCS compared with bulls fed FGC (Table 3). Observed NEm and NEg values (Mcal/kg) were respectively 8.8% and 11.6% greater ($P < 0.001$) for RCS- than for FGC-based diets. The observed NE:expected NE ratios were greater ($P < 0.001$) for RCS- than FGC-based diets (Table 3). Fecal starch was affected by corn processing ($P < 0.05$; Table 3). Mean fecal starch as a percentage of fecal DM was less ($P < 0.001$) for bulls fed RCS diets (5.5%) than for bulls fed FGC diets (11.6%). Similarly, Gouvêa et al. (2016) and Caetano et al. (2019) all reported that fecal starch decreased when the flint corn grain being fed was processed more extensively. As a result of lower fecal starch, fecal pH of bulls fed RCS was about 16% greater than fecal pH of bulls fed FGC. Estimates of NEm_{corn} and NEg_{corn} reflect similar patterns of fecal starch since values were calculated using its content.

Effects of urea source

Post-ruminal release urea (average of PRU-containing diets) increased carcass-adjusted ADG 7.1% ($P < 0.01$) and, because DMI was similar US treatments, carcass-adjusted G:F improved 6.9% ($P < 0.03$) of bulls compared with those fed U-diets (Table 2). Based on it, bulls fed PRU-diets improved final BW ($P < 0.01$) and HCW ($P = 0.04$) in about 14 and 8 kg compared to bulls fed U-diets, respectively. There was a tendency of US effect on carcass-gain efficiency ($P = 0.07$), which was greater in bulls fed PRU than U (102 vs. 92 g/kg DMI). Additionally, rump muscle length was longer in bulls fed PRU than U ($P = 0.02$). Bulls fed PRU had greater observed NE_m and NE_g than bulls fed U (2.12 vs. 2.04 Mcal/kg of NE_m and 1.45 vs. 1.38 Mcal/kg of NEg_{corn}; $P = 0.04$). In addition, PRU-diets resulted in higher observed NEm and NEg values (Mcal/kg) than U-based diets ($P = 0.04$). Replacing U with PRU resulted in a lower fecal starch concentration (7.5 vs. 9.5%; $P = 0.02$) and, consequently, a tendency to improve fecal pH ($P = 0.06$) was observed (6.43 vs. 6.25). Following the same pattern of fecal starch content, total starch digestibility and estimates of NEm_{corn} and NEg_{corn} was enhanced by the replacement of U with PRU ($P = 0.02$).

DISCUSSION

This study shows the interaction effects of substitution of feed-grade urea with post-ruminal release urea and corn grain processing on beef cattle performance. Limited data are available regarding the response of beef cattle to post-ruminal release urea, although there are some studies on the overall performance of grazing beef cattle (Souza et al., 2022; Reis et al., 2023) and dairy cattle (Rauch, 2022). To our knowledge, such an evaluation of replacing a U source by PRU on the performance and carcass traits of finishing beef cattle is unique and novel information. The lack of CPM × US interactions ($P \geq 0.27$) for growth performance variables was not expected and was not consistent with our hypothesis (Table 1). Although there was no difference between treatments on DMI during the entire trial (Table 2), Fig. 1 illustrate some weekly differences for the CPM × US treatments. The DMI of bulls fed FGC+PRU diets was higher than that of bulls fed FGC+U and RCS+U diets during 3 and 2 weeks of the whole study period, respectively (Fig. 1).

The positive effect of PRU on performance could be associated with the supplying of N compounds to rumen microbes and the adequacy of the available absorbed nutrients (Egan and Moir, 1965; Lee et al., 1987; Leng, 1990; Detmann et al., 2014). The first way to improve the utilization of dietary nutrients by ruminants is to optimize the availability of nutrients from rumen fermentation. This can be achieved by ensuring that there are no nutrient deficiencies to the rumen microorganisms. This will allow them to grow efficiently and, through fermentative activity, extract the maximum possible amount of energy from dietary carbohydrates (Detmann et al., 2009; Leng, 1990; Detmann et al., 2014). As flint corn grain has a higher fraction of insoluble N and its based diet present a lower starch degradation rate than RCS (Souza et al., 2020b; Godoi et al., 2021), probably the rate of availability of ruminal ammonia N (**RAN**) from U may not fully match the rate of N utilization of bacteria, because urea has a high solubility and starch from FGC has a slow rate of ruminal digestion. On the other hand, part of PRU is resistant to rumen fermentation and it would transfer into the post-ruminal gastrointestinal tract in parallel with the relatively constant rate of digesta passage from the rumen (Nichols et al., 2022). If intestinal release and absorption of PRU are steady in accordance with its passage into the intestine, this could result in steady urea and ammonia absorption and hepatic ureagenesis. In this sense as reviewed by Nichols and others (2022), probably the association of PRU with a slow rate of starch source (i.e., FGC) sustained a greater DMI from a greater and more efficient microbial synthesis, due to a higher return of urea-N to the rumen and avoids peaks in RAN associated with feeding.

Effects of corn processing

In Brazil and the most countries in South America, corn grain produced is primarily flint corn that contains a greater proportion of vitreous endosperm and lower starch availability compared with dent corn (Correa et al., 2002). According to McAllister et al. (2006) and McAllister and Ribeiro (2013), starch granules in the vitreous endosperm region are densely compacted within a protein matrix whereas ruminal bacteria preferentially colonize exposed starch granules. Corn grains that contain high concentrations of vitreous endosperm when not extensively processed are digested less rapidly in the rumen than corn that contains a higher concentration of floury endosperm (Philippeau and Michalet-Doreau, 1998). However, even when corn grain is milled, the starch–protein matrix, composed mainly of hydrophobic zein proteins (prolamins) may be a physicochemical impairment to starch digestion by rumen microorganisms (Owens et al., 1986; Zinn et al., 2002; Hoffman et al., 2011; McAllister et al., 1990). In this sense, grains processing increases the surface area exposure and improve ruminal and total gastrointestinal starch digestibility (Huntington, 1997; Owens et al., 1997). Fine grinding is still the primary corn processing method adopted by most Brazilian feedlots (Millen et al., 2009; Oliveira and Millen, 2014; Pinto and Millen, 2018; Silvestre et al., 2022). Nevertheless, feedlots nutritionists have shown interest in using processing methods based on ensiling flint corn with high moisture corn (**HMC**; Bernardes and Castro, 2019; Silvestre et al., 2022) to maximize starch–protein matrix breakdown (Mahanna, 2008; Hoffman et al., 2011; Silva et al., 2020a, 2020b), and consequently, increase starch digestibility and nutrients' utilization (Owens et al., 1986).

In this current study, vitreousness of the flint corn grain averaged 86%. Inferior values were reported for Brazilian flint hybrids (Correa et al. (2002); Caetano et al. (2015); Gouvêa et al. 2016, Silva et al., 2021), with reported vitreousness varying from 73 to 77%. The starch granules in flint corn are extensively encapsulated by prolamin (zein), which provides physicochemical impairment to microbial degradation affecting the extent and rate of digestion in ruminants (McAllister et al., 1993; Owens et al., 1986; Philippeau et al., 2000). Researchers (Hoffman et al., 2011; Mahanna, 2008; Silva et al., 2020b) have suggested that processing methods based on ensiling (i.e., HMC, RCS, and snaplage) promotes starch–protein matrix breakdown and increases starch availability. In fact, Silva et al. (2020) evaluated ground corn grains reconstituted with water to reach 65% DM. These authors observed that after 14 d of ensiling, there was a significant reduction in the levels of insoluble N (67.7 versus 54.3%) and a stabilization was reached after day 120 of ensiling (31.8%). Therefore, diets based on RCS can show greater area exposed to enzymatic action by ruminal microorganisms compared with diets based on FGC, which would verify higher kd (Silva et al., 2020a). In addition, the starch–protein matrix degradation linked to proper moisture inside the silo facilitates a reduction in the particles' hydrophobicity and increases their water uptake capacity (Silva et al., 2020a, 2020b). This set of factors may lead to an increase in the density and functional specific gravity of the particles (Lechner-Doll et al., 1991; Nocek and Kohn, 1987), increasing the kp of starch for diets based on ensiled grains (Silva et al., 2020b).

In the present study, replacing FGC with RCS in a diet with 28% corn silage did not affect DMI. This result disagrees with those observed in previous studies, which demonstrate greater ruminal digestion of HMC (Galyean et al., 1976; Huntington, 1997; Cooper et al., 2002) or RCS (Silva et al., 2020; Godoi et al., 2021). In diets with high proportion of concentrates, replacing FGC with RCS or HMC, frequently decreases DMI (Owens et al., 1997; Zinn et al., 2011), because of higher ruminal starch fermentability induces hypophagia. Due the higher starch fermentability, increase on production and absorption of VFA in the forestomach (e.g., propionate; Oba and Allen, 2003), result in a higher net portal flux of propionate likely occurs in RCS- compared with FGC-based diets. In the liver, a high propionate offer increases the anaplerosis in the tricarboxylic acid cycle (oxidation of fuels) and ATP production, which causes satiety mainly by decreasing meal size (Allen et al., 2009; Allen, 2020). Jacovaci et al. (2022) recently review and through meta-analysis they evaluated the effect of ensiling on the feeding value of flint corn grain and performance of feedlot cattle (HMC and RCS). These authors evidenced that ensiling corn grain decreased DMI by 14.1% (10.3 vs. 8.85 kg/d) but did not affect ADG (1.61 and 1.58 kg/d), resulting in 18.3% of increase in feed efficiency (164 and 194 g/kg DMI), for dry and ensiled corn, respectively. Contrary to these authors, we did not found difference for DMI between bulls fed FGC- and RCS-based diets (Table 2; averaging 10.5 kg/d), but beneficial effects of corn processing on carcass-adjusted ADG (1.78 vs. 1.96 kg/d for FGC- and RCS-based diets) and carcass-adjusted G:F (166 vs. 187 g/kg DMI, respectively) in our study are consistent with observations from previously reported studies with flint corn (Gouvêa et al., 2016; Marques et al., 2016).

In the current experiment, HCW was increased by RCS (Table 2). It should be expected that compared with grinding, RCS would increase the extent of ruminal starch digestion (Theurer, 1986; Drouillard and Reinhardt, 2006), increase the molar proportion of propionate in the rumen (Corona et al., 2006; Gouvêa et al., 2016), and increase intake of NEg (Table 3; Zinn et al., 2011), thus resulting in a greater carcass production and heavier final BW.

The presented data corroborate findings of other authors where intensive CPM, such as steam flaked, ensiled corn grain) did not alter dressing percentage (Gouvêa et al., 2016; Marques et al., 2016), back fat thickness (Barajas and Zinn, 1998; Corrigan et al., 2009; Gouvêa et al., 2016; Marques et al., 2016), and LM area (Gouvêa et al., 2016; Marques et al., 2016) when compared with dry-rolled, ground, or whole corn grain.

As described above, processing methods based on ensiling, such as RCS, promotes starch–protein matrix breakdown and increases starch availability (Hoffman et al., 2011;

Mahanna, 2008; Silva et al., 2020b). Although a greater degradation rate has been reported when RCS replace FGC in beef cattle diets, extent of starch digestion in the rumen has not been evidenced (Silva et al., 2020; Godoi et al., 2021). On the other hand, these authors found increases on starch digestion in the small intestine, which can result in reduced FS and increased estimated TSD as observed in this study (Table 3). The increased starch utilization contributed to increasing energy content of the grain and consequently of the diet, but the incremental improvement in total tract digestibility of starch (97.0% vs. 94.3%) in this study does not explain the difference in growth performance between RCS- and FGC-fed cattle. Based on FS concentration, the estimated grain NEm and NEg were only 5.3% and 6.8% greater for RCS when compared with FGC; however, based on cattle growth performance data, observed diet NEm and NEg values increased by 8.5% and 11% when bulls were fed RCS compared with those fed FGC-based diets.

According to the NASEM (2016), NEm and NEg are 2.25 and 1.56 Mcal/kg for ensiled corn (HMC), and 2.17 and 1.49 Mcal/kg for ground corn, respectively. In addition, Brazilian nutritional requirements for beef cattle (BR-Corte; Valadares Filho et al., 2016) reported NEm and NEg of 2.28 and 1.59 Mcal/kg for RCS, and 2.23 and 1.54 Mcal/kg for FGC, respectively. Therefore, NASEM estimates of NEm and NEg are 5.8 and 10.9% lower, while BR-Corte reported these values 4.7 and 3.2% greater, respectively, for RCS than for FGC. Based on performance of bulls in the present study (mean BW, ADG, and DMI), NEm and NEg were 8.5 and 11.2% greater, respectively, for steers fed RCS than for those fed FGC. Several authors have reported that ensiled flint corn increased NE values of grain compared with corn with lesser degrees of processing (Caetano et al., 2015; 2019; Silva 2016). Despite the fact that greater starch digestion frequently is mentioned as the primary cause for this increase in grain energy value, Owens and Basalan (2013) estimated that only 50% of the increase in grain NE could be explained by differences in TSD, with the remaining response being attributable to increase digestibility of other feed components; alterations in rumen fermentation, with a greater proportion of VFA being propionate that consequently reduces loss of methane; and in site and efficiency of digestion. The observed NE:expected NE ratios were consistently greater than 1 for FGC- and RCS-based diets (Table 3). Because no adjustment factor is yet available to adjust energy availability for the degree of vitreousness of fed grain, the current equations available to estimate corn energy values would be expected to underestimate the energy value of flint corn that is not extensively processed (e.g., fed dry ground or whole). Discrepancies by values published in NASEM (2016) and this trial may reflect differences in corn vitreousness, as most data used by the NASEM to estimate NEm and NEg rely on trials with dent corn, whereas this trial was conducted using flint corn. In a similar way, BR-Corte database relies on trials with flint corn. We can also emphasize that estimates of NEm and NEg in this study are based on fewer observations in comparison with the library values reported in both nutritional models.

Effects of urea source

In the present study, DMI was unchanged by urea source (averaging 10.5 kg/d). Nevertheless, when PRU was added to diets resulting in increases for carcass-adjusted ADG (1.93 vs. 1.80 kg/d for PRU and U, respectively) and carcass-adjusted G:F (172 vs. 181 g/kg DMI for PRU and U, respectively). Additionally, a greater rump muscle length (10.8 vs. 11.4 cm) and numeric LMA (87.3 vs. 92.8 cm^2; $P = 0.12$) were evidenced on bulls fed PRU-diets (Table 2). From the results obtained in this study it is observed that replacement of U with PRU improving the N status in animal metabolism and this effect was independent on the corn processing method. This demonstrate that there is clear advantage in substituting a PRU product for urea at the levels usually fed to finishing beef cattle in Brazilian feedlots (Silvestre and Millen et al., 2021).

As mentioned above, positive effects of PRU on performance could be associated with the supplying of N compounds to rumen microbes and the adequacy of the available absorbed nutrients. Firstly, to improve the utilization of dietary nutrients by ruminants is necessary to optimize the availability of nutrients from rumen fermentation. After that, ruminal microorganisms can grow efficiently and, through fermentative activity, extract the maximum possible amount of energy from dietary carbohydrates (Detmann et al., 2009; Leng, 1990; Detmann et al., 2014). In fact, a positive effect of PRU was verified on observed dietary NEm and NEg (Table 3), which seems that this urea source could have promoted positive effects on starch digestion and/or metabolism.

An adequate ruminal ammonia nitrogen concentration is the priority for optimizing fermentative digestion of fibrous and non-fibrous carbohydrates, mainly to low-quality forages (Detmann et al., 2009; Leng, 1990; MacRae et al., 1979; Satter and Slyter, 1974; Detmann et al., 2014). Oliveira et al. (2020) compared the effects of post-ruminal urea delivery continuous versus continuous or pulse dose ruminal delivery in Nellore heifers consuming 4.4%-CP Tifton hay and receiving 1.4% of urea across treatments (dose was adjusted daily based on forage intake to increase the CP content of the diet to 10.0%). These authors observed lower ruminal pH and ammonia-N concentration with continuous infusion of urea into the abomasum compared with continuous or pulse dose ruminal urea delivery. A greater proportion of urea-N entering circulation was recycled to the GIT, N retention increased, and urinary urea-N excretion decreased with continuous urea supply into either the rumen or abomasum compared with a ruminal pulse dose of urea. Indeed, more microbial N was produced per kg of digestible OM and more of this microbial N originated from recycled N with post-ruminal urea compared with the ruminal urea pulse dose. Several other reports have brought into evidence that supplying N in either the abomasum or the duodenum could increase the amount of N recycled to the rumen (Egan, 1965ab; Batista et al., 2016). In this sense, bulls fed PRU-diets probably presented a higher efficiency of microbial N synthesis and microbial N originated from recycled N than bulls fed U, as reported by Oliveira et al. (2021).

Nevertheless, beyond the ruminal degradation effects, metabolic or post-digestive effects of N can also positively affect the cattle performance. The N metabolic effects cannot be separately evaluated because an animal's metabolism is based on integration of different mechanisms, on availability of several substrates and metabolites and on a complex hormonal and biochemical signalling and regulation (Detmann et al., 2014). In this present trial, improvements on bulls' performance can also be attributed with a better adequate protein status (Egan, 1965a; Egan and Moir, 1965; Kempton et al., 1976). In theoretical terms, the expression 'N status' defines the quantitative and qualitative availability of N compounds for different physiological functions in animal metabolism, including functions associated with the metabolism of other compounds, such as energy (Leng et al., 1990; Detmann et al., 2014). When N status is improved, the metabolism can achieve a better adjustment. In other words, molecules of NPN can be direct towards other metabolic pathways, such as the urea cycle. Thus, amino acids utilization for those pathways will decrease, which, in turn, improves the availability of metabolic precursors for protein synthesis (Detmann et al., 2014) and can result in a better N efficiency as probable occurred for bulls fed PRU-diets. In fact, based on performance of bulls in the present study (mean BW and ADG) and by using BR-Corte (2016) equations to estimate efficiency of metabolizable energy (kg) and protein (k), we obtained a significant greater estimate in bulls fed PRU- than U-diets ($P = 0.05$ and $P < 0.01$, respectively; data not reported). The average kg was and 78.3% and 76.8%, and k was 47.3% and 47.1%for PRU and U, respectively. Therefore, the increase either in kg or k could be related to the better N status of bulls fed PRU-diets.

CONCLUSIONS

In summary, reconstituted corn grain silage markedly improved flint corn energy value, NE of diets, animal growth performance, and feed efficiency compared with fine grinding corn, independently of the urea source. With regard to source of urea, observed NE content of the diet, carcass-adjusted gain and G:F (live- and carcass-adjusted) improved as feed-grade urea was replaced by post-ruminal release urea. When cattle are finished on diets based on flint corn like the ones used in this study, independent of the processing method post-ruminal release urea seems to be the optimal source of supplemental NPN.

Table 1. Ingredients and chemical and particle size analysis of the experimental diets

Item	Ground corn		Rehydrated and ensiled corn	
	Feed-grade urea	Post-ruminal release urea	Feed-grade urea	Post-ruminal release urea
Ingredient, % of DM				
Corn shredlage	28.0	28.0	28.0	28.0
Corn, dry ground	61.3	61.3	−	−
Corn, reconstituted and ensiled	−	−	61.3	61.3
Soybean meal	6.3	6.3	6.3	6.3
Feedlot premix[1]	3.0	3.0	3.0	3.0
Feed-grade urea	1.1	−	1.1	−
Post-ruminal release urea[2]	−	1.3	−	1.3
Ammonium sulfate	0.1	0.1	0.1	0.1
Kaolin	0.2	−	0.2	−
Estimated chemical composition, % of DM				
DM, % as-fed	73.2	73.2	54.9	54.9
CP	13.6	13.6	13.6	13.6
Ruminally degradable protein	9.2	7.2	9.1	7.2
Starch	52.2	52.2	51.5	51.5
NDF	21.6	21.6	20.8	20.8
Ether extract	3.4	3.6	3.4	3.6
Particle size analysis[3], % as-fed				
Long (> 19 mm)	2.7 ± 0.26	2.5 ± 0.22	2.7 ± 0.23	2.6 ± 0.26
Medium (8-19 mm)	23.8 ± 0.72	22.8 ± 1.14	23.2 ± 0.90	22.8 ± 0.90
Short (4-8 mm)	10.2 ± 0.84	14.1 ± 0.80	8.5 ± 0.64	14.4 ± 0.84
Fine (< 4 mm)	63.3 ± 1.29	60.6 ± 1.61	65.5 ± 1.56	60.2 ± 1.63
Particles > 4 mm	36.7 ± 1.29	39.4 ± 1.61	34.5 ± 1.56	39.8 ± 1.63

[1] Feedlot premix (BellPeso Essencial, Bellman, Trouw Nutrition Brazil) provided an additional 120 g/kg Ca (minimum), 30 g/kg P, 80 g/kg Na, 50 g/kg K, 68 g/kg Mg, 25 g/kg S, 1,220 mg/kg Zn, 330 mg/kg Cu, 950 mg/kg Mn, 20 mg/kg Co, 24 mg/kg I, 6 mg/kg Se, 67,000 IU/kg vitamin A, 9,500 IU/kg vitamin D3, 950 IU/kg vitamin E and 650 mg/kg Monensin to the diet DM.

[2] N4C4 (SIPENA SAS, St Malo, France).

[3] Particle size distribution of TMR measured using the Penn State Particle Separator with 3 sieves (19, 8, and 4 mm). SD (n = 12 weeks for particle sizes)

Table 2. Effects of corn grain processing method (CPM) and urea source (US), and their interactions on growth performance and carcass characteristics of Nellore bulls

	Ground corn		Rehydrated and ensiled corn			*P*-values		
Item	Feed-grade urea	Post-ruminal release urea	Feed-grade urea	Post-ruminal release urea	SEM	CPM	US	CPM × US
Growth performance[1]								
Initial BW,[1] kg	392	391	393	391	18.5	0.98	0.95	0.96
Final BW,[1] kg	562	579	578	589	5.5	0.02	<0.01	0.66
Adj. Final BW,[2] kg	561	580	577	591	6.6	0.01	0.04	0.65
ADG,[3] kg	1.71	1.87	1.87	1.99	0.055	0.02	<0.01	0.66
Adj. ADG,[2] kg	1.70	1.86	1.89	2.00	0.066	0.01	0.04	0.65
DMI,[4] kg	10.2	10.7	10.4	10.3	0.37	0.86	0.58	0.44
Feed efficiency, g/kg	166	174	178	192	3.2	<0.001	<0.001	0.31
Adj. Feed efficiency, g/kg	166	174	181	192	3.2	<0.001	<0.01	0.60
Carcass characteristics								
HCW, kg	312	321	323	329	3.7	0.01	0.04	0.64
Dressing, %	55.5	55.5	55.8	55.7	0.42	0.46	0.89	0.95
Average daily gain, kg/d	0.93	1.02	1.04	1.09	0.036	0.01	<0.01	0.66
Carcass gain:feed, g/kg	92	96	96	105	2.0	<0.001	<0.01	0.56
Longissimus muscle area, cm^2	87.3	88.8	87.2	96.8	3.58	0.28	0.13	0.27
12th fat tickness, mm	3.3	3.3	4.0	3.6	0.37	0.62	0.20	0.55
Rump muscle lenght, cm	10.8	11.3	10.8	11.4	0.22	0.96	0.02	0.92
12th rib fat thickness, mm	5.4	5.1	5.8	5.8	0.48	0.26	0.73	0.78

[1] Initial and final individual BW measured live and after 16 h of feed restriction.

[2] Carcass-adjusted values. Adjusted (Adj.) final BW was estimated by dividing HCW by the overall average dressing percentage obtained for treatments (55.63%) and so, adjusted ADG and feed efficiency were calculated.

[3] Calculated using initial and final BW (after 16 h of feed and water restriction).

[4] Recorded from each pen (7 pens/treatment) and divided by the number of animals within each pen, and expressed as kg animal/d.

Table 3. Effects of corn processing method (CPM) and urea source (US), and their interactions on dietary net energy (NE) concentrations and fecal characteristics of Nellore bulls

	Ground corn		Rehydrated and ensiled corn			*P*-values		
Item	Feed-grade urea	Post-ruminal release urea	Feed-grade urea	Post-ruminal release urea	SEM	CPM	US	CPM × US
NE$_m$ intake,[1] Mcal/d	20.6	22.4	22.4	23.1	1.03	0.25	0.24	0.63
NE$_g$ intake,[1] Mcal/d	13.8	15.1	15.3	16.0	0.75	0.12	0.19	0.69
Observed NE[2]								
NE$_m$, Mcal/kg	2.00	2.07	2.12	2.21	0.023	<0.001	<0.01	0.54
NE$_g$, Mcal/kg	1.35	1.40	1.45	1.53	0.021	<0.001	<0.01	0.54
Oberved NE:expected NE[3]								
NE$_m$	1.03	1.06	1.09	1.13	0.017	<0.01	0.04	0.73
NE$_g$	1.03	1.07	1.11	1.16	0.022	<0.01	0.04	0.74
Fecal pH	5.71	6.04	6.78	6.82	0.094	<0.001	0.06	0.14
Fecal starch, %	13.0	10.1	6.0	4.9	0.80	<0.001	0.02	0.24
Total starch digestibility, %	92.0	93.9	96.6	97.3	0.52	<0.001	0.02	0.24
Estimated fecal analysis[4]								
NEm$_{corn}$, Mcal/kg	2.22	2.29	2.37	2.40	0.017	<0.001	0.02	0.24
NEg$_{corn}$, Mcal/kg	1.59	1.65	1.72	1.74	0.015	<0.001	0.02	0.24

[1] Calculated using observed NE values based on equation described by Zinn and Shen (1998).

[2] Calculated using cattle growth performance data based on the equation proposed by Zinn and Shen (1998).

[3] Expected NE values were estimated with the equations proposed by NASEM (2016); solution type = empirical level) with addition of monensin as feed additive and using the total digestible nutrient values, which had been calculated with the equation proposed by Weiss et al. (1992).

[4] Estimated from fecal starch as described by Zinn et al. (2002).

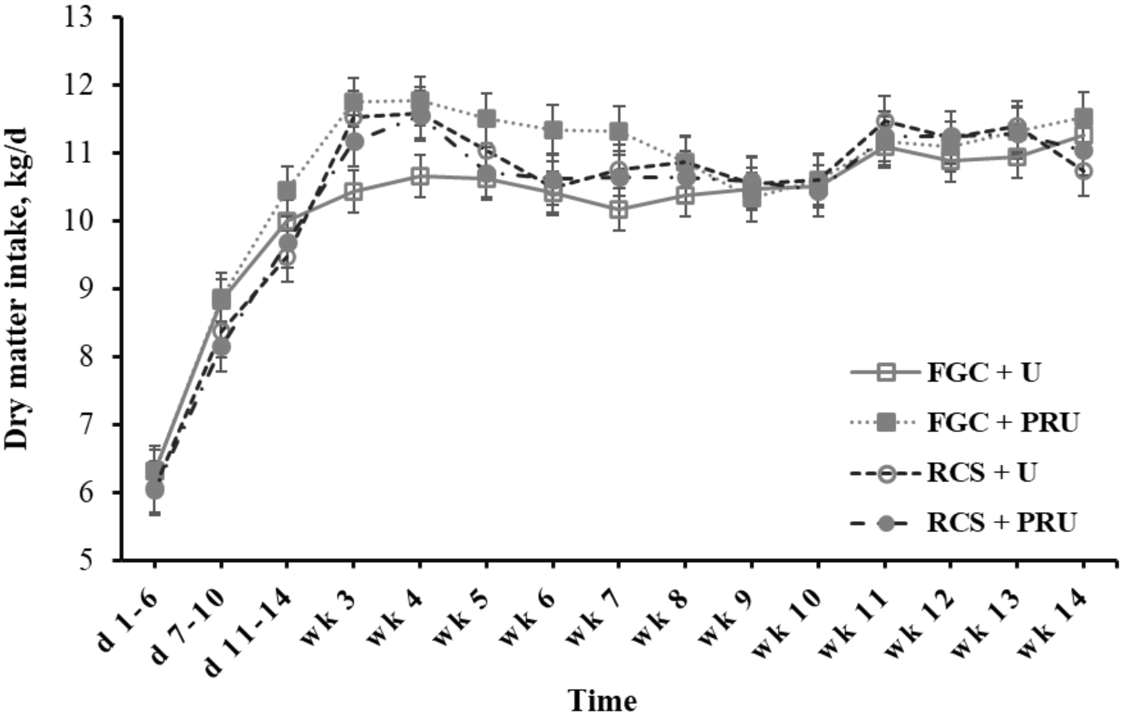

Figure 1. Weekly DMI change by Nellore feedlot bulls fed diets containing finely ground corn (FGC) or reconstituted corn grain silage (RCS) and supplemented with feed-grade urea (U) or post-ruminal release urea (PRU) during a 100-d feedlot period. Time ($P < 0.001$), treatment ($P = 0.81$), and treatment × time ($P < 0.01$). Pooled SEM = 0.43; n = 7 pens per treatment.

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