Effects of dietary roughage neutral detergent fiber levels and flint corn processing method on growth performance, carcass characteristics, feeding behavior and rumen morphometrics of *Bos indicus* cattle[1]

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ABSTRACT: Flint corn processing method [coarse ground corn (**CGC**; 3.2 mm average particle size) or steam-flaked corn (**SFC**; 0.360 kg/L flake density)] was evaluated in conjunction with 4 levels of neutral detergent fiber (**NDF**) from sugarcane bagasse (**SCB**) as roughage source (**RNDF**; 4, 7, 10, and 13%; dry matter basis) to determine impact on growth performance, carcass characteristics, starch utilization, feeding behavior, and rumen morphometrics of *Bos indicus* beef cattle. Two hundred and forty Nellore bulls were blocked by initial body weight (**BW** = 350 ± 37 kg), assigned to 32 feedlot pens and pens within weight block were randomly assigend, in a 2 × 4 factorial arrangement (2 corn processing and 4 levels of RNDF) to treatments. Effects of corn grain processing × RNDF level were not detected ($P \geq 0.14$) for growth performance, dietary net energy concentration, carcass traits, rumen morphometrics, and feeding behavior, except for time spent ruminating and time spent resting ($P \leq 0.04$), and a tendency for papillae width ($P \leq 0.09$). Bulls fed SFC-based diets consumed 7% less ($P = 0.001$), had 10.6% greater carcass-adjusted average daily gain ($P < 0.001$) and 19% greater carcass-adjusted feed efficiency ($P < 0.001$) compared to bulls fed CGC-based diets. Observed net energy for maintenance and gain values were 14.9 and 19.4% greater ($P < 0.001$), respectively, for SFC than for CGC-based diets. Fecal starch concentration was less ($P < 0.001$) for bulls fed SFC compared to those fed CGC. No grain processing effects were detected ($P = 0.51$) for rumenitis score; however, cattle fed SFC presented smaller ruminal absorptive surface area ($P = 0.03$). Dry matter intake increased linearly ($P = 0.02$) and carcass-adjusted feed efficiency tended ($P = 0.06$) to decrease linearly as RNDF increased. Dietary RNDF concentration did not affect carcass characteristics ($P \geq 0.19$), except for dressing percentage, which tended to decrease linearly ($P = 0.06$) as RNDF in finishing diets increased. Increasing RNDF in finishing diets had no effect ($P = 0.26$) on time spent eating, but time spent ruminating and resting increased linearly (min/d; $P < 0.001$) with increased dietary RNDF. Steam flaking markedly increased flint corn energy value, net energy of diets, and animal growth performance, and led to improvements on feed efficiency when compared with grinding, regardless of RNDF content of diets. Increasing dietary RNDF compromised feedlot cattle feed efficiency and carcass dressing.

Key Words: beef cattle, feedlot, ground corn, NDF levels, Nellore, steam-flaked corn.

INTRODUCTION

Corn grain produced in South America, especially in Brazil, is primarily flint corn that contains a greater proportion of vitreous endosperm and lower starch availability compared with dent corn (Correa et al., 2002). Extensive methods of grain processing, such as steam flaking, markedly improved net energy (**NE**) content of flint corn grain and cattle growth performance (Gouvêa et al., 2016; Marques et al., 2016), and these responses exceeded those typically observed with dent corn grain (Zinn et al., 2011; Owens and Basalan, 2013). Steam flaking and high moisture ensiling increases starch degradation in the rumen (Owens and Basalan, 2013), potentially leading to accumulation of organic acids in the rumen and low ruminal pH, which could impair development of ruminal papillae (Owens et al., 1998; Wang et al., 2009) and adversely affect animal growth performance (Nagaraja and Titgemeyer, 2007). Greater amounts of effective fiber may be required in these diets compared to dry processed corn diets (NASEM, 2016).

According to several studies in which *Bos Taurus* cattle were fed yellow dent corn, sorghum, or wheat grain, interactions between grain processing and roughage levels were observed, and more roughage or more effective fiber appears to be required in diets containing high moisture or steam flaked grains compared to whole or dry processed grains (Gill et al., 1981; Stock et al., 1990; Milton et al., 1994; Gorocica-Buenfil and Loerch, 2005; Loerch and Gorocica-Buenfil, 2006; Pritchard, 2007).

Caetano et al. (2015) reported that the amount of neutral detergent fiber (**NDF**) from sugarcane silage (**SCS**) needed to maximize intake in finishing *Bos Indicus* cattle differed between diets containing either ground flint corn [**GC**; 1.3 mm mean particle size; 11.3% NDF from SCS, dry matter (**DM**) basis] or high moisture flint corn (13.7% NDF from SCS; DM basis); however, no interactions between NDF levels from SCS and corn grain processing methods were observed for growth performance or carcass traits. According to

Santos et al. (2017), finishing Nellore bulls fed high concentrate diets (whole cottonseed, soybean hulls, and ground corn) containing 4, 7, 10 or 13% NDF from low quality tropical grass hay (*Panicum maximum*, cv. BRS Tamani) presented quadratic improvements in dry matter intake (**DMI**), average daily gain (**ADG**), and hot carcass weight (**HCW**), but a linear decrease in feed efficiency (**G:F**). Intake of DM, ADG, HCW, and G:F were maximized with 12.11%, 10.27%, 8.75%, and 4% grass hay NDF, respectively. This is in agreement with Brown et al. (2006), who suggested that lower levels of forage inclusion in finishing diets can improve feed efficiency.

Sugarcane bagasse (**SCB**), which is a by-product generated by ethanol plants, is one of the most used roughage sources in Brazilian finishing cattle diets (Oliveira and Millen, 2014). Nevertheless, little information is available about the optimal level of inclusion of SCB in finishing diets to maximize growth performance of finishing *Bos indicus* cattle (Leme et al, 2003).

We hypothesized that roughage NDF levels from SCB (**RNDF**) interact with flint corn grain processing and higher levels of RNDF are necessary in SFC-based diets to improve growth performance of finishing Nellore bulls. To test this hypothesis, effects of flint corn processing methods [coarse ground (**CGC**; 3.2 mm average particle size) or steam flaked corn (**SFC**; 0.360 kg/L)] were evaluated at 4 levels of RNDF (4, 7, 10, and 13% of diet DM) to determine impact on feedlot growth performance, carcass characteristics, starch utilization, diet energy content, feeding behavior, and rumen morphometrics of finishing Nellore bulls.

MATERIALS AND METHODS

This study was conducted at the experimental feedlot cattle facilities of the Animal Science Department of the "Luiz de Queiroz" College of Agriculture (**ESALQ**), University of São Paulo (**USP**), in Piracicaba, State of São Paulo, Brazil. All procedures using animals followed guidelines recommended by the Animal Care and Use Committee of ESALQ/USP, protocol number # 2014-16.

Animals, Housing and Feeding

Two hundred forty Nellore bulls [initial body weight (**BW**) = 350 ± 37 kg) were vaccinated against clostridia (3 mL s.c.; Sintoxan Polivalent T, Merial Saúde Animal Ltda, Paulínia, Brazil), dewormed with 5 mL of 3.15% ivermectin (Ivomec Gold, Merial Saúde Animal Ltda), and received an injection of vitamins A, D, and E (5 mL s.c.; Valléevita ADE, Vallée S/A Produtos Veterinários, Montes Claros, Brazil) at the beginning of the experiment (d 0). The trial was preceded by a 21-d adaptation period. During the adaptation period, dietary concentration of the sugarcane bagasse was reduced each week from 30 to 20 to 15% of the diets (DM basis) and replaced with ground corn accordingly. A randomized complete block design was used with a 2 × 4 factorial arrangement of treatments (4 replications/treatment), in which cattle were blocked by initial BW (d 0; 2 BW blocks) and allocated into 1 of 32 partially covered feedlot pens with concrete floors [24 pens with 6 bulls/pen (5.3 m^2/bull) and 8 pens with 12 bulls/pen (7 m^2/bull)].

Treatments were randomly assigned to pens within each weight block (4 pens/treatment: 3 pens with 6 bulls + 1 pen with 12 bulls), and consisted of diets containing either CGC corn (3.2 mm average particle size) or SFC (0.360 kg/L density) combined with 1 of 4 levels of RNDF (4, 7, 10, and 13%; dry matter basis) from SCB. The minimum number of replicates per treatment required to detect a 20% difference in feed efficiency ($P < 0.05$; $1 - \beta = 0.95$) was determined by using error variance from results published by Gouvêa et al. (2016).

All diets were formulated to meet or exceed requirements of finishing Nellore bulls for 1.5 kg ADG as specified by NRC (1996; Table 1 and 2). All corn grain used in this trial was flint corn, as is regularly used in Brazil. In order to obtain SFC, grains were processed to a flake density of 0.360 kg/L at a commercial feedyard (Fazenda Conforto, Nova Crixás, Brazil), air dried to approximately 86% dry matter, and delivered to the research feedlot twice monthly. The CGC was processed through a hammer mill (DPM-4; Nogueira S/A Máquinas Agricolas, São João da Boa Vista, Brazil) for a mean particle size of 3.2 mm (Table 3). Sugarcane bagasse is the fibrous portion remaining after sugarcane stalks are crushed and juices extracted (Marques et al., 2016). Throughout the experimental period, using SCB had an average particle size of approximately 8.2 mm, with particle size distribution using the Penn State Particle Separator of 5.0, 39.8, 12.9, and 42.3% for the screens 19.0, 8.0, 3.5, and pan, respectively (Heinrichs, 1999; Kononoff et al., 2003).

Bulls were fed fresh mixed diets once daily at 0700 throughout the experiment and had free-choice access to feed and fresh water. Feed ingredients, except for the SCB that was weighed into the feed wagon, were individually weighted using a fixed scale (Weightech WT1000, Weightech Equipamentos de Pesagem, Florianópolis, SC, Brazil). Total mixed ration was prepared using a feed-mix wagon (Totalmix 25, Casale Equipamantos, São Carlos, Brazil) and mixing time was set according manufacture's recommendation. The amount of fresh feed offered to each pen was adjusted daily based on the DMI of the previous day, and the amount of orts should not exceed 3%. Orts were collected weekly, weighed, sampled and dried in a forced-air oven at 55°C for 72 h to estimate DMI for each pen.

Sample Collection and Analyses

Before the beginning (d 0) and at the end of the experimental period, individual BW was recorded after a 16-h period of feed and water withdrawal, and these data were used to calculate ADG. The G:F was calculated by dividing ADG by DMI for each pen.

For diet adjustments and diet DM determination, samples of SCB, CGC, SFC, and soybean meal (**SBM**) were collected weekly throughout the experiment and dried at 105°C for 12 h.

Samples of SCB, CGC, SFC, and SBM were also collected weekly and stored at -20°C. At the end of the trial, feed samples were thawed, composited by week, dried in a forced-air oven at 55°C for 72 h, and ground using a Wiley-type mill (MA-680 Marconi Ltda, Piracicaba, SP, Brazil) through a 1-mm screen. All samples were analyzed for dry matter at 105° C (method 930.15; AOAC, 2000), ash (method 942.05; AOAC, 2000), ash-corrected NDF (Van Soest et al., 1991 modified for Ankom 200 fiber analyzer, Ankom Technology Corp.) using sodium sulfite for all the samples and heat-stable α-amylase for CGC and SFC, acid detergent fiber (Goering and Van Soest, 1970), ether extract (method 920.85; AOAC, 1986), and total nitrogen (Leco FP-528, Leco Corp., St. Joseph, MI).

Corn grain vitreousness (Table 3) was determined by manual dissection of 50 randomly selected whole kernels from each non-processed CGC and SFC samples as described previously by Gouvêa et al. (2016). Duplicate samples of each processed grain (CGC and SFC; 100 g) were placed on the top screen (6-mm openings) of a testing sieve (Produtest T Model; Telastem Peneiras para Análises Ltda., São Paulo, SP, Brazil) and vigorously agitated with approximately 60 shakes/min for 5 min. Sieves with 6.0, 3.5, 2.0, and 1.25-mm pores were used to calculate grain particle size as described by Yu et al. (1998; Table 3).

Feeding behavior was visually evaluated by 8 trained individuals (4 pen for each person, who were blinded to dietary treatments) on d 60 using a procedure adapted from

Robles et al. (2007). Behavior data were recorded every 10 min during a 24-h period from two randomly selected bulls per pen as follows: minutes spent eating, ruminating, and resting (if they were not eating or ruminating) (Robles et al., 2007; Pereira et al., 2016). Activities per unit of DMI and NDF intake were also calculated by dividing total minutes by the mean of each parameter measured.

On d 70, three bulls per pen were randomly selected and approximately 300 g of fresh fecal samples were collected (Charles et al., 2011) before feeding dietary treatments. Samples were dried at 55°C for 72 h, ground through a 1-mm screen using a Wiley-type mill (MA-680 Marconi Ltda, Piracicaba, SP, Brazil), and analyzed for dry matter (method 930.15; AOAC, 1986). Fecal starch (**FS**) concentration was determined according to procedures described by Bach Knudsen (1997). Fecal starch values were used to calculate total tract starch digestion (**TSD)** and NE content of corn as described previously by Zinn e t al. (2007).

Calculations for observed net energy of maintenance (**NE_m**) and gain (**NE_g**) of each dietary treatment were based on the equation proposed by Zinn and Shen (1998) taking into account average values from growth performance data of bulls in each pen. These calculated NE concentrations were compared to those predicted by equations from NASEM (2016; solution type = empirical) with addition of monensin [2.3% increase in diet metabolizable energy (**ME**) content], and based on the numeric sum of total digestible nutrients (**TDN**; Weiss et al., 1992) for feed ingredients assuming processing adjustment factors of 0.95 and 1.04 for CGC and SFC, respectively (NRC, 2001).

At the end of the feeding trial, animals were withheld from feed and water for 16 h, weighed, and shipped 10.3 km (approximately 20 min) using 12 commercial beef trucks (20 bulls/truck)] to a commercial packing plant (Frigorifico Angelleli S/A, Piracicaba, Brazil), where they were slaughtered on the following day. Bulls from block 1 (heavy) and 2 (light) were assigned to slaughter on 2 separate dates, 28 d apart (n = 96 bulls after 95 d on feed

[**DOF**]; n = 144 bulls after 123 DOF). Slaughter dates were established based on estimated mature weight of 497 kg for Nellore bulls (Costa e Silva et al., 2012). The HCW was obtained at the time of slaughter after evisceration and removal of kidney, pelvic, and heart fat. Dressing percentage was calculated as the ratio of HCW to final shrunk BW. Average dressing percent (55.12 %) was used to estimate carcass-adjusted final BW from HCW and so, carcass-adjusted average daily gain and feed efficiency were also calculated. These carcass-adjusted data were used in the discussion section. Subcutaneous fat thickness and loin muscle area were measured over the 12th rib after a 24-h carcass chill at 4°C using a digital caliper and a numbered grid, respectively.

Livers were scored for abscess incidence and severity using a 4-point numeric scale (1 = no visible abscess and 4 = severe with more than 4 small abscesses or one or more abscess greater than 2.5 cm in diameter; Brown et al., 1975). After cattle evisceration, rumens were washed and scored for presence of lesions (rumenitis) and abnormalities (e.g., papillae clumped) using an 10-point scale (0 = no lesions and abnormalities and 10 = severe ulcerative lesions; Bigham and McManus, 1975; Pereira et al., 2016). Two bulls per pen were randomly selected and a 1-cm^2 fragment of ruminal epithelium was collected from cranial sac (atrium ruminis) and placed into a PBS solution for subsequent macroscopic morphometric evaluation as described by Pereira et al. (2016). From the ventral sac of the rumen, a 1-cm^2 fragment was collected for microscopic morphometric evaluation of ruminal-papilae, such as height, width, surface area, and keratinized layer thickness (Pereira et al., 2016).

Statistical Analyses

Feedlot growth performance, carcass characteristics, FS excretion, feeding behavior, rumen morphometrics, and diet energy values were analyzed using the PROC MIXED procedure of SAS (SAS Inst., Inc., Cary, NC) as a generalized randomized block design (4 replications/treatment) with a 2 × 4 factorial arrangement of treatments [2 corn grain processing methods (CGC and SFC) and 4 levels of RNDF (4, 7, 10, and 13%; DM basis)]. Bulls were blocked by initial BW (total of 2 blocks; two replicates per treatment within each block). Pen was the experimental unit and Satterthwaite approximation was used to determine denominator degrees of freedom for testing fixed effects. All model statements included fixed effects of corn grain processing, RNDF level, and corn grain processing × RNDF level interaction. Pen (corn grain processing × RNDF level × block) and bull (pen) were used as random variables for all variables analyzed, excepted for DMI and G:F that didn't included bull (pen). Trained individuals were also included as random effect for feeding behavior analyses. When no significant interactions were detected, main effects of corn processing and RNDF levels were evaluated. When significant interactions were observed, however, orthogonal polynomial contrasts were used to detect linear and quadratic effects of RNDF inclusion levels within each corn processing methods. The Solution statement was used to estimate regression coefficients. Results are reported as least-squares means. Differences were declared significant $P \leq 0.05$ and regarded as tendencies when $P > 0.05$ and $P \leq 0.10$.

RESULTS

Effects of corn grain processing × RNDF level were not detected ($P \geq 0.14$) for any feedlot growth performance, dietary NE concentration, carcass traits, rumen morphometrics, and feeding behavior variables, except for time spent ruminating (as expressed as min/kg NDF; $P = 0.01$), time spent resting ($P = 0.04$) and a tendency for papillae width ($P = 0.09$).

Effects of corn processing × roughage NDF level. No effect of RNDF levels were observed in time spent ruminating for bulls fed SFC-based diets ($P = 0.15$) but increasing RNDF levels tended ($P = 0.07$) to linearly increase the time spent ruminating (expressed as min/kg NDF) in bulls fed CGC-based diets (Fig. 1). At RNDF levels greater than 10% of diet

DM, bulls fed SFC-based diets spent more time resting than bulls fed CGC-based diets (Fig. 2). No effect of RNDF levels were observed in papillae width for bulls fed SFC-based diets (P = 0.42), but increasing RNDF levels tended to linearly increase the papillae width in bulls fed CGC-based diets (P = 0.07; Fig. 3).

Effects of corn processing. As designed, initial BW were similar (P = 0.99) among bulls assigned SFC or CGC-based diets (Table 4). Bulls fed SFC-based diets had 7.0% less DMI (P = 0.001), 10.6% greater carcass-adjusted ADG (P < 0.001) and 19% greater carcass-adjusted G:F (P < 0.001) compared to bulls fed CGC-based diets (Table 4). Corn grain processing method didn't affect carcass-adjusted final body weight and carcass traits ($P \geq$ 0.18). Bulls fed SFC-based diets spent less time (P = 0.007) eating (min/d and min/kg of DMI) and tended to increase (P = 0.08; min/d) or increased (P < 0.01; min/kg of DMI) time spent ruminating compared to bulls fed CGC-based diets (Table 5). Dietary NE intakes, which were calculated from growth performance measurements (BW, ADG, and DMI), were greater ($P \leq$ 0.03) for bulls fed SFC compared to bulls fed CGC (Table 6). Observed NE_m and NE_g values were respectively 14.9% and 19.4% greater (P < 0.001) for SFC- than for CGC-based diets (Table 6). The observed NE:expected NE ratios were greater (P < 0.001) for SFC- than CGC-based diets (Table 6). Fecal starch concentration was reduced (P < 0.001) for bulls fed SFC vs. CGC-based diets. Consequently, bulls fed SFC-based diets had greater (P < 0.001) TSD compared to CGC-fed cattle (Table 6). Based on FS values and calculations described by Zinn et al. (2007), steam flaking increased (P < 0.001) NE_m and NE_g of flint corn grain by 8.0 and 10.2%, respectively, compared to grinding (Table 6).

Corn grain processing method did not affect ($P \geq$ 0.45) rumenitis score, papillae area, papillae height, papillae surface area, or keratinized layer thickness (Table 7), whereas bulls fed SFC-based diets had reduced ($P \leq$ 0.05) number of papillae and absorptive surface area (ASA).

Liver abscess incidence was very low in the present study. Just two bulls presented one small abscess each (2-point numeric scale) and for this reason, a statistical analysis was not performed.

Effects of roughage NDF level. Dry matter intake increased linearly (P = 0.02) when RNDF levels increased (Table 4) while carcass-adjusted ADG was not affected (P = 0.15), resulting in a tendency (P = 0.06) for a linear decrease in carcass-adjusted feed efficiency. However, such increase in DMI was insufficient ($P \geq 0.19$) to affect carcass characteristics variables evaluated, except for dressing percentage, which tended to decrease linearly (P = 0.06) as RNDF levels increased in the finishing diets (Table 4). Increasing RNDF in the finishing diets had no effect (P = 0.26) on time spent eating, whereas as the RNDF levels increased, time spent ruminating (min/d and min/kg of DMI) increased linearly ($P < 0.001$; Table 5). No differences was noted ($P \geq 0.27$) for NE intake, dietary NE concentration, fecal variables, or corn NE as concentration of RNDF increased from 4 to 13% of the fishing diet (Table 6). No effects of RNDF levels were observed ($P \geq 0.30$) for rumenitis score or and rumen morphometric variables (Table 7).

DISCUSSION

Effects of Grain Processing. Published research examining methods of processing of yellow dent corn grain is abundant with finishing *Bos taurus* cattle fed high-concentrate diets (Owens et al., 1997; Zinn et al., 2011; Owens and Basalan, 2013). Less is known, however, about potential impacts of processing of flint corn typically used in feedlot diets for *Bos indicus* cattle (Oliveira and Millen, 2014; Gouvêa et al. 2016; Marques et al. 2016). The lower DMI of bulls fed SFC compared to CGC in the present study is consistent with previous reports pertaining to finishing cattle fed high-concentrate diets containing either yellow dent corn (Zinn et al., 2011; Owens and Basalan, 2013) or flint corn (Gouvêa et. al., 2016; Marques et al., 2016). When comparisons were based on only paired trials, Zinn et al. (2011) and Owens and Basalan (2013) reported that cattle fed yellow dent corn processed by steam flaking consumed 3.8% and 4.3% less DM respectively than cattle fed dry rolled corn (**DRC**). On the other hand, the decrease in DMI appears to be greater when flint corn is steam-flaked. Similar to our findings, Gouvêa et al. (2016) reported 7.9% lower DMI for bulls fed flint SFC compared with GC (1.32 mm mean particle size), while Marques et al. (2016) reported 17% lower DMI for flint corn processed as steam-flaked compared with whole corn. Brazilian flint corn has higher vitreousness and lower starch availability compared with U.S. yellow dent corn when fed as dry processed corn (Correa et al., 2002). Granules of starch in the vitreous endosperm region are densely compacted within a protein matrix, which has negative impact on starch colonization by ruminal bacteria and consequently on starch digestion in flint corn (McAllister and Ribeiro, 2013). Based on the greater relative increase in starch digestion and energy value for dent versus flint corn grain, the response to steam-flaking on DMI appear greater for the flint corn.

Beneficial effects of corn processing on carcass-adjusted ADG and on carcass-adjusted G:F in our study are consistent with observations from previously reported studies with flint corn (Gouvêa et al., 2016; Marques et. al., 2016). Gouvêa et al. (2016) reported 12.5% greater ADG and 23.3% greater G:F for cattle fed diet high in flint SFC compared with GC (both diets contained 100% corn and no citrus pulp). Marques et al. (2016) reported no difference in ADG but 20.3% greater G:F for cattle fed diet high in flint corn processed by steam flaking compared with whole corn (both diets contained 6% sugarcane bagasse). Owens and Basalan (2013) summarized comparisons from 17 paired trials with yellow dent corn and reported that SFC increased ADG by 3.9% and G:F by 8.4% compared with DRC.

In contrast to the current experiment, where HCW was not increased by SFC, Owens and Gardner (2000) reported that cattle fed SFC had heavier carcass weights than those fed

DRC, high-moisture, or whole grains. It should be expected that compared with grinding, flaking corn 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 NE_g (Zinn et al., 2011), thus resulting in a greater carcass production and heavier final BW.

The presented data corroborates findings of other authors where SFC did not alter dressing percentage (LaBrune et al., 2008; Corrigan et al., 2009; 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 (Scott et al., 2003; Luebbe et al., 2012; Gouvêa et al., 2016; Marques et al., 2016) when compared with DRC, ground corn, or whole grain. Within breeds and at similar HCW, carcass traits generally are similar.

Steam-flaking of corn disrupts the grain pericarp, breaks down the recalcitrant barriers such as the protein matrix, and increases the surface area available for microbial attachment and colonization, thus leading to greater rate and extent of starch digestion in the rumen (McAllister et al., 2006). Steam flaking also increases starch digestion in the small intestine (Owens and Soderlund, 2007), resulting in reduced FS and increased estimated TSD as observed in the present study. 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 (98.2 vs 92.2%) in the present study was less than that reported by Owens and Soderlund (2007) for dent corn and it does not explain the difference in growth performance between SFC- and CGC-fed cattle. Based on FS concentration, the estimated grain NE_m and NE_g were only 8.0% and 10.2% greater for SFC when compared with CGC; however, based on cattle growth performance data (mean BW, ADG, and DMI), observed diet NE_m and NE_g values increased by 14.9% and 19.4% when bulls were fed SFC compared with those fed CGC-based diets, respectively. Assuming the improvements are attributable solely to processing of corn that constitutes 81.4% of the diet (DM basis; average value for the roughage levels), steam flaking increased the NE_m and NE_g of corn grain by 18.3% and 23.8%, respectively. These increments with flint corn are greater than the ones reported with dent corn where steam flaking increased NE_m by 15% and NE_g by 18% compared with cracked or DRC (Zinn et al., 2002), and are explained primarily because flint corn contains higher proportion of vitreous endosperm and lower starch availability compared with dent corn (Correa et al., 2002). In agreement with current data, Gouvêa et al. (2016) and Marques et al. (2016), also reported that the beneficial effect of steam flaking on grain energy content was greater for flint than for dent corn.

Underestimation of the improvement in grain energy content with steam flaking based on FS concentration compared to the increment based on growth performance data may have occurred because the increase in starch digestion is the major but not the only cause for the increase in grain energy value when it is steam-flaked. Owens and Basalan (2013) pointed out the potential importance of increased ruminal propionate production, decreased methane production, increases in digestibility of other feed components, and the site and efficiency of starch digestion as contributing factors. Assuming the starch digestibility values proposed by Owens and Soderlund (2007) for CGC of 63.80, 58.83 and 56.32% and for SFC of 84.05, 92.48 and 20.47% within the rumen, small intestine, and large intestine, respectively , and the observed total daily starch intake of 5.34 and 4.96 kg for CGC and SFC, respectively, the amounts of starch digested in the rumen, small intestine, and large intestine would be respectively 3.41, 1.13 and 0.45 kg for CGC and 4.17, 0.73 and 0.01 kg for SFC. Based on these calculations, cattle fed SFC would have the advantage of digesting more starch in the total tract with essentially no starch digestion in the large intestine. Energy losses are greater when starch is digested in the large intestine compared with the rumen and small intestine (McLeod et al., 2007).

The general concept is that cattle on high-grain diets (2.7 to 3.3 Mcal of ME/kg of DM) eat to maintain energy intake (Krehbiel et al., 2006), and according to this review, the upper caloric limit for maximizing energy intake and ADG was 3.16, while for maximizing G:F the value was 3.45 Mcal ME/kg of DM (assuming feed ingredients energy values from the 1996 NRC). In the present study, diets containing CGC and SFC averaged 2.88 and 3.01 Mcal ME/kg of DM, respectively (expected energy content based on chemical composition of ingredients) and 2.81 and 3.15 Mcal ME/kg of DM (observed energy based on growth performance data). Thus, cattle fed flint SFC were able to consume 11.6% more NE_g despite their lower DMI, and gained more weight with greater G:F than cattle fed CGC.

Based on the observed NE_g:expected NE_g ratios of 0.96 for CGC and 1.07 for SFC diets, and recognizing that corn comprised 76.0 to 86.7% of diet DM, we can speculate that energy values for flint corn grain calculated from chemical composition of ingredients and using Weiss et al. (1992) equations for TDN, were overestimated for CGC and underestimated for SFC. The same was observed by Gouvêa et al. (2016) and by Marques et al. (2016) with flint corn.

As expected, eating time decreased for cattle fed SFC, because of lower DMI. Increasing the energy content of corn by steam flaking typically decreases intake (Zinn et al. 2011) because dietary energy is the primary regulator of DMI for concentrate-based diets (Krehbiel et al., 2006). In addition, the tendency for increasing ruminating time in SFC-based diets may be associated to the larger geometric size of the SFC compared with CGC, which can increase retention time in the rumen, thus leading to increased rumination time (Savari et al., 2017). The lower DMI, lower content of NDF in the diet and the tendency for greater ruminating time (min/d) for cattle fed SFC compared with cattle fed CGC explains the greater time spent ruminating expressed as kg of ingested DM and NDF of cattle fed SFC. One may speculate that the greater time spent ruminating by cattle fed SFC diets, besides stimulated by the greater particle size of SFC, also could be a protective mechanism against rumen acidosis when highly fermentable starch sources are fed.

According to Perdigão et al. (2016), the adequate development and growth of papillae are closely associated with feeding habits of cattle, such as dietary adaptation protocol, availability and digestibility of feed, and proportion of concentrate in the diet. High-concentrate rations increased the absorptive surface area of the rumen by increasing the length and width of rumen papillae compared to animals fed forage-based diets (Zitnan et al., 2003). Melo et al. (2007) reported that absorptive surface area of rumen wall was the morphometric variable most correlated to the speed of VFA absorption. According to Costa et al. (2008), propionate is the VFA responsible for promoting the physiological growth of metabolically active papillae. In the present study, cattle fed SFC had greater NE intake and theoretically greater rumen degradable starch intake [4.17 vs 3.40 kg/d; assuming 63.80 vs 84.05% ruminal starch degradation for CGC and SFC, respectively (Owens and Soderlund, 2007)]. Bulls fed SFC-based diets had reduced number of papillae, resulting in smaller absorptive surface area and papillae width compared with bulls fed CGC-based diets, however. Wang et al. (2009) reported that excessive starch degradation in the rumen resulted in lower ruminal pH, which impaired development of rumen papillae. No differences between SFC and CGC were observed with respect to rumenitis scores in the present study, and cattle fed SFC spent more time ruminating and had superior growth performance compared to their counterparts fed CGC. Kern et al. (2016) reported that morphological characteristics of rumen papillae did not affect feed intake or BW gain in finishing cattle.

No effect of RNDF levels was observed in papillae width for bulls fed SFC-based diets, but a tendency for linear effects of RNDF levels was observed in bulls fed CGC-based diets. Greater rumen papillae width was observed when animals were fed diets containing higher physical effective fiber (Wang et al. 2017), but the reasons why RNDF level just increased papillae width in CGC-based diets in the present study are unclear.

Effects of roughage NDF level. In finishing beef diets, forage is usually included in small amounts to promote better mixing of the diet, to stimulate saliva production and rumination (Armbruster, 2007), and to maintain digestive function and maximize energy intake (Galyean and Hubbert, 2014). In addition, several review articles (Galyean and Defoor, 2003; Pritchard, 2007; Galyean and Hubbert, 2014) have demonstrated that including a small amount of roughage in high-concentrate feedlot diets containing low levels of NDF (<15%), increased intakes of DM and NE_g. These increases in DMI could be attributed, at least partially, to an attempt by the animal to maintain a constant energy intake (Krehbiel et al., 2006). In the current study, the linear increase in DMI when diet RNDF levels increased is in agreement with the 11 experiments summarized by Galyean and Defoor (2003) with a variety of roughage sources such as corn silage, alfalfa hay, sorghum silage, sudan grass silage, cottonseed hulls and wheat straw, fed at 0 to 30% of diet DM to supply 0 to 26.5% roughage NDF in the diet. Farran et al. (2006) and Parsons et al. (2007) also reported a linear increase on DMI of cattle fed diets containing wet corn gluten feed and roughage levels varying from 0 to 9.0% (DM basis). On the other hand, Hales et al. (2013), Caetano et al. (2015), Marques et al. (2016), and Santos et al. (2017) fed different roughage sources as alfalfa hay, sugarcane silage, sugarcane bagasse and low quality grass hay, respectively, and reported a quadratic response in DMI as RNDF level increased in the feedlot diet. The last three authors also used *Bos indicus* cattle, as in the present study.

The absence of interaction between grain processing method and RNDF level in the present study is in contrast with most of the literature reviewed (Gill et al., 1981; Stock et al., 1990; Milton et al., 1994; Gorocica-Buenfil and Loerch, 2005; Owens, 2005; Loerch and Gorocica-Buenfil, 2006; Pritchard, 2007; Caetano et al., 2015). Gil et al. (1981) reported that

8, 12 and 16% roughage (1/3 alfalfa hay + 2/3 corn silage) in the diet DM was required to optimize ADG of cattle fed SFC, SFC:high moisture corn (**HMC**) mixture and HMC diets respectively. Caetano et al. (2015) reported that the level of NDF from sugarcane silage to maximize DMI in finishing cattle differed between animals fed diets containing either ground corn or high-moisture corn (11.3 vs. 13.7% NDF from roughage, respectively; DM basis). These outcomes could be attributed to the higher ruminal degradation rate of starch from high moisture corn compared with starch from dry processed or steam-flaked corn (Owens and Soderlund, 2007). In the present study, greater ruminating time of cattle fed SFC diets may have counterbalanced its greater starch degradability in the rumen and its greater potential for causing acidosis compared with CGC.

Despite the linear increase in DMI as RNDF levels from SCB increased, observed diet NE content, NE intake and consequently cattle carcass-adjusted ADG were not altered. It is possible that more than 7% RNDF levels from SCB have caused some filling effect limiting a significant increase in DMI (Allen, 1997). Based on data from 8 reviewed experiments, inclusion of roughage in the diet caused a linear increase in intakes of DM and NE_g in 4 experiments (Defoor et al., 2002; Farran et al., 2006; Parsons et al., 2007) and a quadratic increase in the other 4 experiments (Hales et al., 2013; Caetano et al., 2015; Marques et al., 2016; Santos et al., 2017). Therefore, we can speculate that the type of response, linear or quadratic, may be affected by several factors such as the NDF content of the roughage source, the effectiveness of the fiber source, the level of roughage inclusion in the diet and also, by the level and degradability of starch in the diet. Since carcass-adjusted ADG was not different, we did not expect to observe effects of RNDF level on HCW, back fat thickness, or LM area, but carcass dressing percent tended to decrease linearly as RNDF level was increased in the diets. Santos et al. (2017) reported a linear decrease in carcass dressing percent in *Bos indicus* cattle as grass hay NDF was increased in the diet from 4 to 13% probably due to the filling effect of greater roughage inclusion in the diet.

The tendency for the linear decrease in carcass-adjusted G:F as RNDF level from SCB was included in the diet was caused by the linear increase in DMI, with no alteration in carcass-adjusted ADG. The effects of RNDF levels on cattle G:F are not consistent in the literature and may be dictated by level and source of roughage and grain source and processing methods. Stock et al. (1990) reported that adding roughage (0, 4, 8 and 12% of diet DM) to HMC or dry rolled grain sorghum diets decreased G:F in one trial, but in a second trial, in comparison with no roughage diets (0%) adding 10% of roughage decreased G:F of cattle fed DRC diets but had no effect on G:F of cattle fed dry rolled wheat. In most recent studies with corn grain, the inclusion of roughage decreased G:F in 9 studies (Calderon-Cortez and Zinn, 1996; Farran et al., 2006; Turgeon et al., 2010; Carareto, 2011; May et al., 2011; Hales et al., 2013; Shreck et al., 2015; Santos et al., 2017) and had no effect on G:F in other 7 studies (Leme et al., 2003; Parsons et al., 2007; Sindt et al., 2002; Depenbusch et al., 2009; Benton et al., 2015; Caetano et al., 2015; Marques et al., 2016).

Diet NE_g estimated from chemical composition of ingredients was expected to decrease (1.35, 1.31, 1.27, and 1.24 Mcal/kg DM) as RNDF level increased in the diets. When calculated from growth performance data, however, NE_g was not decreased by addition of RNDF to the diets. The same response was observed by Marques et al. (2016) who hypothesized that the inclusion of roughage in the diet should increase chewing or rumination time and saliva flow and consequently, ruminal pH, passage rate and rumen fermentation, counterbalancing the lower energy value of roughage compared to corn grain. In the present study, time spent ruminating increased linearly as RNDF level increased in the diet, however, greater ruminating time did not increase starch digestion form either CGC or SFC.

Changes in ruminal papillae surface could be related to differences in dietary NDF supplied by roughage (Allen, 1997), but according to Galyean and Defoor (2003), it is still unknown whether roughage source or level in feedlot finishing diets affect ruminal surface area for absorption. In the present study, RNDF levels did not impact neither rumenitis score nor rumen morphometrics. Nevertheless, research is still warranted to fully elucidate the impacts of RNDF levels and corn processing on rumen morphometrics.

In summary, steam flaking markedly increased flint corn energy value, NE of diets, animal growth performance, and feed efficiency compared with coarse grinding, independently of the dietary roughage level. Benefits of steam flaking on energy value for flint corn were considerably greater than what has been previously reported in the literature for yellow dent corn. Varying the level of neutral detergent fiber from sugarcane bagasse from 4 to 13% increased DMI, had no effect on observed NE content of the diet, NE intake, rumen morphometrics and cattle carcass-adjusted ADG, but decreased carcass-adjusted feed efficiency and carcass dressing. Varying estimated NE content of the diets through steam flaking flint corn is a powerful and more effective strategy to increase NE intake and growth performance of *Bos indicus* cattle than varying the level of neutral detergent fiber from sugarcane bagasse in the diet.

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Figure 1. Effects of flint corn grain processing method [coarse ground corn (**CGC**; 3.2 mm) or steam flaked corn (**SFC**; 0.360 kg/L)] and neutral detergent fiber (**NDF)** levels (% of dry matter) from sugarcane bagasse (**RNDF**) on feeding behavior of finishing Nellore bulls. Effect of corn grain processing × RNDF level was detected for time spent ruminating expressed as min/kg of NDF intake (**TRu**; $P = 0.01$; SEM = 16.5). No effect of RNDF levels on TRu was observed in SFC-based diets ($P = 0.15$; SEM = 16.3) but a tendency of linear effect of RNDF levels was detected in CGC-based diets ($P = 0.07$; SEM = 16.6). Animals were visually evaluated by 8 trained individuals (4 pens for each evaluator blinded to dietary treatments) on d 60 of the feeding period using a procedure adapted from Robles et al. (2007). Behavior data were recorded every 10 min during a 24-h period from two randomly selected bulls per pen as follows: minutes spent eating, ruminating, and resting (if they were not eating or ruminating) (Robles et al., 2007; Pereira et al., 2016). Activities per unit of DMI and NDF intake were also calculated by dividing total minutes by the mean of each parameter measured.

Figure 2. Effects of flint corn grain processing method [coarse ground corn (**CGC**; 3.2 mm) or steam flaked corn (**SFC**; 0.360 kg/L)] and neutral detergent fiber (**NDF)** levels (% of dry matter) from sugarcane bagasse (**RNDF**) on feeding behavior of finishing Nellore bulls. Effect of corn grain processing × RNDF level was detected for time spent resting (**TRe**; $P = 0.04$; SEM = 26.7). Linear effect of RNDF levels in CGC diets ($P < 0.001$; SEM = 49.4) and SFC diets ($P < 0.001$; SEM = 41.9). Animals were visually evaluated by 8 trained individuals (4 pens for each evaluator blinded to dietary treatments) on d 60 of the feeding period using a procedure adapted from Robles et al. (2007). Behavior data were recorded every 10 min during a 24-h period from two randomly selected bulls per pen as follows: minutes spent eating, ruminating, and resting (if they were not eating or ruminating) (Robles et al., 2007; Pereira et al., 2016). Activities per unit of DMI and NDF intake were also calculated by dividing total minutes by the mean of each parameter measured.

Figure 3. Effects of flint corn grain processing method [coarse ground corn (**CGC**; 3.2 mm) or steam flaked corn (**SFC**; 0.360 kg/L)] and neutral detergent fiber (**NDF)** levels (% of dry matter) from sugarcane bagasse (**RNDF**) on rumen tissue morphometrics of finishing Nellore bulls. A tendency for corn grain processing × RNDF level was detected for rumen papillae width, mm (**RPW**; *P* = 0.09; SEM = 0.04). No effect of RNDF levels on RPW were observed in SFC diets (*P* = 0.42; SEM = 0.07), but a tendency for positive linear effect of RNDF levels on RPW was observed in CGC diets (*P* = 0.07; SEM = 0.04). Bulls from block 1 and 2 were assigned to slaughter on 2 separate dates, 28 d apart (n = 96 bulls after 95 d on feed [**DOF**]; n = 144 bulls after 123 DOF). Rumen samples were collected from two randomly selected bulls in each pen. Approximately a 1-cm^2 fragment of rumen was collected from cranial sac (atrium ruminis) and placed into a phosphate-buffered saline solution as described by Pereira et al. (2016).

Table 1. Chemical composition (% of dry matter) of steam-flaked corn (**SFC**), coarse ground corn (**CGC**), soybean meal (**SBM**), and sugarcane bagasse (**SCB**) used in experimental diets[1]

Item	SFC	CGC	SBM	SCB[2]
Dry matter	86.1	89.2	88.2	49.6
Crude protein	7.52	8.43	47.2	2.30
Extract Ether	3.15	5.30	1.50	0.430
Neutral detergent fiber	8.70	14.7	28.1	85.9
Acid detergent fiber	2.51	3.64	10.0	58.2
Lignin	0.62	0.38	0.51	12.2
Ash	1.10	1.54	6.00	5.01
Total digestible nutrients[3]	90.5	86.3	76.6	39.5
Starch	70.4	71.2	-	-

[1]All corn grain used was flint corn as is regularly used in Brazil. To form steam-flaked corn, it was processed to a flake density of 0.360 kg/L at a commercial feed mill (Fazenda Conforto, Nova Crixás, Brazil), air dried, and delivered to the research feedlot twice monthly. Ground corn was processed through a hammer mill (DPM-4; Nogueira S/A Máquinas Agricolas, São João da Boa Vista, Brazil) to achieve a mean particles size of 3.2 mm.
[2]A byproduct from the ethanol industry; it is the fibrous portion remaining after sugarcane stalks are crushed and juices extracted (Marques et al., 2016).
[3]The total digestible nutrient content was calculated according to the equations described by Weiss et al. (1992), and using the processing adjusted factors (0.95 and 1.04 for ground corn and steam-flaked corn, respectively; NRC, 2001).

Table 2. Ingredients and chemical composition of experimental diets (dry matter basis)

	Coarse ground corn				Steam-flaked corn			
	Neutral detergent fiber levels from sugarcane bagasse							
Item	4	7	10	13	4	7	10	13
Ingredient, % of dry matter								
Sugarcane bagasse[1]	4.70	8.10	11.6	15.1	4.70	8.10	11.6	15.1
Coarse ground corn[2]	86.7	83.2	79.6	76.0	-	-	-	-
Steam-flaked corn[2]	-	-	-	-	86.7	83.2	79.6	76.0
Soybean meal	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Urea	1.10	1.20	1.30	1.40	1.10	1.20	1.30	1.40
Mineral supplement[3]	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Analyzed composition[4]								
Dry matter, %	87.7	86.4	84.9	83.6	85.0	83.8	82.5	81.2
Crude protein, %	13.0	13.1	13.0	13.0	12.2	12.3	12.2	12.3
Neutral detergent fiber, %	18.2	20.6	23.1	25.5	13.0	15.6	18.3	21.0
Total digestible nutrients, %	80.5	78.8	77.1	75.4	84.2	82.3	80.5	78.6
NE_m,[5] Mcal/kg	2.01	1.96	1.91	1.86	2.12	2.07	2.01	1.95
NE_g,[5] Mcal/kg	1.36	1.31	1.27	1.22	1.45	1.41	1.36	1.31

[1]A byproduct from the ethanol industry; it is the fibrous portion remaining after sugarcane stalks are crushed and juices extracted (Marques et al., 2016).

[2]All corn grain used was flint corn as is regularly used in Brazil. To form steam-flaked corn, it was processed to a flake density of 0.360 kg/L at a commercial feed mill (Fazenda Conforto, Nova Crixás, Brazil), air dried, and delivered to the research feedlot twice monthly. Ground corn was processed through a hammer mill (DPM-4; Nogueira S/A Máquinas Agricolas, São João da Boa Vista, Brazil) to achieve a mean particles size of 3.2 mm.

[3]Custom blend manufactured by Agroceres Multimix, Piracicaba, Brazil, containing (dry matter basis) 260 g/kg Ca, 20 g/kg P, 50 g/kg Na, 10 g/kg Mg, 20 g/kg S, 1000 mg/kg of Mn, 1800 mg/kg of Zn, 350 mg/kg of Cu, 35 mg/kg of Co, 30 mg/kg of I, 12 mg/kg of Se, 1100 mg/kg of monensin, 160,000 IU/kg of vitamin A, 120,000 IU/kg of vitamin D3, 1500 IU/kg of vitamin E.

[4]Based on chemical analysis of ingredients collected weekly throughout the experiment (n = 17 samples). At the end of the trial, feed samples were thawed, composited by week, dried in a forced-air oven at 55°C for 72 h, and ground using a Wiley-type mill for analysis.

[5]Net energy for maintenance (NE_m) and gain (NE_g) were estimated according the equations proposed by NASEM (2016; solution type = empirical level) with the addition of monensin as feed additive, and based on the sum of total digestible nutrient values from each ingredient calculated according to the equations described by Weiss et al. (1992) using assumed processing adjustment factors of 0.95 and 1.04 for ground corn and steam-flaked flint corn, respectively.

Table 3. Impacts of grain processing method (coarse ground corn [**CGC**] or steam-flaked corn [**SFC**]) on characteristics of corn grains

Item	CGC	SFC
Corn particle size distribution,[1] % of total		
> 6 mm	7.10	70.6
≤ 6 and > 3.5 mm	28.7	16.1
≤ 3.5 and > 2.0 mm	36.0	7.50
≤ 2.0 and > 1.25 mm	15.6	2.60
≤ 1.25 mm	12.6	3.20
Mean particle size	3.20	9.40
Vitreousness,[2] % of total endosperm	70.8	67.9

[1]Duplicates samples of each processed grain (CGC and SFC; weight = 100 g) were placed on the top screen (6-mm openings) of a testing sieve (Produtest T Model; Telastem Peneiras para Análises Ltda., São Paulo, SP, Brazil) and vigorously agitated with approximately 60 shakes/min for 5 min. Sieves with 6.0-, 3.5-, 2.0-, and1.25-mm pores were used to calculate the grain particle size as described by Yu et al. (1998).

[2]Determined by manual dissection of 50 randomly selected whole kernels from each non-processed CGC and SFC samples as described previously by Gouvêa et al. (2016).

Table 4. Effects of flint corn grain processing (**PRC**) method [coarse ground corn (**CGC**; 3.2 mm) or steam flaked corn (**SFC**; 0.360 kg/L)] and neutral detergent fiber (**NDF)** levels (% of dry matter) from sugarcane bagasse (**RNDF**) on growth performance, feeding behavior, and carcass traits of finishing Nellore bulls

Item	Corn grain processing method		NDF levels from sugarcane bagasse				SEM	*P*-value		
	CGC	SFC	4	7	10	13		PRC	RNDF	PRC × RNDF
Growth performance										
Initial body weight,[1] kg	360	360	360	360	360	360	19.5	0.99	0.99	0.99
Final body weight,[1] kg	492	508	496	506	497	503	13.1	0.08	0.86	0.98
Adj. final body weight,[2] kg	494	508	500	507	494	502	14.6	0.18	0.85	0.97
Average daily gain,[3] kg	1.22	1.37	1.25	1.34	1.26	1.32	0.050	<0.001	0.19	0.79
Adj. average daily gain,[2] kg	1.23	1.36	1.29	1.35	1.23	1.31	0.053	<0.001	0.15	0.76
Dry matter intake ,[4,5] kg	9.11	8.47	8.29	9.00	8.80	9.09	0.266	0.001	0.02	0.85
Feed efficiency, g/kg	136	164	153	153	146	149	5.77	<0.001	0.54	0.57
Adj. feed efficiency,[5] g/kg	137	163	157	154	142	147	6.06	<0.001	0.06	0.48
Carcass characteristics										
Hot carcass weight, kg	272	280	276	280	272	277	7.96	0.18	0.84	0.96
Dressing percentage[5]	55.3	55.0	55.6	55.2	54.8	55.0	0.289	0.19	0.06	0.61
12th rib fat thickness, mm	3.79	3.96	4.07	3.92	3.84	3.66	0.297	0.43	0.58	0.40
Longissimus muscle area, cm^2	66.3	67.3	67.1	66.9	66.2	67.1	1.76	0.40	0.94	0.87

[1]Initial and final individual body weight measured live and after 16 h of feed and water restriction. Bulls from block 1 and 2 were assigned to slaughter on 2 separate dates, 28 d apart (n = 96 bulls after 95 d on feed [**DOF**]; n = 144 bulls after 123 DOF).

[2]Carcass-adjusted values. Adjusted (**Adj**.) final body weight was estimated by dividing hot carcass weight by the overall average dressing percentage obtained for treatments (55.12%) and so, adjusted average daily gain and feed efficiency were calculated.
[3]Calculated using initial and final body weight (after 16 h of feed and water restriction).
[4]Recorded from each pen (4 pens/treatment: 3 pens with 6 bulls + 1 pen with 12 bulls) and divided by the number of animals within each pen, and expressed as kg animal/d.
[5]Orthogonal contrast: Linear effect of NDF levels from sugarcane bagasse (main effect; $P \leq 0.05$).

Table 5. Effects of flint corn grain processing (**PRC**) method [coarse ground corn (**CGC**; 3.2 mm) or steam flaked corn (**SFC**; 0.360 kg/L)] and neutral detergent fiber (**NDF)** levels (% of dry matter) from sugarcane bagasse (**RNDF**) on feeding behavior of finishing Nellore bulls

	Corn grain processing method		NDF levels from sugarcane bagasse					*P*-value		
Item[1]	CGC	SFC	4	7	10	13	SEM	PRC	RNDF	PRC × RNDF
Time spent eating										
min/d	148	107	110	119	136	145	18.6	<0.01	0.26	0.72
min/kg of DMI	15.7	12.3	12.9	12.7	15.1	15.4	2.12	0.03	0.44	0.71
min/kg of NDFI	72.1	74.4	84.4	70.1	72.4	66.2	12.3	0.80	0.50	0.55
Time spent ruminating										

min/d	300	364	227	311	369	422	29.8	0.08	0.001	0.15
min/kg of DMI[2]	31.9	41.9	27.3	33.7	41.3	45.2	3.14	<0.001	<0.001	0.12
min/kg of NDFI	143	250	190	193	206	197	16.5	<0.001	0.78	0.01
Time spent resting, min/d	993	970	1,104	1,011	935	875	26.7	0.24	0.001	0.04

[1]Visually evaluated by 8 trained individuals (4 pen for each evaluator, blinded to dietary treatments) on d 60 using a procedure adapted from Robles et al. (2007). Behavior data were recorded every 10 min during a 24-h period from two randomly selected bulls per pen as follows: minutes spent eating, ruminating, and resting (if they were not eating or ruminating) (Robles et al., 2007; Pereira et al., 2016). Activities per unit of dry matter intake (**DMI**) and NDF intake (**NDFI**) were also calculated by dividing total minutes by the mean of each parameter measured.
[2]Orthogonal contrast: Linear effect of NDF levels from sugarcane bagasse (main effect; $P \leq 0.05$).

Table 6. Effects of flint corn grain processing (**PRC**) method [coarse ground corn (**CGC**; 3.2 mm) or steam flaked corn (**SFC**; 0.360 kg/L)] and neutral detergent fiber (**NDF**) levels (% of dry matter) from sugarcane bagasse (**RNDF**) on dietary net energy (**NE**) concentrations, fecal starch, total tract starch digestion (**TSD**), and energy values of flint corn

	Corn grain processing method		NDF levels from sugarcane bagasse					*P*-value		
Item	CGC	SFC	4	7	10	13	SEM	PRC	RNDF	PRC × RNDF
NE_m intake[1], Mcal/d	17.1	17.7	17.3	18.1	17.4	17.0	0.690	0.03	0.42	0.91
NE_g intake[1], Mcal/d	11.2	12.5	11.6	12.2	11.7	12.0	0.510	<0.01	0.58	0.87
Observed NE[2]										
NE_m, Mcal/kg	1.88	2.16	2.07	2.03	1.98	1.98	0.052	<0.001	0.28	0.51
NE_g, Mcal/kg	1.24	1.48	1.41	1.37	1.33	1.34	0.045	<0.001	0.27	0.52
Observed NE : expected NE[3]										
NE_m	0.971	1.06	1.00	1.01	1.01	1.04	0.024	<0.001	0.38	0.58
NE_g	0.960	1.07	1.00	1.01	1.01	1.05	0.035	<0.001	0.37	0.56
Estimated fecal analysis[4]										
Starch, %	13.7	3.76	10.3	9.00	8.08	7.63	1.70	<0.001	0.46	0.59
TSD, %	92.2	98.2	94.1	95.0	95.6	95.9	1.20	<0.001	0.42	0.55
Corn NE_m, Mcal/kg	2.26	2.44	2.32	2.35	2.36	2.37	0.030	<0.001	0.48	0.57
Corn NE_g, Mcal/kg	1.57	1.73	1.62	1.65	1.66	1.67	0.030	<0.001	0.49	0.51

[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).

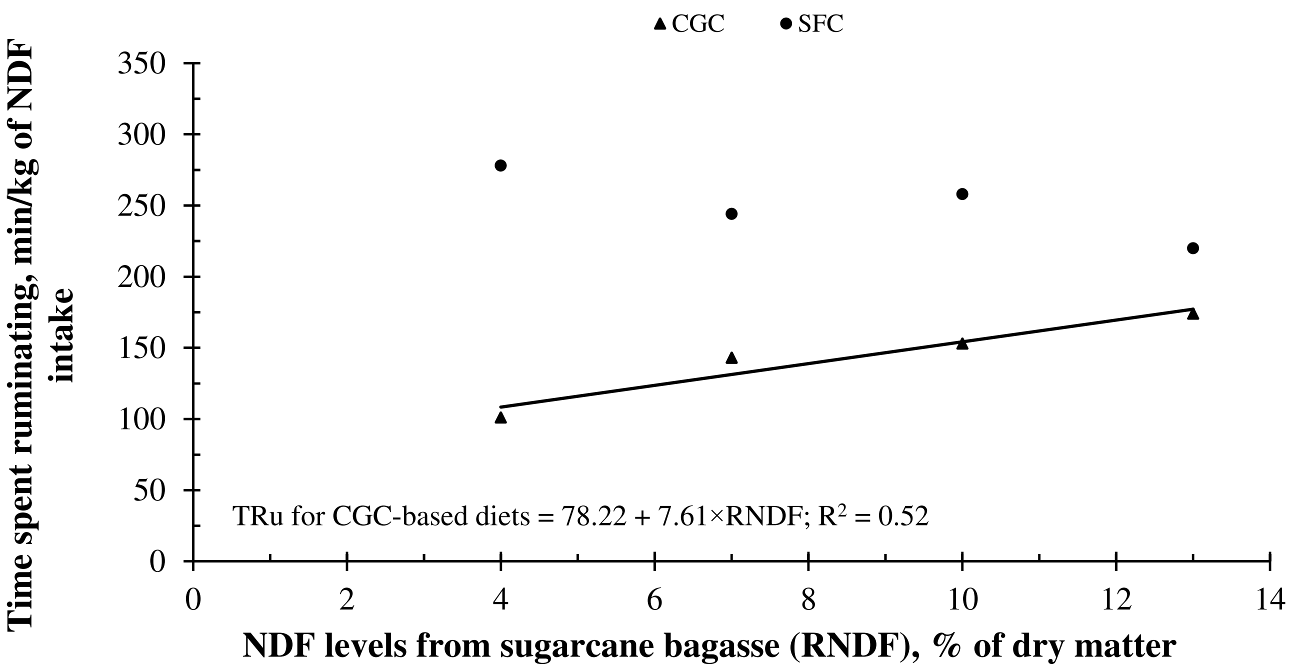
[3]Expected NE values were estimated with the equations proposed by NASEM (2016; solution type = empirical level) with addition of monensin as feed additive and using the total digestible nutrient values, which had been calculated with the equation proposed by Weiss et al. (1992), and using the processing adjustment factors (0.95 and 1.04 for ground and steam-flaked flint corn, respectively; NRC, 2001).
[4]Fecal samples were collected on d 70 from three bulls per pen, randomly selected (Charles et al., 2011) and starch concentration was determined according to procedures described by Bach Knudsen (1997). Fecal starch values were used to calculate TSD and the net energy for maintenance (NE_m) and gain (NE_g) of corn as described by Zinn et al. (2007).

Table 7. Effects of flint corn grain processing (**PRC**) method [coarse ground corn (**CGC**; 3.2 mm) or steam flaked corn (**SFC**; 0.360 kg/L)] and neutral detergent fiber (**NDF**) levels (% of dry matter) from sugarcane bagasse (**RNDF**) on rumenitis score and rumen tissue morphometrics of finishing Nellore bulls

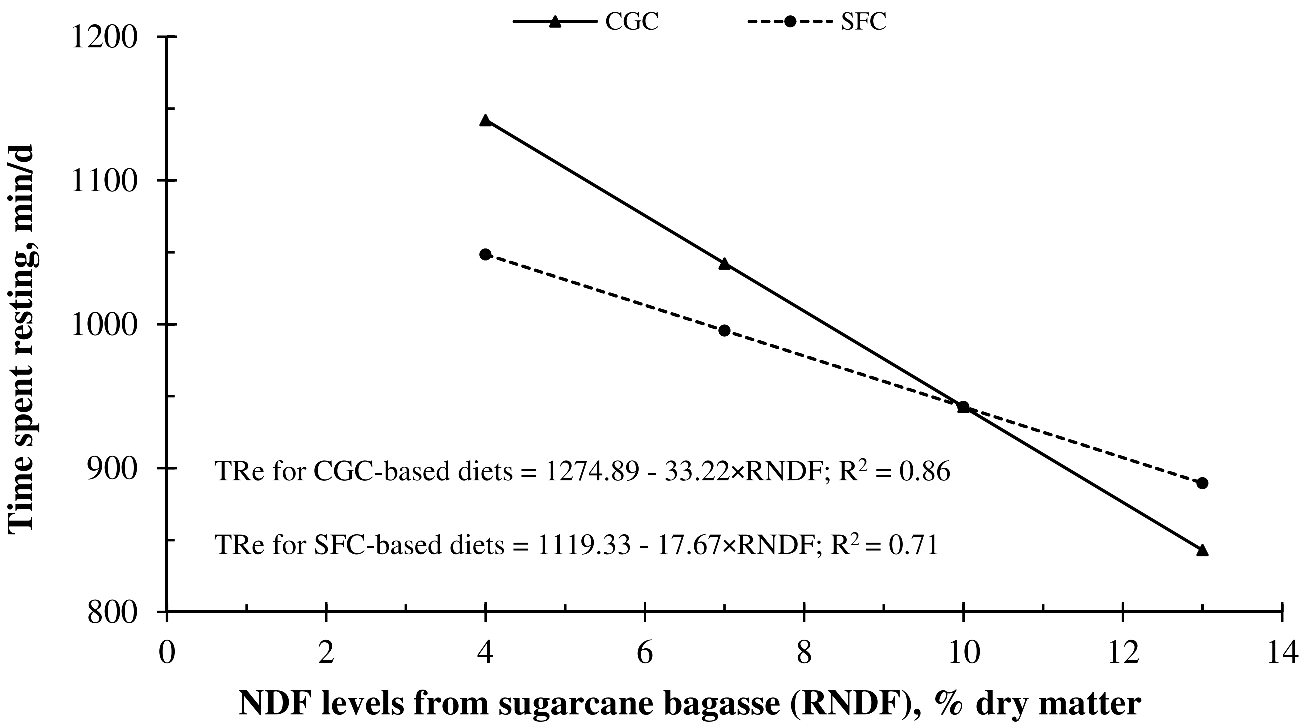
Item	Corn grain processing method		NDF levels from sugarcane bagasse				SEM	*P*-value		
	CGC	SFC	4	7	10	13		PRC	RNDF	PRC × RNDF
Rumenitis score[1]	2.00	1.78	2.36	1.90	2.05	1.24	0.510	0.51	0.38	0.23
Tissue morphometrics										
Macroscopic measurements[2]										
Number of papillae, no.	45.5	40.4	41.9	43.7	39.8	46.4	3.55	0.05	0.30	0.14
Papillae area, cm^2	0.694	0.679	0.725	0.646	0.795	0.681	0.061	0.73	0.59	0.58
ASA, cm^2/cm^2 of rumen wall	32.0	27.7	30.0	29.0	28.8	31.6	2.70	0.03	0.71	0.19
Microscopic measurements[3]										
Papillae height, mm	3.61	3.75	3.67	3.53	3.97	3.56	0.349	0.69	0.81	0.87
Papillae width, mm	0.512	0.434	0.440	0.511	0.477	0.480	0.048	0.03	0.53	0.09
Papillae surface area, mm^2	1.93	1.82	1.64	1.70	1.98	1.63	0.322	0.76	0.30	0.81
Keratinized layer thickness, µm	17.7	18.8	18.6	18.9	15.5	18.8	1.43	0.45	0.73	0.39

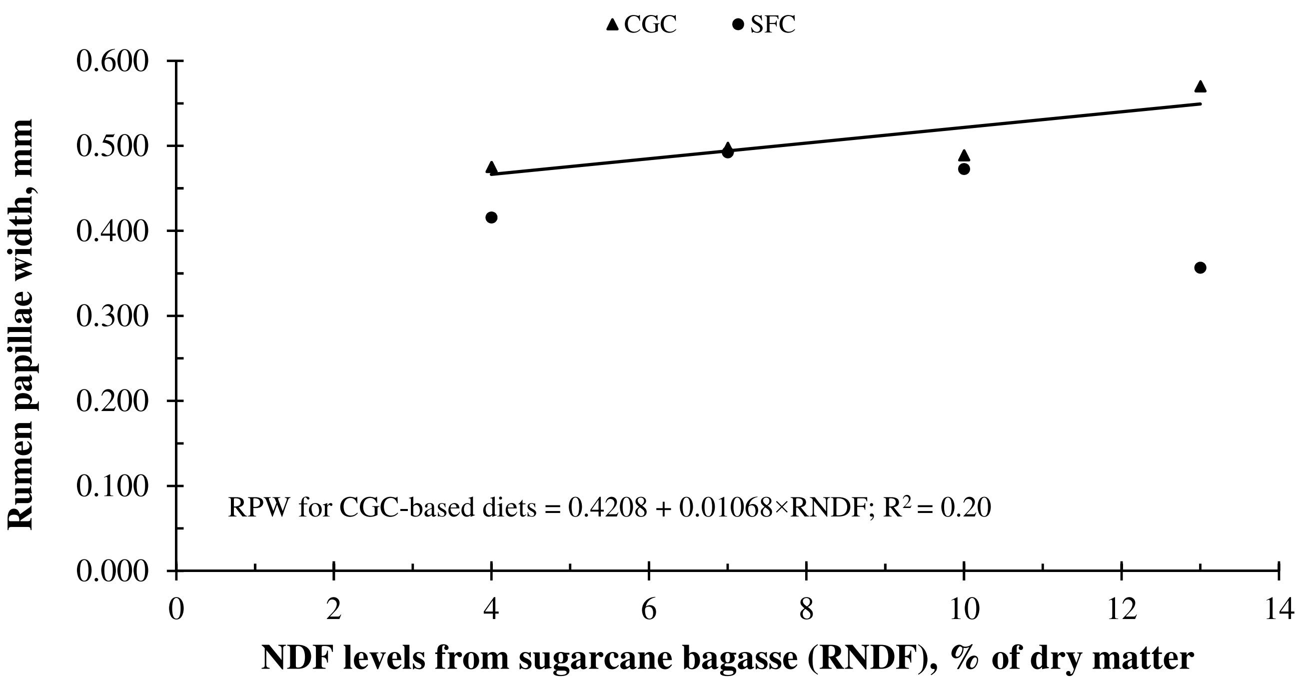
[1]Bulls from block 1 and 2 were assigned to slaughter on 2 separate dates, 28 d apart (n = 96 bulls after 95 d on feed [**DOF**]; n = 144 bulls after 123 DOF). Rumens were washed and scored for incidence of lesions and abnormalities (e.g., papillae clumped) using a 10-point scale (0 = no lesions and abnormalities and 10 = severe ulcerative lesions; Bigham and McManus, 1975; Pereira et al., 2016).
[2]Rumen samples were collected from two randomly selected bulls in each pen. Approximately a 1-cm^2 fragment of rumen was collected from cranial sac (atrium ruminis) and placed into a phosphate-buffered saline solution as described previously by Pereira et al. (2016). ASA= absorptive surface area.

[3]Samples were collected from the ventral sac of the rumen (1-cm^2 fragment) from two randomly selected bulls in each pen as described by Pereira et al. (2016).



CGC
SFC
Time spent ruminating, min/kg of NDF intake
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
TRu for CGC-based diets = 78.22 + 7.61×RNDF; R^2 = 0.52
NDF levels from sugarcane bagasse (RNDF), % of dry matter


CGC
SFC
1200
1100
1000
900
800
Time spent resting, min/d
TRe for CGC-based diets = 1274.89 - 33.22×RNDF; R2 = 0.86
TRe for SFC-based diets = 1119.33 - 17.67×RNDF; R2 = 0.71
0
2
4
6
8
10
12
14
NDF levels from sugarcane bagasse (RNDF), % dry matter



CGC
SFC
Rumen papillae width, mm
0.600
0.500
0.400
0.300
0.200
0.100
0.000
RPW for CGC-based diets = 0.4208 + 0.01068×RNDF; R2 = 0.20
0
2
4
6
8
10
12
14
NDF levels from sugarcane bagasse (RNDF), % of dry matter