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Effects of energy sources and inclusion levels of concentrate in sugarcane silage-based diets of finishing Nellore young bulls: Feeding behaviour, performance and blood parameters

Animal Research Paper

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Abstract

Replacing ground maize (GM) with steam-rolled maize typically increases feed efficiency in maize-silage-based diets. However, little is known about optimal carbohydrate supplementation in sugarcane silage-based diets. The objective was to quantify the effect of partially replacing GM with steam-rolled maize (SRM) or pelleted citrus pulp (PCP) at two concentrate levels (600 or 800 g/kg DM) in sugarcane-based diets on feeding behaviour, performance and blood parameters of finishing Nellore bulls. One hundred and eight young bulls were allocated to 36 pens in a randomized block design and fed for 84 d. Feeding 800 g/kg concentrate decreased time spending eating and ruminating, but improved G:F ratio, hot carcass weight and carcass dressing, compared to 600 g/kg concentrate. Bulls fed SRM and PCP diets with 600 g/kg concentrate had lower intake compared to GM. Both final weight and average daily gain decreased when bulls were fed PCP and SRM with 600 g/kg concentrate compared to GM diets, and when fed with PCP and 800 g/kg concentrate. Substituting PCP for GM decreased gain efficiency, carcass weight, rumination time and intake efficiency, indicating that the bulls consumed less feed per hour spent eating. Substituting SRM for GM increased backfat thickness and blood urea concentration. In conclusion, the replacement of GM with PCP reduces intake and enhances selection against large particles, decreasing rumination, performance and final carcass weight and dressing. Replacement of GM with SRM increases blood urea and fat deposition, with no impact on performance.

Introduction

Beef cattle performance during the finishing phase is associated with the intake of high-quality feedstuffs to maximize energy consumption. Energy intake can be limited either by rumen fill, which usually occurs in diets with high inclusion of forages with low digestibility, or by metabolic satiety caused by excess rumen fermentation of non-fibrous carbohydrates (Allen *et al.*, 2009).

Sugarcane is a roughage that has high production of nutrients per hectare, making it an excellent tool to reduce cost of production. Additionally, sugarcane has high levels of non-fibre carbohydrates (NFC), usually around 500 g/kg dry matter (DM) and most in the form of sucrose (Miranda *et al.*, 2015). However, due to its lower fibre digestibility (Carvalho *et al.*, 2010; Santos *et al.*, 2011) it is necessary to include a source of high-quality carbohydrate in order to increase the energy intake of sugarcane-based diets for finishing beef cattle.

Maize is the grain most used as an energy source in cattle diets; however, the protein matrix encapsulates starch granules and acts as a barrier to hydrolysis (Giuberti *et al.*, 2014). Therefore, processing methods of the kernel increase starch digestion of maize and, consequently animal performance (Owens, 2005) compared to the whole grain. The steam-rolling of maize is a common processing method where the kernel is steam treated, runs through a roller mill and reaches ~15% moisture or lower. This process increases the surface area for microbial attachment and improve the ruminal starch fermentation, with higher production of propionate (Theurer *et al.*, 1999) and, consequently, stem-rolling of maize can improve the average daily gain (ADG) and feed efficiency (Owens and Basalan, 2016). However, it possibly decreases intake due to excess propionate production in the rumen. On the other hand, rumen fermentation of citrus pulp, a high pectin by-product available in the dry season (Oni *et al.*, 2008), tends to yield more acetate and prevent the increase of lactate in the rumen compared to maize (Bampidis and Robinson, 2006; Hall and Eastridge, 2014). Additionally, Giger-Reverdin *et al.* (2002) reported a moderate buffering capacity of citrus pulp, compared with 23 other feedstuffs, which contributes to a low risk of ruminal acidosis. Therefore, citrus pulp is usually included in replacement of rapid fermentable starchy feedstuffs in finishing diets to prevent acidosis.

Thus, the current study was conducted to quantify the effect of partial replacement of ground maize (GM) by steam-rolled maize or pelleted citrus pulp (PCP) in two concentrate levels in sugarcane-based diets on feeding behaviour, performance, carcass traits and blood parameters of Nellore cattle. It was hypothesized that replacing GM with citrus pulp would decrease rumen acidosis and increase intake, and replacing GM with steam-rolled maize would increase feed efficiency.

Materials and methods

Animals and diets

To increase the power of the test, the feedlot performance experiment was conducted in subsequent years (2012 and 2013). In each year, 54 Nellore young bulls, 20 to 24 months old, with average initial body weight (BW) of 365 ± 3.1 kg, were blocked by initial BW (three blocks) and randomly distributed within blocks to six collective pens (three bulls per pen – total of 18 pens per year). Pen dimensions were 9 × 3 m with concrete floor, covered bunk and shade. Automatic water troughs were located in each pen.

Six treatments were randomly assigned to the pens, in a 2 × 3 factorial arrangement of treatments. The factors consisted of two levels of concentrate in the diet (CONC) either 600 or 800 g/kg DM, and three NFC sources: PCP, steam-rolled maize (SRM, density 415 g/l) and partially replacing GM. Sugarcane silage was used as the roughage source and harvested at the maturity stage (above 18% sucrose in the juice). At harvest, sugarcane had 20.1% sucrose in the juice. Sugarcane (variety IAC-SP 93-3046) was harvested mechanically and chopped to obtain particle sizes of 8–10 mm. During chopping, sugarcane was inoculated with *Lactobacillus buchneri* (strain NCIMB 40788-LALSIL Cana; Lallemand Animal Nutrition, Aparecida de Goiânia, GO, Brazil) to prevent alcoholic fermentation, and ensiled in a surface silo for 32 d before the beginning of the experiment, as recommended by Pedroso *et al.* (2005) and the inoculant manufacturer. Diets were formulated according to NRC (2000) to fulfil the maintenance requirements and promote ADG of 1.4 kg/d. Chemical composition of diets is described in Table 1.

Bulls were fed the experimental diets as total mixed ration, twice daily, in two equal feedings at 07.00 and 15.00 h. Feed was offered *ad libitum* allowing for 50 to 100 g of orts per kg of offered feed, based on the previous day. The bulls were kept in the experiment for a total of 98 d, with 14 d for adaptation to the feedlot and to experimental diets, followed by four 21 d periods.

Performance and carcass traits

Samples of dietary ingredients and orts were collected weekly, dried and ground to pass a 1 mm screen in a Wiley mill (Wiley Mill, Model 4; Arthur H. Thomas, Philadelphia, PA, USA). Samples were analysed for DM and ash according to AOAC (2000) methods 930.15 and 942.05, respectively. Concentration of nitrogen (N) was assayed by a combustion method (Leco model FP-528; LECO Corporation, St. Joseph, MI, USA) and crude protein (CP) content was calculated as concentration of $N \times 6.25$. The neutral detergent fibre (NDF) content was determined using the method described by Van Soest *et al.* (1991) using 8 M urea and heat stable α-amylase (Sigma A3306; Sigma Chemical Co., St. Louis, MO, USA) in an ANKOM A200 Fibre Analyser (Ankom Technology Corporation, Fairport, NY, USA). Acid detergent lignin and acid detergent fibre (ADF) were analysed according to Van Soest and Robertson (1985).

For calculation of ADG and gain:feed ratio (G:F), animals were weighed at the beginning of the experiment and at the end of each 21 d period after 16 h solid fasting. ADG was determined for each animal as the slope of the linear regression of BW on days of experiment. Fat deposition and muscular growth (*Longissimus dorsi* muscle area [LMA]) were measured at the beginning and at the end of the experiment using an Aloka 500 V system equipped with a 3.5 MHz, 17 cm transducer (Aloka USA, Inc., Wallingford, CT, USA). Fat deposition was evaluated by the fat thickness on the 12^{th} rib on *Longissimus dorsi* muscle (BFT), and by fat thickness on *Biceps femoris* muscle (rump fat thickness [RFT]).

At the end of the experiment bulls were slaughtered at a commercial slaughterhouse in accordance with current guidelines after 16 h fast from solids and water. The bulls were stunned by cerebral concussion, suspended and exsanguinated through the jugular vein, and weighed to obtain hot carcass weight (HCW). Because treatments are expected to affect the carcass dressing percentage (Dressing), the final BW (FBW) was adjusted for HCW by dividing carcass weight by the decimal fraction of the average dressing percentage of all steers (HCW/average Dressing).

Feeding behaviour

Feeding behaviour of animals was evaluated on d 19 of each experimental period, by visual observations with 5 min intervals beginning at 8 h, during 24 h (Bürger *et al.*, 2000). To promote better data collection the bulls were adapted to artificial light at night for 3 days before the evaluation. All intake, ruminating and idle activities were registered. The intake efficiency of DM (IEDM, kg/h) was calculated dividing the dry matter intake (DMI) (kg/d) by time spent eating (h/d), according to Bürger *et al.* (2000).

Sorting index

For this analysis, the total mixed ration (TMR) and orts were weekly sampled for particle size distribution using the Penn State Particle Separator (PSPS, Nasco, Fort Atkinson, WI, USA), as described by Heinrichs and Kononoff (2002). To determine the intensity of sorting of large particles, the sorting index (SI) was calculated as the actual intake/expected intake for particles retained in the top two sieves (above 8 mm). Actual intake was determined as the amount of feed offered × particle size distribution in the TMR (percentage of fresh material) − the amount of orts × particle size distribution in orts percentage of fresh material. Expected intake was determined as the particle size distribution of the TMR percentage of fresh material × actual fresh feed intake. A SI of 1 indicates no sorting, a SI < 1 indicates sorting against and >1 sorting for particles retained in each screen (Silveira *et al.*, 2007).

Blood samples

At the end of each experimental period, before the first meal, blood samples were collected into two vacuum tubes (BD

Table 1. Ingredient content and chemical composition of experimental diets with three sources of non-fibrous carbohydrate and two levels of concentrate

	600 g/kg concentrate			800 g/kg concentrate			
Item	GM	SRM	PCP	GM	SRM	PCP	S.E.M.
	g/kg DM						
Sugarcane silage[a]	400	400	399	200	201	200	–
GM	518	156	155	721	215	214	–
Steam-rolled maize	–	363	–	–	505	–	–
PCP[b]	–	–	363	–	–	504	–
Soybean meal	50	50	50	50	50	50	–
Urea	11	11	16	8	8	14	–
Limestone	8	8	–	8	8	–	–
Mineral mixture[c]	11	11	11	11	11	11	–
Salt	2	2	2	2	2	2	–
Dicalcium phosphate	–	–	4	–	–	5	–
Analysed composition	g/kg DM						
DM	645	649	648	761	761	765	4.4
CP	120	118	125	123	121	121	0.6
NDF	316	320	335	210	213	236	3.8
Lignin	38	41	38	27	30	26	2.2
Starch	354	357	122	483	479	156	24.4
EE	26	22	24	30	24	25	0.6
Ash	47	49	68	47	49	48	1.5
NFC	491	491	448	590	593	570	21.6
Dietary NE values, MJ/kg of DM[d]							
NE_m	6.8	7.1	6.5	7.9	8.2	7.4	0.59
NE_g	4.3	4.5	4.0	5.2	5.4	4.8	0.42

DM, dry matter; CP, crude protein; NDF, neutral detergent fibre; EE, ether extract; NFC, non-fibrous carbohydrate, NEm, net energy of maintenance; NEg, net energy of gain, GM, ground maize; SRM, steam-rolled maize; PCP, pelleted citrus pulp.
aDM = 309 g/kg; CP = 46.7 g/kg DM; NDF = 642 g/kg DM; ADF = 432 g/kg DM; lignin = 73.3 g/kg DM and starch = 16.2 g/kg DM.
bDM = 881 g/kg; CP = 67.9 g/kg DM; NDF = 162 g/kg DM; ADF = 169 g/kg DM; lignin = 13.9 g/kg DM and starch = 25.8 g/kg DM.
cGuaranteed levels per kg: calcium 210 g; cobalt 24 mg; copper 720 mg; sulphur 74 g; fluorine 240 mg; phosphorus 24 g; iodine 40 mg; magnesium 30 g; manganese 1500 mg; selenium 8 mg; sodium 60 g; zinc 2080 mg and monensin 1830 mg.
dCalculated based on the NE requirements equations of NRC (2000).

Vacutainer, Becton and Dickinson, NJ, USA) by jugular venepuncture from each bull from all treatments. One tube contained fluoride oxalate for glucose determination in blood plasma and the other without anticoagulant for total protein, albumin and urea determination in serum samples. Serum was obtained by centrifugation of blood samples at 700 × ***g*** for 20 min at 4 °C, collected, and stored at −20 °C until analysis. All blood samples were analysed colorimetrically according to standard procedures using commercially available diagnostic kits (Randox Laboratories, São Paulo, SP, Brazil) in an ABS-200 automatic biochemistry analyser (CELM, São Caetano do Sul, SP, Brazil).

Statistical methods

The statistical analyses were conducted using the MIXED procedure of the SAS version 9.1.2 for Windows (SAS Institute Cary, NC, USA). Data were analysed as a randomized complete block design, with a 3 × 2 factorial arrangement of treatments. The model included the fixed effects of the concentrate level (CONC: 600 or 800 g/kg), of the three NFC sources (NFC: SRM, PCP and GM) and their interaction (CONC × NFC). Year and block were included in the model as a random effect, and pen was considered as the experimental unit. For the data collected per pen, such as intake, the model was:

$$Y_{ij} = \mu + A_i + B_j(A_i) + \alpha_k + \tau_l + (\alpha\tau)_{kl} + e_{ijkl}$$

while for the data collected individually, such as carcass traits, the model was:

$$Y_{ij} = \mu + A_i + B_j(A_i) + \alpha_k + \tau_l + (\alpha\tau)_{kl} + C_m \times B_j(A_i) + e_{ijklm}$$

where: Y_{ijkl} = dependent variable; μ = overall mean; A_i = random effect of year i {i = 1,2}; $B_j(A_i)$ = random effect of block j within year A_i {j = 1, 2, 3}; α_k = fixed effect of concentrate level k {600,800}; τ_l = fixed effect of NFC source l { *SRM, PCP, GM*};

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Table 2. Intake, feeding behaviour and SI of Nellore young bulls fed diets containing three sources of non-fibrous carbohydrate and two levels of concentrate

	600 CON			800 CON				*P*-Value		
Item	GM	SRM	PCP	GM	SRM	PCP	S.E.M.	CON	NFC	CON × NFC
DMI, kg/d	10.4	9.5	9.0	9.3	9.3	9.0	0.43	0.025	0.007	0.046
NDFI, kg/d	3.2	3.0	3.1	2.0	2.0	2.2	0.10	<0.001	0.050	0.050
CPI, kg/d	1.2	1.1	1.1	1.1	1.1	1.1	0.05	0.084	0.112	0.297
Eating, h/d	3.3	3.2	4.4	3.1	2.8	3.4	0.28	0.048	0.049	0.534
Ruminating, h/d	7.7	6.8	6.1	5.7	5.2	4.8	0.71	<0.001	<0.001	0.910
Idle, h/d	12.8	13.7	13.3	15.0	15.9	15.6	0.44	<0.001	0.139	0.983
IEDM, kg/h	3.2	3.1	2.1	3.2	3.9	2.5	0.29	0.091	<0.001	0.381
SI	0.97	0.99	0.96	1.05	1.02	0.93	0.009	0.005	<0.001	<0.001

DMI, dry matter intake; NDFI, neutral detergent fibre intake; CPI, crude protein intake; IEDM, intake efficiency of dry matter; SI, sorting index for particles above 7.9 mm; GM, ground maize; SRM, steam-rolled maize; PCP, pelleted citrus pulp; CON, concentrate inclusion effect; NFC, non-fibrous carbohydrate effect; CON × NFC, CON and NFC interaction effect.

$(\alpha\tau)_{kl}$ = interactions between main effects; $C_m \times B_j(A_i)$ = random effect of pen m within block B_j and year A_i; e_{ijklm} = random residual variation.

Denominator degrees of freedom were calculated using the Kenward–Roger approximation. When there was a significant interaction, the effects of treatments were compared using the SLICE option of the MIXED procedure. Treatment effects were considered significant at $P \leqslant 0.05$.

Results

Dry matter intake and feeding behaviour

There was a significant NFC × CONC interaction on DMI (P = 0.046) and NDF intake (P = 0.050, Table 2). Bulls fed SRM and PCP diets with 600 g/kg concentrate had lower DMI compared to GM diets. Compared to GM, NDF intake was decreased by SRM when fed at 600 g/kg concentrate and increased by PCP when fed at 800 g/kg concentrate (P = 0.050, Table 2). There was no effect of treatments on CP intake (Table 2).

There was a NFC × CONC (P < 0.001) interaction on SI (particles > 7.9 mm, Table 2). Bulls fed GM and SRM selected for larger particles (SI > 1.0) when fed 800 g/kg concentrate in the diet, compared to PCP (Table 2). Feeding the 800 g/kg concentrate diet increased idle time (15.5 *v.* 13.3 h/d, P < 0.001), decreased eating time (3.1 *v.* 3.3 h/d, P = 0.048) and decreased rumination time (5.2 *v.* 6.8 h/d, P < 0.001), compared to 600 g/kg concentrate diet (Table 2). Substituting PCP for GM decreased rumination time (5.4 *v.* 6.7 h/d, P < 0.001) and IEDM (2.29 *v.* 3.24 kg DM/h, P < 0.001), indicating that the bulls consumed less feed per hour spent at the feed bunk.

Animal performance and blood parameters

Analysing the performance data, there was a significant NFC × CONC interaction on FBW and ADG. The FBW was decreased (P = 0.0285, Table 3) when bulls were fed PCP and SRM with 600 g/kg concentrate compared to GM diets, with no differences on 800 g/kg concentrate diets. The SRM and PCP decreased ADG (P < 0.001) when fed with 600 g/kg concentrate, and PCP decreased this parameter compared to GM and SRM with 800 g/kg concentrate in the diet. Increasing concentrate from 600 to 800 g/kg of the diet improved the G:F ratio (0.133 *v.* 0.148 kg/kg, P = 0.02), HCW (252 *v.* 259 kg, P = 0.027) and dressing percentage (529 *v.* 537 g/kg, P = 0.025, Table 3). The greater concentrate inclusion also increased the NE_m (P = 0.026) by 7.2% and the NE_g (P = 0.026) by 10.3% compared to the 600 g/kg concentrate diets. Substituting PCP for GM decreased the G:F ratio (0.147 *v.* 0.131, P = 0.049) and HCW (261 *v.* 249 kg, P = 0.009, Table 3). Feeding SRM increased BFT (4.3 *v.* 3.7 mm, P = 0.027) and RFT (6.1 *v.* 4.8 mm, P = 0.032, Table 3). There was no effect of treatments on LMA (P > 0.096, Table 3).

There was no effect of treatments on serum glucose or serum albumin concentration ($P \geqslant 0.20$, Table 4). Feeding a diet with 800 g/kg concentrate increased serum total protein concentration (6.9 *v.* 7.3 mg/dl, P = 0.003, Table 4). Substituting SRM for GM increased blood urea concentration (34.78 *v.* 30.58 mg/dl, P = 0.02, Table 4).

Discussion

Higher concentrate inclusion in the diet and partial replacement of GM with PCP or SRM decreased DMI. Possible factors affecting intake of PCP include density, texture, physical size of the pellet (~1.8 cm length in the current study) or taste differences between citrus sources (Cribbs *et al*., 2015). Cribbs *et al*. (2015) partially replaced steam-processed maize with PCP in an inclusion lower than 0.40 of the total diet and found linear decreases in DMI, ADG and G:F ratio as PCP increased.

On the other hand, Gouvêa *et al*. (2016) reported that replacing up to half of the GM with citrus pulp improved DMI, ADG and HCW in sugarcane bagasse-based diets, with no effect on energy values of the diet. Additionally, Prado *et al*. (2000) replaced GM with PCP at 140, 190, 250 and 310 g/kg DM in maize silage-based diets and observed no negative effect on performance and carcass traits of finishing cattle. In the present study, PCP comprised 363 and 504 g/kg DM, and both levels decreased DMI, G:F ratio and HCW.

Reduced palatability is another possible explanation for lower intake of diets with PCP compared to GM. According to Baumont (1996), when only one feed is given to indoor-fed animals, palatability can be evaluated by the eating rate at the beginning of the meal. The results for feeding behaviour in the present study demonstrate that greater concentrate levels in the diet reduced the time that the bulls spent at the feed bunk, but not the substitution

Table 3. Productive performance and carcass traits of Nellore young bulls fed diets containing three sources of non-fibrous carbohydrate and two levels of concentrate

	600 CON			800 CON				*P*-Value		
Item	GM	SRM	PCP	GM	SRM	PCP	s.e.m.	CON	NFC	CON × NFC
IBW, kg	372	361	365	364	367	363	14.9	0.727	0.518	0.246
FBW, kg	492	472	466	484	489	475	14.2	0.236	0.039	0.028
ADG, kg/d	1.5	1.3	1.2	1.4	1.5	1.3	0.07	<0.001	<0.001	<0.001
G:F, kg/kg	0.14	0.13	0.13	0.15	0.16	0.13	0.016	0.027	0.049	0.428
HCW, kg	261	250	246	261	265	251	7.5	0.035	0.009	0.154
Dressing, kg/100 kg	53.0	53.0	52.8	53.9	54.2	52.9	0.51	0.025	0.138	0.415
LMA, mm	80	75	75	76	80	78	1.7	0.403	0.701	0.096
BFT, mm	3.7	4.1	3.0	3.7	4.5	3.5	0.39	0.297	0.027	0.826
RFT, mm	5.6	5.9	4.7	4.1	6.3	5.2	0.48	0.638	0.032	0.084
Dietary NE values, MJ/kg of DM[a]										
NE_m	7.7	7.4	7.5	8.2	8.3	7.7	0.54	0.026	0.371	0.387
NE_g	5	5	5	5	6	5	1.2	0.026	0.371	0.387

IBW, initial body weight; FBW, final body weight; ADG, average daily gain; G:F, gain to feed ration; HCW, hot carcass weight; Dressing, carcass dressing; LMA, *Longissimus dorsi* muscle area; BFT, back-fat thickness; RFT, fat thickness on *Biceps femoris* muscle; GM, ground maize; SRM, steam-rolled maize; PCP, pelleted citrus pulp; CON, concentrate inclusion effect; NFC, non-fibrous carbohydrate effect; CON × NFC, CON and NFC interaction effect.
aCalculated from intake and performance data based on the NRC (2000) equations.

Table 4. Serum parameters of Nellore young bulls fed diets containing three sources of non-fibrous carbohydrate and two levels of concentrate

	600 CON			800 CON				*P*-Value		
Item	GM	SRM	PCP	GM	SRM	PCP	s.e.m.	CON	NFC	CON × NFC
	mg/dl									
Glucose	66	74	68	69	68	68	8.3	0.591	0.371	0.243
Urea	28	35	31	33	35	29.0	2.2	0.603	0.022	0.139
Albumin	3.5	3.6	3.6	3.5	3.6	3.6	0.07	0.918	0.206	0.928
Total protein	6.9	6.9	7.0	7.3	7.3	7.3	0.16	0.003	0.845	0.915

GM, ground maize; SRM, steam-rolled maize; PCP, pelleted citrus pulp; CON, concentrate inclusion effect; NFC, non-fibrous carbohydrate effect; CON × NFC, CON and NFC interaction effect.

of GM for PCP. However, when data were analysed as the amount of feed consumed by each hour spent eating (IEDM), PCP inclusion in the diet reduced this parameter. In addition, inclusion of PCP in the diet caused the bulls to avoid large particles (>7.9 mm) and, visually, the majority of the feedstuff retained in the two upper screens of the PSPS of the orts was PCP, demonstrating selectivity of the bulls against the pellets. In the study by Gouvêa *et al*. (2016), in which replacing GM with citrus pulp had no effect on energy values, the processing of citrus pulp was not described. Zebeli *et al*. (2009) demonstrated that lowering the particle size of the diet modulated the selective consumption of feedstuffs and improved intake of energy and nutrients of dairy cows. If that were the case, grinding of PCP would be expected to increase intake.

On the other hand, the DMI reduction when bulls were fed SRM compared to GM can be explained by a possibly greater propionate production in the rumen. Propionate is a primary end product of starch fermentation, and its production rate varies depending on starch concentration and fermentability (Allen, 2000). Increased propionate production and absorption is likely to decrease intake because it is the primary fuel stimulating hepatic oxidation within meals (Allen *et al*., 2009). Similarly, according to Owens *et al*. (1997), compared with dry rolling, either steam rolling or flaking of maize, milo and wheat decreased DMI, and those authors associated the reduced DMI of rapidly fermented and extensively processed grain to excessive rates of acid production in the rumen. Also, Gouvêa *et al*. (2016) reported that steam-flaking of flint maize reduced DMI but improved energy contents of the diet compared to GM.

Regulation of intake in ruminants fed high-forage diets is primarily a function of physical fill or rumen distention for diets that are energetically dilute and less digestible (Waldo, 1986). When DMI is limited by distention, the limitation results from the low rate of removal of digesta from the rumen by digestion, absorption and passage (Allen, 2000). The results from the present study, however, indicate that intake was not regulated by NDF content, because diets with greater roughage inclusion promoted greater NDF intake with no reduction in DMI. On the other hand, when bulls are fed high-concentrate diets, feed intake seems to be regulated by the energy consumed (Allen *et al*., 2009).

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Some of the animal performance data can be explained by the effects of treatments on DMI. Both ADG and FBW were decreased by PCP and by SRM at 600 g/kg concentrate diets, and by PCP at 800 g/kg concentrate diets. Partially substituting PCP by GM did not maintain performance, regardless of the level of concentrate inclusion, decreasing G:F ratio and HCW, which can be attributed to lower intake. Feeding the 800 g/kg concentrate-diet increased HCW, dressing percentage and G:F ratio, even with lower DMI compared to 600 g/kg concentrate-diets. For Nkrumah *et al.* (2006), feed efficiency may be influenced by several potential metabolic and physiological pathways such as efficiency of conversion of gross energy into metabolizable energy (because of differences in digestibility, generation of gases during ruminal fermentation, absorption of nutrients, waste excretion and heat production) and the subsequent efficiency of metabolizable energy conversion to retained energy for maintenance and growth. In the present study, the observed NE_m and Ne_g were greater when 800 g/kg concentrate diets were fed.

Replacing SRM with GM did not improve the G:F ratio. Owens and Gardner (2000) observed an increase on feed efficiency, carcass weight, dressing and fat thickness when animals were fed steam-rolled maize rather than dry-rolled maize diets and attributed these results to a shift in the site of digestion, with increased fat deposition being related to greater starch digestibility and less ruminal escape of dietary starch. According to Pearce *et al.* (2008), the higher the available energy the greater is the fat deposition in the animal carcass: when animals are fed higher energy content the increased propionate production stimulates concentration of insulin, the hormone regulating fat deposition in the carcass. However, in the present performance study, the SRM only increased fat thickness, with no effects on the ADG or G:F ratio. One explanation for the lack of effect of SRM on animal performance is the increase in the fat deposition which requires more energy compared to the same amount of muscle deposited. The fat deposition process is more efficient than protein, but requires more energy per unit of weight gain because of the high-caloric density of fat, and because the muscle is ∼0.75 water (Lawrence and Fowler, 2002).

The greater rumen starch digestibility of SRM can influence both carbohydrate and protein metabolism. The hypothesis was that replacing GM with PCP would reduce the availability of propionate causing a detectable decrease in blood glucose, as observed by Broderick *et al.* (2002) and Hall *et al.* (2010). Similarly, replacing GM with SRM would increase propionate availability and increase blood glucose. However, blood glucose was not altered by NFC sources in the present study.

The effects of NFC sources on protein metabolism were evaluated measuring blood urea, albumin and total protein concentrations. The total amount and rate of starch digestion in the rumen may influence the ammonia utilization by the microbes, altering the microbial protein synthesis and total availability of amino acids to the animals. The hypothesis was that replacing GM with SRM would increase the substrate for microbial production, increasing protein fraction in the blood. It was expected that replacing GM with PCP would increase nutrient intake, also potentially increasing microbial protein production and nitrogen metabolism. Plasma albumin is also used as an indicator of the nutritional status of ruminants (Solaiman *et al.*, 2010).

In the present study, replacing GM with SRM increased blood urea nitrogen, without altering total protein or albumin concentrations. Theurer *et al.* (1999) stated that a more processed grain improves cycling of urea to the gastro-intestinal tract, because of the greater rumen degradability of the carbohydrates, and therefore, more energy is available to utilize the rumen ammonia for microbial CP production (Owens and Zinn, 1988). In this sense, more protein is being enzymatically broken down in the small intestines, and more amino acids are being absorbed into the bloodstream (Santos and Pedroso, 2011). Consequently, the possibly greater rumen starch digestibility of SRM could explain the increased blood urea nitrogen compared to animals receiving GM in the present study. Similarly, feeding greater concentrate increased substrate availability for rumen fermentation and serum total protein concentration. However, because blood was sampled only before feeding in the present study, it is not possible to thoroughly describe the treatment effects on blood protein fractions.

Feeding more concentrate in the diet increased serum total protein concentration in the present study, probably reflecting the greater rumen fermentable substrates and greater microbial protein production. Both biomarkers, serum total protein and urea concentration, have been shown to increase with greater protein absorption (Larsen *et al.*, 2014; Amanlou *et al.*, 2017).

Conclusion

In sugarcane silage-based diets, with high levels of residual sugar, there is no benefit in partial replacement of GM with PCP, as animal performance and carcass weight and dressing are reduced. There is a potential energetic benefit of replacing GM with SRM, as it increases fat deposition, with no impact on animal performance.

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Conflicts of interest. None.

Ethical standards. All experimental animal procedures were approved by the Animal Bioethics Committee from the Faculty of Veterinary Medicine and Animal Science of the University of São Paulo.

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