Corn grain-processing method interacts with calcium salts of palm fatty acids supplementation on milk production and energy balance of early-lactation cows grazing tropical pasture

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ABSTRACT

The objective of our study was to investigate the associative effects of feeding Ca salts of palm fatty acids (FA) and corn grain-processing method on production, nutrient digestibility, energy balance, and carryover effects of early-lactation dairy cows grazing a tropical pasture. Treatment diets were offered from 3 to 16 wk postpartum (treatment period), in which all cows grazed elephant grass (*Pennisetum purpureum* L. Cameroon) and treatments were added to a concentrate supplement. Treatments were flint corn grain-processing method either as fine ground (FGC) or steam-flaked (SFC) associated with Ca salts of palm FA supplementation either not supplemented or supplemented (CSPO). From 17 to 40 wk postpartum (carryover period) all cows received a common diet fed as total mixed ration. During the treatment period, a tendency for an interaction between CSPO and corn grain-processing method were observed for milk yield, milk fat yield, and energy-corrected milk (ECM), as CSPO caused them to increased to a greater extent in the FGC diet compared with the SFC diet. Furthermore, a tendency for an interaction between CSPO and corn grain-processing method was observed for body weight change, because CSPO increased body weight loss in the FGC diet but not in the SFC diet. The CSPO increased milk yield, milk fat yield, 3.5% fat-corrected milk, ECM, and cumulative milk yield compared with not supplemented. Also, CSPO increased energy intake, milk energy output, and energy partitioning toward milk, whereas reduced energy was allocated to body reserves. The SFC increased milk yield, ECM, milk protein yield, milk casein yield, and cumulative milk yield, and decreased milk urea N compared with FGC. The SFC compared with FGC also increased body condition score and body weight change, and increased energy partitioning toward body reserves. During the carryover period, an interaction between CSPO and corn grain-processing method was observed for milk yield, which occurred because CSPO maintained higher milk yield in the FGC diet but not in the SFC diet. Therefore, in the carryover period, the additive effect between SFC and CSPO that occurred in the treatment period was not maintained throughout the carryover period. However, CSPO increased yields of milk fat, protein, casein as well as fat-corrected milk and ECM. In conclusion, corn grain-processing method interacts with CSPO supplementation on production responses and carryover effects of grazing cows. When CSPO was fed in the FGC diet, milk production increased to a greater extent than when fed in the SFC diet, but also caused greater mobilization of reserves at early lactation. This suggests an interaction between fat supplementation and corn grain-processing method on energy partitioning of dairy cows. Also, both supplementation with CSPO and SFC were effective strategies to increase energy intake and yields of milk and milk solids. The carryover effect on milk production was greater for CSPO supplementation than corn grain-processing method, whereas feeding SFC diets had lower mobilization of reserves and less body weight and body condition score variation throughout lactation.

Key words: calcium salts, corn processing, palm fatty acids, steam-flaked corn

INTRODUCTION

Following parturition, cows enter a period of negative energy balance because they cannot consume enough nutrients to support lactation (NRC, 2001). Under grazing conditions, this negative energy balance may even be greater as a consequence of a lower DMI compared with cows consuming a TMR diet (Muller and Fales, 1998), as well as the greater requirement for maintenance because of more physical activity

(Dohme-Meier et al., 2014). This state of negative energy balance results in increased mobilization of body reserves, and optimizing energy intake during the early lactation period is important to provide sufficient available energy to support milk production and avoid pronounced reserves mobilization (McCarthy et al., 2015). Approaches to increase energy intake of postpartum cows include increasing dietary energy density by raising starch digestibility or by fatty acid (**FA**) supplementation.

Feeding concentrate based on cereal grains is the most common strategy used to enhance energy intake in pasture-based systems (Bargo et al., 2003). Starch is an important source of fuels for lactating dairy cows and for microbial protein production in the rumen (Oba and Allen, 2003). However, slug feeding higher amounts of starch-based supplements may result in decreased ruminal pH (Wales and Doyle 2003), NDF digestibility (Wales et al., 2004), and total DMI (Auldist et al., 2013). Rather than increasing the amount of starch, increased starch fermentability through extensive grain processing (e.g., steam-flaking) may improve total-tract starch digestibility and the efficiency of milk production (Owens and Soderlund, 2007). Theurer et al. (1999) observed that steam-flaking of dent corn compared with dry- and steam-rolling of corn consistently improved milk production and milk protein yield. However, these results were obtained in experiments conducted with dent corn grain, which is less vitreous than the flint corn grain typically grown and fed in several countries (e.g., Brazil, Colombia, and Northern Europe; Correa et al., 2002). Because vitreousness has been negatively correlated with ruminal starch availability (Philippeau and Michalet-Doreau, 1998), extensive processing of corn grain would be expected to be of greater benefit with flint than with dent corn. However, to our knowledge the potential benefit of extensively flint corn processing has not been evaluated in dairy cows.

Additionally, supplemental fat can be used to increase the energy density of diets and replace, at least in part, cereal grain. Although fat supplementation has been shown to increase milk production in housed systems with cows receiving TMR (Rabiee et al., 2012), the potential response of supplemental fat in pasture-based diets is still not well described (Schroeder et al., 2004), particularly for cows grazing on tropical pastures. Tropical grasses are commonly described as low-quality forages, but with higher potential for herbage mass accumulation (Santos et al., 2014). Low-quality tropical grasses, which have high fiber content and low DM digestibility, have a negative effect on voluntary feed intake and consequent animal performance (Moore and Mott, 1973). This would be especially important for early-lactation high-producing cows due to their greater nutrient requirements. With cows grazing on tropical pastures, de Souza et al. (2017) observed that supplementation with Ca salts of palm FA was an effective strategy to increase energy intake, milk production, and yield of milk components, as well as having a positive carryover effect when fed to early-lactation cows replacing fine ground corn. The effectiveness of Ca salts to reduce the deleterious effects of feeding fat to ruminal population is largely dependent on ruminal pH and the degree of unsaturation of the fat source (Sukhija and Palmquist, 1990). An increase in starch fermentability through extensive grain processing may lead to a reduced ruminal pH (Krause and Combs, 2003). Likewise, increasing starch fermentability resulted in greater accumulation of CLA isomers responsible for milk fat depression (Lascano et al., 2016). As diets that induce milk fat depression have been associated with repartitioning of energy toward adipose tissue (Harvatine et al., 2009), starch fermentability may reduce the stability of Ca salts supplements and potentially affect the response and energy partitioning of dairy cows to Ca salts of palm FA supplementation.

Therefore, the objective of our study was to investigate the associative effects of feeding Ca salts of palm FA and corn grain-processing method on production, nutrient digestibility, energy balance, and carryover effect of early-lactation dairy cows grazing tropical pasture. We hypothesized that high-producing, early-lactation dairy cows grazing on tropical pastures have a greater negative energy balance and feeding more fermentable starch and supplemental fat in the diet could be advantageous, with potentially greater milk yield throughout the entire lactation. We also postulated that the production responses to Ca salts of palm FA supplement would be affected by the corn grain-processing method because of ruminal fermentation and energy partitioning.

MATERIALS AND METHODS

The study was conducted in Piracicaba, São Paulo, Brazil. All procedures involving the animals were approved by the Ethical Committee for Animal Research of the University of São Paulo, Piracicaba.

Animals and Treatments

Forty-four multiparous dairy cows (24 Holstein × Gir and 20 Jersey × Holstein), with 494 ± 55 kg of BW, 3.20 ± 0.12 BCS, milk yield of 19.2 ± 2.8 kg, and 17 ± 2.2 DIM were used. Cows were blocked by breed, and cows within each block were balanced by parity, BCS, and previous lactation 305-d milk production. Animals were randomly assigned to 4 treatments arranged in a

2×2 factorial design and the dietary treatments were offered from 3 to 16 wk postpartum (treatment period). Treatments were corn grain-processing method either as fine ground (**FGC**) or steam-flaked (**SFC**; density of 360 g/L) and Ca salts of palm FA supplementation either not supplemented (**CON**) or supplemented (**CSPO**; 400 g of CSPO cow/d, Nutri Gordura Lac, Nutricorp Inc., Araras, São Paulo, Brazil). This level of fat supplementation was adopted to provide 2.0% of FA of diet DM, assuming an intake of 17.5 kg/d and 85% of FA in the Ca salts supplement (NRC, 2001). From 17 to 40 wk postpartum (carryover period), all cows received a common diet fed as TMR. All diets were formulated to meet the predicted requirements according to the NRC (2001).

During the treatment period (3 to 16 wk postpartum), all cows were rotationally grazed elephant grass (*Pennisetum purpureum* L. Cameroon) as one herd and the treatments were added to a concentrate supplement (8 kg of DM/d). The treatments were fed individually in 2 equal feedings at 0400 and 1600 h before milking. Chemical composition and in vitro starch degradability of corn processed either as fine ground or steam-flaked used in dietary treatments is presented in Table 1. The ingredients and chemical composition of the concentrate mixes used are presented in Table 2. Cows were milked twice a day after concentrate feeding. Distance from pastures to the milking parlor averaged 0.4 km (ranged between 0.2 and 0.7 km). During the treatment period, average temperature was $23.0 \pm 2.3°C$ and rainfall was 264 ± 55.5 mm.

The 6.0 ha of pasture used in this experiment were fertilized with 60 kg of N/ha after each grazing. The experimental cows were allocated to a new paddock with 2,000 m^2 every day, after evening milking, with free access to natural shade and fresh water. Elephant grass was managed in a rotational grazing system based on canopy height; the entry height was 103 cm, previously determined as the point for the canopy to intercept 95% of the incident light (Voltolini et al., 2010). The experimental group of cows grazed the canopy down to an average of 66 ± 3.2 cm (Supplemental Table S1; https://doi.org/10.3168/jds.2016-12503). Subsequently, a group of dry cows and heifers were used to graze down the pasture to final postgrazed height (40 ± 4.2 cm). The average grazing interval was 24 ± 2.5 d.

Experimental Measures and Sample Collection During the Treatment Period

Sward height was measured every day at 20 randomized points before animals entrance to the paddock and after they left. Pre- and postgrazing forage mass were measured in 2 paddocks every week by clipping the forage inside of 4 rectangles (1.5×0.75 m) at 3 cm above ground level from sites that represented the mean sward height of the paddock. Total forage mass was weighed, and 2 representative subsamples (500 g) were taken. The first subsample was dried in a forced-air oven at 55°C for 72 h for determining DM content. The second subsample was separated into leaves, stems, and senescent material. Concentrate and forage ingredients were collected for chemical composition weekly. Hand-plucked forage samples were taken according to De Vries (1995) at 25 randomized points per paddock in 3 paddocks per week before cows had access. All samples were dried in a forced-air oven at 55°C for 72 h, ground through a 1-mm screen (Wiley Mill, Thomas Scientific, Philadelphia, PA), and composited by month.

During the treatment period, forage intake and nutrient digestibility were measured at wk 6, 10, and 14 postpartum from total fecal excretion and feed indigestibility. To determine fecal excretion, TiO$_2$ was dosed twice a day (20 g/cow per day) after each milking for 15 d (de Souza et al., 2015). Fecal grab samples were collected after morning and afternoon milking from the last 5 d, and immediately frozen in liquid N to avoid starch degradation, and then stored in a −20°C freezer. Subsequently, samples were thawed, dried at 55°C in a forced-air oven, ground through a 1-mm screen (Wiley Mill, Thomas Scientific, Philadelphia, PA), and composited by cow.

Cows were milked twice a day at 0600 and 1600 h and milk yield was recorded daily. Milk samples from both milking sections were collected once a week and preserved with a bronopol preservative pill. An additional milk sample was collected at each milking every 30 d and stored without preservative at −20°C for determination of milk FA profile. Cows were weighed weekly after the morning milking. Body condition was scored weekly by 2 trained investigators on a 5-point scale, where 1 = thin and 5 = fat, as described by Wildman et al. (1982).

Table 1. Composition of corn processed either as fine ground or steam flaked used in dietary treatments

Item, % DM (unless noted)	Dry ground corn	Steam-flaked corn
NDF	2.75	2.84
ADF	1.21	1.24
CP	8.61	8.24
Starch	79.2	77.8
7-h Starch degradability,[1] % starch	35.4	68.2

[1]Measured as the starch disappearance after in vitro incubation for 7 h. In vitro procedure was conducted according to Gouvêa et al. (2016).

Table 2. Composition of the forage and experimental concentrates

Item	Hand-plucked pasture	Treatment period[1] FGC CON	FGC CSPO	SFC CON	SFC CSPO	Carryover period diet[2]
Ingredient, % of DM						
Fine ground corn		80.2	77.0	—	—	22.1
Steam-flaked corn		—	—	80.2	77.0	—
CSPO[3]		—	4.20	—	4.21	—
Soybean meal		9.0	9.0	9.0	9.0	14.6
Soybean meal, bypass		4.0	4.0	4.0	4.0	—
Sodium bicarbonate		1.20	1.20	1.20	1.20	1.0
Urea		—	—	—	—	0.50
Limestone		1.60	0.60	1.60	0.60	0.50
Mineral and vitamin mix[4]		4.0	4.0	4.0	4.0	2.0
Corn silage		—	—	—	—	59.3
Nutrient composition, % of DM						
DM	19.9	89.9	89.9	90.1	90.1	55.1
CP	18.8	15.1	14.9	15.2	15.0	17.0
NDF	58.2	9.81	9.32	9.82	8.91	36.3
ADF	41.8	4.31	3.40	4.28	3.36	16.7
Lignin	4.81	0.40	0.41	0.41	0.39	2.30
Ash	6.60	7.0	7.11	6.99	7.10	5.73
Starch	3.01	56.1	54.0	55.5	53.4	26.0
Fatty acids	3.60	2.70	6.0	2.70	6.0	1.91
16:0	0.70	0.35	1.94	0.38	1.91	0.29
18:0	0.09	0.06	0.20	0.11	0.24	0.05
18:1 *cis*-9	0.06	0.63	1.74	0.65	1.76	0.37
18:2 *cis*-9,*cis*-12	0.52	1.22	1.18	1.22	1.26	0.89
18:3 *cis*-9,*cis*-12,*cis*-15	1.94	0.05	0.05	0.05	0.06	0.10

[1]During the treatment period (3 to 16 wk postpartum) cows grazed elephantgrass (*Pennisetum purpureum* L. Cameroon) and received treatments as a concentrate supplement. Concentrate fed during treatment period contained either fine ground corn (FGC) or steam-flaked corn (SFC) associated or not with Ca salts of palm oil supplementation [not supplemented (CON) or supplemented (CSPO)].

[2]During the carryover period (17 to 40 wk postpartum) cows received a common diet fed as TMR.

[3]Ca salts of palm oil (CSPO; Nutri Gordura Lac, Nutricorp Inc., Araras, São Paulo, Brazil) 84.9% fatty acids (48.6% C16:0, 4.40% C18:0, 34.3% C18:1 *cis*-9, 5.5% C18:2 *cis*-9,*cis*-12, and others <2% each).

[4]Provided the following per kilogram of product DM: 250 g of Ca, 45 g of P, 65 g of Na, 10 g of Mg, 10 g of S, 2,375 mg of Mn, 2,375 mg of Zn, 562 mg of Cu, 12.5 mg of Co, 31 mg of I, 15.8 mg of Se, 200,000 IU of vitamin A, 50,000 IU of vitamin D_3, and 1,250 IU of vitamin E.

Experimental Measures and Sample Collection During the Carryover Period

From 17 to 40 wk postpartum (carryover period) all cows received a common diet fed as TMR once a day at 0900 h. Cows were milked twice a day at 0700 and 1500 h and milk yield was recorded every day. Milk samples from both milking procedures were collected once a week and preserved with a bronopol preservative pill. Feed ingredients were collected weekly and stored at −20°C. Subsequently, samples were thawed, dried at 55°C in a forced-air oven, ground through a 1-mm screen (Wiley Mill, Thomas Scientific, Philadelphia, PA), and composited by month. Cows were weighed and BCS recorded weekly as previously described.

Sample Analysis and Calculations

Composite forage, concentrate, and fecal samples were analyzed for DM (drying samples in an oven at 105°C for 24 h), ash (AOAC International, 2005; method 942.05), total N content (Leco FP-2000 N Analyzer; Leco Instruments Inc., St. Joseph, MI), NDF (Van Soest et al., 1991) with sodium sulfite and heat-stable α-amylase for concentrate samples, ADF and lignin (AOAC International, 2005; method 973.18), and gross energy by bomb calorimeter (Parr Instrument Inc., Moline, IL). Starch was measured by an enzymatic method (Karkalas, 1985) after samples were gelatinized with sodium hydroxide, glucose concentration was measured with glucose oxidase (Glucose kit #G0543; Sigma Chemical Co., St. Louis, MO), and absorbance was determined with a spectrophotometer (UV-1601 PC, Shimadzu, Kyoto, Japan).

Milk samples were analyzed for fat, protein, lactose, TS, and MUN using infrared procedures (Foss 4000; Foss North America, Eden Prairie, MN). Milk samples for FA profile were extracted according to Hara and Radin (1978) using a 3:2 (vol:vol) mixture of hexane and isopropanol followed by a 67 g/L of sodium sulfate

solution. The fat cake was previously obtained by milk centrifugation at 15,000 × g for 30 min at 8°C. Milk FAME were obtained by base-catalyzed transmethylation using a freshly prepared methylation reagent according to Christie (1982) with modifications (Chouinard et al., 1999). The FAME were determined by GC (model 6890 N; Agilent Technologies Brasil Ltda., Barueri, Brazil) fitted with a flame-ionization detector and equipped with a CP-Sil 88 fused-silica capillary column (100 m × 0.25 mm × 0.2 µm film thickness; Varian Inc., Mississauga, ON). The yield of individual FA in milk fat was calculated by correcting for glycerol content according to Schauff et al. (1992), and other milk lipid classes according to Glasser et al. (2007).

Forage intake was calculated from total fecal excretion and feed indigestibility. To determine fecal excretion, fecal samples were analyzed for titanium concentration according to Myers et al. (2004). To determine indigestibility, the indigestible NDF (**iNDF**) content of forage, concentrate, and fecal samples was determined according to Huhtanen et al. (1994). The iNDF contents of forage and concentrate were divided by the iNDF content in the feces of each cow to calculate the indigestibility of feeds for each animal. Total fecal excretion, fecal excretion coming from the concentrate, and forage intake were calculated according to de Souza et al. (2015).

Energy values were calculated based on NRC (2001) as described by Harvatine and Allen (2006) as follows: digestible energy intake = gross energy intake × gross energy digestibility; NE_L intake was calculated from digestible energy according to NRC (2001). Milk NE_L (Mcal/ d) was calculated as milk yield (kg) × [0.0929 × (fat %) + 0.0563 × (true protein %) + 0.0395 × (lactose %)] (NRC, 2001); NE_L BW change was calculated according to NRC (2001); and NE_L available for Maintenance = NE_L intake − NE_L milk − NE_L BW change. Energy partitioning was calculated as described by Boerman et al. (2015) as percent allocated to milk, maintenance, or body gain = [milk energy output, maintenance, or body tissue gain/(NE_L intake × 100)].

Statistical Analyses

Data were analyzed separately for treatment period (from 3 to 16 wk postpartum) and carryover period (from 17 to 40 wk postpartum). All weekly or monthly data were analyzed using the MIXED procedure of SAS v.9.4 (SAS Institute Inc., Cary, NC) according to the following model as repeated measures:

$$Y_{ijkl} = \mu + b_i + C_j + F_k + CF_{jk} + T_l + CT_{jl}$$
$$+ FT_{kl} + CFT_{jkl} + e_{ijkl},$$

where Y_{ijkl} is the variable of interest; μ is the overall mean; b_i is the random effect of block (i = 1 to 11); C_j is the fixed effect of corn grain-processing method (j = FGC or SFC); F_k is the fixed effect of CSPO supplementation (k = CON or CSPO); CF_{jk} is the fixed effect of interaction between corn grain-processing method and CSPO supplementation; T_l is the fixed effect of time (day, week or month); CT_{jl} is the interaction between corn grain-processing method and time; FT_{kl} is the interaction between CSPO and time; CFT_{jkl} is the interaction between corn grain-processing method, CSPO, and time; and e_{ijkl} is the residual error. Normality of the residuals was checked with normal probability and box plots and homogeneity of variances with plots of residuals versus predicted values. Unless otherwise specified, first-order autoregressive was the covariate structure used for analysis because it resulted in the lowest Bayesian information criterion for most of the variables measured. Denominator degrees of freedom were adjusted by the Kenward-Rogers method. Interactions with time were removed from the model when nonsignificant ($P > 0.20$) and a reduced model was used to determine treatment effects. Significances was determined at $P \leq 0.05$ and tendencies at $P \leq 0.10$. Two cows were removed from analysis in the carryover period because they developed mastitis during 2 consecutive weeks.

RESULTS

Production Responses During the Treatment Period

The CSPO increased ($P < 0.01$) milk yield during the treatment period, as well as yield of fat, protein, lactose, and casein compared with CON (Table 3). In addition, CSPO increased ($P < 0.01$) 3.5% FCM and ECM by 3.1 kg/d, cumulative milk yield by 264 kg, and feed efficiency compared with CON. In contrast, CSPO decreased milk protein content ($P = 0.04$) and BCS ($P = 0.01$) and tended to decrease casein content ($P = 0.10$) and BW change ($P = 0.08$) compared with CON. Likewise, a time × CSPO interaction ($P = 0.03$) was observed for BW as a result of CSPO having a lower BW at wk 7 and 12 postpartum compared with CON (Figure 1).

During the treatment period, SFC increased milk yield ($P = 0.03$), milk protein content ($P < 0.01$), casein content ($P < 0.01$), milk protein yield ($P < 0.01$), milk lactose yield ($P < 0.01$), milk casein yield ($P < 0.01$), and ECM ($P = 0.02$), and tended to increase 3.5% FCM ($P = 0.10$) compared with FGC. Furthermore, cows that received SFC increased ($P = 0.04$) the cumulative milk yield during treatment and feed efficiency compared with FGC. In contrast, cows supplemented

with SFC had lower milk fat content ($P = 0.01$) and MUN ($P < 0.01$) than FGC cows. The SFC increased BCS ($P = 0.01$) and BW change ($P = 0.01$) compared with FGC. A time × corn grain-processing method was observed for BW ($P = 0.02$) because SFC increased BW between the wk 12 and 16 postpartum compared with FGC (Figure 1).

We observed an interaction ($P < 0.01$) between CSPO and corn grain-processing method for milk fat content because CSPO increased milk fat content in FGC diet, whereas it reduced milk fat content in the SFC diet. A tendency for an interaction ($P = 0.10$) between CSPO and corn grain-processing method was observed for milk yield due to CSPO increasing milk yield to a greater extent in the FGC diet compared with the SFC diet. In addition, a tendency for an interaction ($P = 0.07$) between CSPO and corn grain-processing method was observed for milk protein content because CSPO reduced milk protein content in the FGC diet but not in the SFC diet. A tendency for an interaction between CSPO and corn grain-processing method were also observed for milk fat yield ($P = 0.07$) and for ECM ($P = 0.10$) due to CSPO increasing milk fat yield and ECM to a greater extent in the FGC diet compared with the SFC diet. In addition, a tendency for an interaction

between CSPO and corn grain-processing method was observed for BW change ($P = 0.07$) and BCS ($P = 0.06$) because CSPO reduced BW and BCS in the FGC diet but had no effect in the SFC diet.

Production Responses During the Carryover Period

In the carryover period, CSPO increased ($P \leq 0.01$) yield of milk, milk fat, milk protein, and milk lactose compared with CON (Table 4). However, no differences in milk composition were observed ($P > 0.10$). Cows supplemented with CSPO had higher ($P = 0.01$) 3.5% FCM and ECM as well as cumulative milk yield than CON. Moreover, CSPO tended to reduce BW compared with CON during the carryover period ($P = 0.06$).

Although SFC tended to increase ($P = 0.10$) milk yield compared with FGC, no differences in contents and yields of milk components were observed ($P > 0.10$). However, SFC tended to increase 3.5% FCM ($P = 0.10$), ECM ($P = 0.08$), and cumulative milk yield by 103 kg ($P = 0.08$) compared with FGC. Also, SFC tended to increase BCS ($P = 0.09$) and BW change ($P = 0.09$) compared with CON.

An interaction between CSPO and corn grain-processing method was observed for milk yield in the car-

Table 3. Corn grain-processing method and Ca salts of palm fatty acids supplementation on production, milk composition, and feed efficiency of dairy cows during the treatment period (3 to 16 wk postpartum)

| | Treatment[1] | | | | | P-value[2] | | |
| | FGC | | SFC | | | | | |
Item	CON	CSPO	CON	CSPO	SEM	Corn	Fat	Corn × fat
Yield, kg/d								
Milk	20.3	24.0	22.3	25.1	0.65	0.03	<0.01	0.10
Fat	0.68	0.82	0.73	0.80	0.04	0.35	<0.01	0.07
Protein	0.64	0.74	0.76	0.84	0.03	<0.01	<0.01	0.67
Lactose	0.94	1.11	1.03	1.16	0.03	<0.01	<0.01	0.23
Casein	0.47	0.53	0.56	0.61	0.02	<0.01	<0.01	0.22
35% FCM[3]	19.7	23.6	21.4	23.8	0.68	0.10	<0.01	0.12
ECM[4]	20.0	23.8	22.1	24.6	0.71	0.02	<0.01	0.10
Cumulative milk yield, kg	1,908	2,163	2,028	2,301	52.9	0.04	<0.01	0.90
Feed efficiency[5]	1.38	1.51	1.42	1.54	0.05	0.04	<0.01	0.94
Milk composition, % (unless noted)								
Fat	3.33	3.40	3.26	3.18	0.05	0.01	0.33	<0.01
Protein	3.17	3.09	3.39	3.36	0.04	<0.01	0.04	0.07
Lactose	4.64	4.62	4.61	4.62	0.06	0.68	0.32	0.27
Casein	2.33	2.22	2.49	2.45	0.03	<0.01	0.10	0.10
MUN, mg/dL	16.4	16.3	11.3	12.3	0.37	<0.01	0.41	0.30
BW, kg	503	490	480	497	13.4	0.61	0.85	0.43
BW change, kg/d	0.05	0.01	0.14	0.11	0.02	0.05	0.08	0.07
BCS	3.10	3.00	3.20	3.17	0.04	0.02	0.01	0.06

[1]Concentrate fed during the treatment period contained either fine ground corn (FGC) or steam-flaked corn (SFC) associated or not with Ca salts of palm oil supplementation [not supplemented (CON) or supplemented (CSPO)].

[2]P-values associated with the main effect of corn processing (corn), main effect of CSPO supplementation (fat), and the interaction between corn processing and CSPO supplementation.

[3]3.5% FCM = [(0.4324 × milk yield) + (16.216 × fat yield)].

[4]ECM = [(0.327 × kg of milk) + (12.95 × kg of milk fat) + (7.20 × kg of milk protein)].

[5]Feed efficiency = 3.5% FCM (kg/d)/DMI (kg/d).

Table 4. Corn grain-processing method and Ca salts of palm fatty acids supplementation on production and milk composition of dairy cows when fed a common diet during the carryover period (17 to 40 wk postpartum)

Item	FGC		SFC			P-value[2]		
	CON	CSPO	CON	CSPO	SEM	Corn	Fat	Corn × fat
Yield, kg/d								
Milk	13.9	15.5	14.8	15.6	0.57	0.10	<0.01	0.02
Fat	0.60	0.64	0.62	0.66	0.08	0.14	0.01	0.83
Protein	0.47	0.53	0.49	0.53	0.10	0.38	0.01	0.78
Lactose	0.61	0.69	0.66	0.69	0.12	0.18	0.01	0.81
Casein	0.37	0.41	0.39	0.40	0.01	0.41	0.10	0.33
3.5% FCM[3]	15.7	17.0	16.7	17.4	0.58	0.10	0.01	0.74
ECM[4]	15.7	17.1	16.7	17.4	0.58	0.08	0.01	0.69
Cumulative milk yield, kg	2,562	2,863	2,754	2,876	65.5	0.08	0.01	0.52
Milk composition, % (unless noted)								
Fat	4.32	4.12	4.24	4.23	0.14	0.81	0.33	0.83
Protein	3.42	3.47	3.34	3.43	0.08	0.25	0.73	0.49
Lactose	4.42	4.55	4.43	4.42	0.11	0.81	0.27	0.73
Casein	2.65	2.67	2.63	2.55	0.08	0.34	0.89	0.44
MUN, mg/dL	9.78	9.51	9.83	9.65	0.31	0.44	0.54	0.65
BW, kg	542	524	544	530	12.3	0.45	0.06	0.43
BW change, kg/d	0.22	0.25	0.29	0.23	0.03	0.08	0.34	0.65
BCS	3.45	3.40	3.52	3.42	0.06	0.09	0.12	0.54

[1]Concentrate fed during the treatment period contained either fine ground corn (FGC) or steam-flaked corn (SFC) associated or not with Ca salts of palm oil supplementation [not supplemented (CON) or supplemented (CSPO)].

[2]P-values associated with the main effect of corn processing (corn), main effect of CSPO supplementation (fat), and the interaction between corn processing and CSPO supplementation.

[3]3.5% FCM = $[(0.4324 \times \text{milk yield}) + (16.216 \times \text{fat yield})]$.

[4]ECM = $[(0.327 \times \text{kg of milk}) + (12.95 \times \text{kg of milk fat}) + (7.20 \times \text{kg of milk protein})]$.
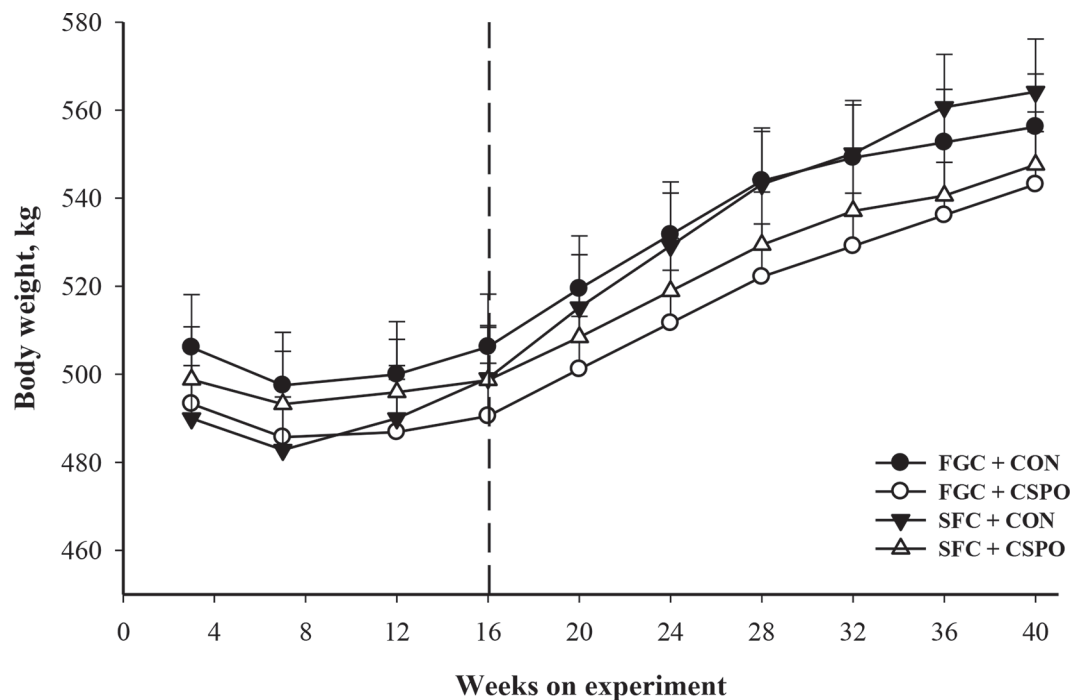

Figure 1. Effects of corn grain-processing method and supplementation with Ca salts of palm fatty acids (CSPO) on BW over time during the treatment and carryover periods. The dashed line on wk 16 indicates the start of the carryover period. Concentrate fed during the treatment period contained either fine ground corn (FGC) or steam-flaked corn (SFC) associated or not with Ca salts of palm oil supplementation [not supplemented (CON) or supplemented (CSPO)]. Error bars indicate SEM.
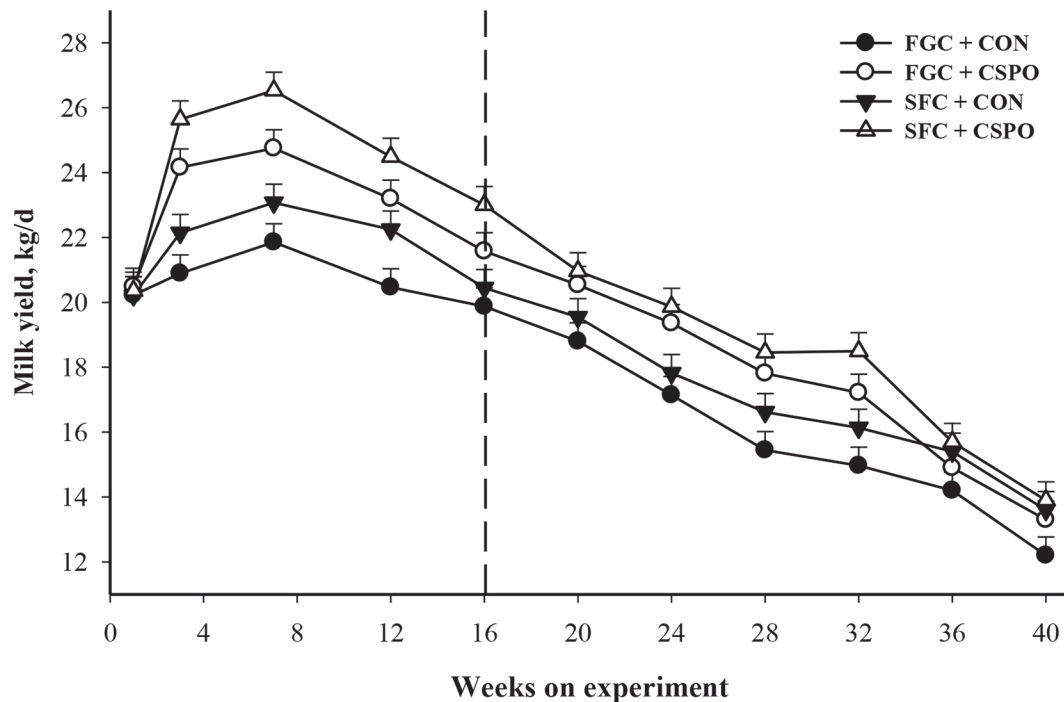
Figure 2. Effects of corn grain-processing method and supplementation with Ca salts of palm fatty acids (CSPO) on milk yield (kg/d) over time during the treatment and carryover periods. The dashed line on wk 16 indicates the start of the carryover period. Concentrate fed during the treatment period contained either fine ground corn (FGC) or steam-flaked corn (SFC) associated or not with Ca salts of palm oil supplementation [not supplemented (CON) or supplemented (CSPO)]. Error bars indicate SEM.

ryover period ($P = 0.02$), which occurred due to CSPO maintaining higher milk yield in the FGC diet but not in the SFC diet. Therefore, in the carryover period, the additive effect between SFC and CSPO that occurred in the treatment period was not maintained (Figure 2). No interactions were observed between CSPO and corn grain-processing method for milk composition and yield of milk components as well as BW and BCS ($P > 0.10$).

Intake, Total-Tract Digestibility, and Feed Efficiency

The CSPO did not affect DMI and intakes of OM, CP, NDF, and starch compared with CON ($P > 0.10$). As expected, CSPO increased ($P < 0.01$) FA intake compared with CON (Table 5). Although CSPO did not affect ($P > 0.10$) the digestibility of DM, CP, NDF, and starch, it tended to increase ($P = 0.07$) the digestibility of OM and increase ($P < 0.01$) FA digestibility.

Corn grain-processing method did not affect DMI and intake of nutrients ($P > 0.10$). Likewise, corn grain-processing method did not affect digestibilities of CP ($P = 0.51$), NDF ($P = 0.45$) and FA ($P = 0.56$). In contrast, SFC tended to increase DM digestibility (72.3 vs. 71.4%; $P = 0.10$) and OM digestibility (73.5 vs. 71.6%; $P = 0.08$) compared with FGC; SFC also increased starch digestibility compared with FGC (91.7

vs. 86.8%; $P < 0.01$). No interactions were observed between CSPO and corn grain-processing method for intake of nutrients and digestibility ($P > 0.10$).

Energy Partitioning

The NE_L intake and milk NE_L output were increased ($P \leq 0.01$) by CSPO compared with CON (Table 6). In contrast, CSPO decreased ($P = 0.03$) NE_L directed to BW change, but did not affect ($P > 0.10$) NE_L available for maintenance compared with CON. Overall, CSPO changed the energy partitioning (as percent of energy intake), directing more energy toward milk production ($P < 0.01$) and less energy to body reserves ($P = 0.04$) and maintenance ($P = 0.01$) than CON.

The SFC increased NE_L intake ($P = 0.05$) and NE_L directed toward BW reserves ($P = 0.01$) and tended to increase NE_L in milk ($P = 0.09$), whereas NE_L available for maintenance were not affected ($P > 0.10$) compared with CON. Generally, SFC increased NE_L partitioning toward body reserves ($P = 0.02$) and did not affect ($P > 0.10$) NE_L partitioned to milk and maintenance.

We observed an interaction between CSPO and corn grain-processing method for milk NE_L output ($P = 0.05$) due to CSPO increasing milk NE_L output to a greater extent in the FGC diet compared with the

Table 5. Corn grain-processing method and Ca salts of palm fatty acids supplementation on intake of nutrients and total-tract digestibility of dairy cows during the treatment period (3 to 16 wk postpartum)

| | Treatment[1] | | | | | P-value[2] | | |
| | FGC | | SFC | | | | | |
Item	CON	CSPO	CON	CSPO	SEM	Corn	Fat	Corn × fat
Intake, kg/d								
DM	17.5	17.2	17.5	16.7	0.58	0.53	0.12	0.15
OM	15.8	15.4	15.8	15.0	0.52	0.60	0.12	0.14
CP	2.66	2.68	2.64	2.57	0.18	0.56	0.61	0.73
NDF	4.84	5.03	4.91	4.65	0.56	0.58	0.50	0.17
Starch	4.77	4.59	4.76	4.69	0.45	0.54	0.88	0.68
Fatty acids	0.56	0.81	0.52	0.82	0.04	0.88	<0.01	0.76
Digestibility, %								
DM	70.9	72.0	71.8	72.7	0.35	0.10	0.16	0.34
OM	69.7	73.5	72.7	74.2	0.95	0.08	0.07	0.48
CP	75.1	73.8	73.9	73.2	1.65	0.51	0.50	0.88
NDF	55.7	53.1	52.1	55.1	3.31	0.45	0.54	0.89
Starch	87.0	86.6	91.9	91.4	0.72	<0.01	0.26	0.44
Fatty acids	75.2	81.0	76.2	80.8	1.71	0.56	<0.01	0.68

[1]Concentrate fed during the treatment period contained either fine ground corn (FGC) or steam-flaked corn (SFC) associated or not with Ca salts of palm oil supplementation [not supplemented (CON) or supplemented (CSPO)].

[2]P-values associated with the main effect of corn processing (corn), main effect of CSPO supplementation (fat), and the interaction between corn processing and CSPO supplementation.

SFC diet. Similarly, an interaction between CSPO and corn grain-processing method was observed for energy partitioning toward milk because CSPO increased more energy partitioned to milk in the FGC diet compared with the SFC diet ($P < 0.01$). In contrast, energy partitioned to maintenance decreased more in FGC rather than SFC when CSPO was fed (interaction $P < 0.01$).

Milk FA Yields and Profile

The CSPO increased the summation of mixed milk FA ($P = 0.04$), preformed milk FA ($P = 0.05$), and SFA ($P < 0.01$) compared with CON (Table 7). The summation of de novo milk FA was reduced ($P < 0.01$) and the concentration of MUFA tended to reduce ($P =$

Table 6. Corn grain-processing method and Ca salts of palm fatty acids supplementation on energy partitioning of dairy cows during the treatment period (3 to 16 wk postpartum)

| | Treatment[1] | | | | | P-value[2] | | |
| | FGC | | SFC | | | | | |
Item	CON	CSPO	CON	CSPO	SEM	Corn	Fat	Corn × fat
NE_L intake,[3] Mcal/d	26.6	28.1	27.8	29.1	0.49	0.05	<0.01	0.16
Production, Mcal/d								
Milk NE_L[4]	13.6	16.1	15.1	16.8	0.41	0.09	0.01	0.05
NE_L BW change[5]	0.38	0.18	1.09	0.42	0.021	0.01	0.03	0.29
NE_L avail. maint., Mcal/d[6]	11.6	11.8	11.6	11.5	0.92	0.71	0.36	0.32
Energy partitioning, % of energy intake								
Milk	51.2	57.5	54.3	57.8	1.04	0.43	<0.01	<0.01
Reserves	1.43	0.64	3.92	1.43	0.21	0.02	0.04	0.47
Maintenance	47.5	41.9	41.8	40.8	0.96	0.15	0.01	<0.01

[1]Concentrate fed during the treatment period contained either fine ground corn (FGC) or steam-flaked corn (SFC) associated or not with Ca salts of palm oil supplementation [not supplemented (CON) or supplemented (CSPO)].

[2]P-values associated with the main effect of corn processing (corn), main effect of CSPO supplementation (fat), and the interaction between corn processing and CSPO supplementation.

[3]$NE_{L(intake)} = DMI \times NE_{L(diet)}$.

[4]$NE_{L(milk)} = $ Milk yield (kg) $\times$ (0.0929 $\times$ fat% + 0.0563 $\times$ true protein% + 0.0395 $\times$ lactose%) (NRC, 2001).

[5]$NE_{L(BW\ change)}$ calculated according to NRC (2001).

[6]NE_L available for maintenance $= NE_{L(intake)} - NE_{L(BW\ gain)} - NE_{L(milk)}$.

Table 7. Corn grain-processing method and Ca salts of palm fatty acids supplementation on the concentration of milk fatty acids of dairy cows during the treatment period (3 to 16 wk postpartum)

| | Treatment[1] | | | | | P-value[2] | | |
| | FGC | | SFC | | | | | |
Item	CON	CSPO	CON	CSPO	SEM	Corn	Fat	Corn × fat
Profile, g/100 g of fatty acids								
C4:0	2.52	2.70	2.45	2.56	0.07	0.14	0.03	0.65
C6:0	1.72	1.59	1.66	1.55	0.06	0.40	0.03	0.98
C8:0	1.15	0.93	1.14	0.98	0.05	0.67	<0.01	0.67
C10:0	2.55	1.99	2.73	2.13	0.15	0.29	<0.01	0.89
C12:0	2.19	1.74	2.61	1.94	0.16	0.05	<0.01	0.44
C14:0	9.93	8.41	9.65	8.27	0.39	0.59	<0.01	0.86
C14:1 *cis*-9	0.74	0.57	0.77	0.62	0.06	0.37	<0.01	0.88
C15:0 *iso*	0.31	0.30	0.30	0.29	0.01	0.29	0.22	0.95
C15:0 *anteiso*	0.43	0.39	0.45	0.41	0.02	0.39	0.03	0.88
C15:0	1.09	0.94	1.15	0.95	0.07	0.54	<0.01	0.69
C16:0	26.4	27.7	26.7	28.8	0.68	0.42	<0.01	0.66
C16:1 *cis*-9	0.94	0.85	0.91	0.82	0.07	0.65	0.14	0.95
C18:0	13.5	13.7	12.6	12.3	0.62	0.03	0.97	0.63
C18:1 *trans*-6, -7, -8, and -9	0.49	0.53	0.48	0.68	0.05	0.15	0.01	0.11
C18:1 *trans*-10	1.64	2.21	1.72	2.17	0.12	0.81	<0.01	0.58
C18:1 *cis*-9	22.9	24.2	23.5	23.7	0.79	0.93	0.31	0.45
C18:2 *cis*-9,*cis*-12	1.61	1.72	1.83	1.91	0.10	0.04	0.33	0.82
C18:2 *cis*-9,*trans*-11	0.73	0.82	0.78	0.86	0.05	0.24	0.03	0.82
Summation by source[3]								
Σ <C16	23.6	20.3	24.2	20.9	0.94	0.46	<0.01	0.98
Σ C16 + C16:1	28.1	29.7	28.2	30.5	0.70	0.48	0.04	0.51
Σ >C16	48.2	50.0	47.6	51.4	1.34	0.36	0.05	0.69
Summation by saturation								
Σ Saturated	62.1	64.8	63.2	63.8	0.64	0.96	<0.01	0.22
Σ Monounsaturated	34.7	32.1	33.3	32.9	0.91	0.75	0.09	0.21
Σ Polyunsaturated	3.28	3.14	3.51	3.33	0.10	0.02	0.19	0.99

[1]Concentrate fed during the treatment period contained either fine ground corn (FGC) or steam-flaked corn (SFC) associated or not with Ca salts of palm oil supplementation [not supplemented (CON) or supplemented (CSPO)].

[2]P-values associated with the main effect of corn processing (corn), main effect of CSPO supplementation (fat), and the interaction between corn processing and CSPO supplementation.

[3]De novo fatty acids originate from mammary de novo synthesis (<16 carbons), preformed fatty acids originate from extraction from plasma (>16 carbons), and mixed fatty acids originate from both sources (C16:0 plus *cis*-9 C16:1).

0.09) in CSPO compared with CON. Although CSPO did not affect the yield of de novo milk FA (Table 8; $P > 0.10$), it increased ($P \leq 0.05$) the yield of mixed milk FA, preformed FA, SFA, and MUFA in milk than CON.

Corn grain-processing method did not affect summation by source of milk FA and the concentration of SFA and MUFA ($P > 0.10$). The SFC increased the concentration of PUFA ($P = 0.02$) and the yield of PUFA ($P = 0.05$) compared with FGC. Although corn grain-processing method did not affect the concentration of most individual FA (Table 7), SFC increased the yield of some MUFA and PUFA compared with FGC (Table 8). No interactions were observed between CSPO and corn grain-processing method for milk FA yields and profiles ($P > 0.10$).

DISCUSSION

The recent adoption of intensive management grazing practices has improved the nutritive value of tropi-

cal grasses (Da Silva et al., 2013) and animal performance (Voltolini et al., 2010). Nonetheless, the higher NDF content of tropical grasses and the possible low particle fragility are major limitations to forage intake and performance. Hence, energy intake is most likely the major restriction to better performance in pasture-based systems (Hills et al., 2015). To overcome these limitations, we evaluated whether corn grain-processing method and fat supplementation interact during early lactation increasing energy intake and performance, and the potential carryover effects throughout lactation on production responses.

Depending on the stage of lactation, an increase in energy density due to fat supplementation could increase milk production, milk fat yield, and body reserves as long as dietary fat supplements do not reduce DMI or negatively affect the digestibility of other nutrients (Boerman et al., 2015). The effect of fat supplements on DMI is variable and usually depends on the type of fat being fed (Rabiee et al., 2012). In our study, DMI was

not affected by CSPO supplementation, which agrees with a recent study feeding CSPO to early-lactation grazing cows (de Souza et al., 2017). Also, we observed that CSPO increased FA digestibility and tended to increase OM digestibility; this increase in FA digestibility is possibly associated with the FA profile of CSPO supplement, as UFA have higher digestibility than SFA (Boerman et al., 2015). Therefore, the positive effects of CSPO supplementation on FA digestibility, with no effect on DMI, resulted in greater NE_L intake for CSPO-supplemented diets and better milk production responses during the treatment period.

In addition, we did not observe effects of corn grain-processing method on DMI. Oba and Allen (2003) observed that a more rapidly fermentable starch source (high-moisture corn) reduced feed intake by 8% of mid-lactation cows compared with a less fermentable starch source (dry ground corn) by decreasing meal size. Similar to our results, Theurer et al. (1999) and

Ferrareto et al. (2013) did not observe differences in DMI between steam-flaked corn and dry ground or rolled corn. Although corn grain-processing method did not affect fiber digestibility in our study, Theurer et al. (1999) noted that steam-flaking corn decreased fiber digestibility by 16%. Corroborating our findings, Ferrareto et al. (2013) did not observe differences in fiber digestibility between steam-flaked corn and dry ground or rolled corn. We observed that SFC increased total-tract starch digestibility by 5% units compared with FGC, which is greater than the 2% units improvement reported by Ferrareto et al. (2013) when comparing steam-flaked corn and dry ground or rolled corn. These differences might be associated with the kernel vitreousness, as grain vitreousness is negatively correlated with total-tract starch digestibility (Correa et al., 2002; Lopes et al., 2009). Similarly, with beef cattle, Gouvêa et al. (2016) reported that steam-flaking of flint corn resulted in marked improvements in animal

Table 8. Corn grain-processing method and Ca salts of palm fatty acids supplementation on milk fatty acids yield of dairy cows during the treatment period (3 to 16 wk postpartum)

| Item | Treatment[1] | | | | | P-value[2] | | |
| | FGC | | SFC | | | | | |
	CON	CSPO	CON	CSPO	SEM	Corn	Fat	Corn × fat
Yield, g/d								
C4:0	18.0	20.4	16.9	19.5	0.71	0.15	<0.01	0.91
C6:0	11.8	12.1	11.5	11.8	0.56	0.52	0.97	0.97
C8:0	7.82	7.10	7.88	7.43	0.48	0.66	0.21	0.77
C10:0	17.4	15.2	18.8	16.3	1.21	0.32	0.05	0.87
C12:0	14.9	13.4	17.9	14.8	1.15	0.08	0.05	0.49
C14:0	66.1	63.3	68.4	63.8	2.45	0.66	0.03	0.78
C14:1 *cis*-9	2.12	2.22	2.06	2.12	0.09	0.37	0.38	0.87
C15:0 *iso*	2.89	2.96	3.07	3.04	0.12	0.32	0.91	0.71
C15:0 *anteiso*	5.09	4.37	5.33	4.68	0.45	0.45	0.06	0.91
C15:0	7.37	7.07	7.98	7.17	0.44	0.44	0.22	0.57
C16:0	182	208	183	214	6.41	0.6	<0.01	0.71
C16:1 *cis*-9	6.84	6.45	6.35	6.24	0.51	0.51	0.64	0.79
C18:0	82.6	101	82.8	88.6	12.7	0.91	0.43	0.25
C18:1 *trans*-6, -7, -8, and -9	2.76	2.51	2.69	2.34	0.22	0.61	0.18	0.83
C18:1 *trans*-10	9.10	10.3	8.50	9.20	4.71	0.04	0.04	0.53
C18:1 *cis*-9	160	182	161	178	5.61	<0.01	0.27	0.85
C18:2 *cis*-9,*cis*-12	11.3	11.7	16.2	16.4	0.91	<0.01	0.85	0.65
C18:2 *cis*-9,*trans*-11	3.51	3.32	5.23	4.00	0.42	0.89	<0.01	0.69
Summation by source[3]								
Σ <C16	154	166	159	164	5.47	0.52	0.14	0.94
Σ C16 + C16:1	194	219	193	225	17.1	0.67	<0.01	0.59
Σ >C16	334	380	326	368	12.9	0.38	<0.01	0.85
Summation by saturation								
Σ Saturated	431	488	435	478	10.4	0.82	<0.01	0.61
Σ Monounsaturated	238	243	225	247	6.80	0.76	0.05	0.39
Σ Polyunsaturated	22.6	23.5	24.2	25.5	0.74	0.05	0.25	0.87

[1]Concentrate fed during the treatment period contained either fine ground corn (FGC) or steam-flaked corn (SFC) associated or not with Ca salts of palm oil supplementation [not supplemented (CON) or supplemented (CSPO)].

[2]P-values associated with the main effect of corn processing (corn), main effect of CSPO supplementation (fat), and the interaction between corn processing and CSPO supplementation.

[3]De novo fatty acids originate from mammary de novo synthesis (<16 carbons), preformed fatty acids originate from extraction from plasma (>16 carbons), and mixed fatty acids originate from both sources (C16:0 plus *cis*-9 C16:1).

performance and those responses to the flaking of flint corn were considerably greater than reported in the published literature for flaking of dent corn grain (Zinn et al., 2011). According to McAllister et al. (2007), the benefits of steam-flaking on digestion of corn are related to an increased surface area of grains and gelatinization of the starch due to denaturation of the protein matrix. Therefore, the greater beneficial effects of flaking for flint corn than for dent corn matches our hypothesis, that the benefit of steam-flaking should be greater for the flint corn, as used in the present study, than commonly is observed for dent corn in trials from North America (Owens and Basalan, 2013). Also, our results indicate that increasing corn grain-processing method of flint corn increased energy intake due to the increase in total-tract starch digestibility.

In our study, during the treatment period CSPO increased milk yield in both the FGC and SFC diets. The positive effect of fat supplementation on milk production has been reported in both housed animals receiving TMR (Rabiee et al., 2012) and grazing animals (Schroeder et al., 2004). This effect could be associated with the greater energy density of the fat-supplemented diets providing more energy for metabolic functions. Fat supplementation also increases energetic efficiency in lactating cows by increasing total energy intake, by generating ATP more efficiently compared with VFA, and by direct incorporation of long-chain FA into milk fat (Palmquist, 1994). Schroeder et al. (2004) compiled 18 studies feeding different fat supplements to cows grazing on temperate pastures and observed that supplemental fat increased milk yield, on average, by 5%. As high-producing dairy cows grazing on tropical pastures likely have lower energy intake due to the reduced nutritive value and forage intake of tropical pastures compared with temperate pastures (Da Silva et al., 2013), they probably are more responsive to energy supplementation (de Souza et al., 2017). This possibly explains the greater milk yield response in our study to supplemental fat when compared with Schroeder et al. (2004).

As we hypothesized, CSPO increased milk yield and ECM, but also tended to increase to a greater extent in the FGC (18.2%) than the SFC (12.5%) diet during the treatment period. In addition, we observed a tendency for an interaction between CSPO and corn grain-processing method for BW change and BCS due to CSPO, which reduced them in the FGC diet but had no effect in the SFC diet. These results indicate an interaction between fat supplementation and corn grain-processing method on energy partitioning of dairy cows. Similarly, Weiss and Pinos-Rodríguez (2009) observed that when high-forage diets were supplemented with

fat, the increased NE_L intake was partitioned toward body energy reserves; whereas when low-forage diets were supplemented with fat, milk yield increased with no change in body reserves. Our results corroborate this hypothesis and suggest that corn grain-processing method also might alter energy partitioning. Additionally, the greater benefit of CSPO supplementation in the FGC diet supports the concept that extensive grain processing (i.e., steam-flaking) increases the energetic value of corn grain (Zinn et al., 2007) and explains the greater milk yield response to CSPO supplementation with the FGC diet. Altogether, our results demonstrated that CSPO increased milk yield and ECM in cows grazing tropical pastures, but also corroborated our initial hypothesis that the magnitude of the response is affected by corn grain-processing method. Additionally, we observed that CSPO supplementation increased yield of milk components during the treatment period. The increase in fat yield by CSPO supplementation was mainly result of the increase in yield of C16:0 and C16:1 *cis*-9. This result was likely associated with the greater amount of C16:0 in our fat supplement, as recent studies feeding C16:0-enriched supplements have shown that C16:0 consistently increase milk fat yield (Lock et al., 2013; Piantoni et al., 2013).

Changes in feeding level during early lactation not only have an immediate effect on production, but level of nutrition during the first few weeks of lactation can have a major effect on subsequent lactation performance (Jørgensen et al., 2016). One of our goals was to evaluate the potential carryover effect of corn grain-processing method and fat supplementation to early-lactation cows throughout lactation. The carryover effect may be important in determining the economic impact of specific feeding strategies, as fat supplementation and more fermentable sources of starch are generally expensive compared with other dietary components or ingredients. Usually, each extra kilogram of milk secreted at peak production results in approximately 200 kg of milk subsequent during lactation (Roche et al., 2013), suggesting that supplementation during early lactation that increases milk production at peak could have positive effects even though supplementation ceased. In our study, we observed that fat supplementation had a positive carryover effect on milk yield and increased cumulative milk yield by 8.0%, whereas SFC also tended to increase cumulative milk yield by 3.8% compared with FGC. Similarly, de Souza et al. (2017) observed that feeding supplemental fat to grazing cows had a positive carryover effect on milk yield, but the magnitude of the response was affected by the FA profile of the fat supplement. Our results also agree with a recent review in which most results showed that a more

generous energy feeding strategy during early lactation caused a positive carryover effect on subsequent production (Jørgensen et al., 2016). Interestingly, our results suggest that the source of energy (glucogenic vs. lipogenic precursors) affect the magnitude of the carryover effect. The possible explanations for the carryover effect on milk yield involve either an increase in mammary cell number (Akers, 2002) or cell secretory activity (Nørgaard et al., 2005). The expansion of epithelial cell populations in the mammary gland is mainly regulated by ovarian steroids, in particular estrogen (Arendt and Kuperwasser, 2015). In rodents, flaxseed oil was shown to alter mammary development (Tou and Thompson, 1999), modify mammary gland morphology, and increase the number of estradiol receptor binding sites in the mammary gland of mice (Hilakivi-Clarke et al., 1998). Although evidence exists that FA can increase mammary cell number in rodents, to our knowledge this has not been evaluated in dairy cows. Based on our study and the study of de Souza et al. (2017), supplementation with CSPO at early lactation has positive carryover effect on milk yield. However, further studies are needed to comprehend factors associated with carryover effects and to determine the duration and magnitude of this under different dietary conditions.

Although CSPO supplementation increased milk production during the carryover period, we observed an interaction between CSPO and corn grain-processing method for milk yield due to CSPO maintaining higher milk yield in the FGC diet but not the SFC diet. Therefore, the additive effect between SFC and CSPO that occurred in the treatment period was not maintained throughout carryover period. These results are probably associated with the tendency for SFC diets to increase BW and BCS during the carryover period. The association between the general shape of the lactation curve and calving BCS as well as BCS change between calving and nadir is nonlinear (Roche et al., 2009b). Roche et al. (2007) reported such nonlinear associations, with lactation milk yield increasing with BCS loss postcalving, up to 0.5 BCS units, and decreasing with further BCS loss. Although feeding SFC reduced BW and BCS loss and improved energy balance during early lactation, this faster recovery of body condition is likely important to improve reproductive performance. However, cows that gain excessive BCS in mid and late lactation are at a higher risk for culling in the subsequent lactation due to increased incidence of metabolic diseases and reproductive failure (Roche et al., 2009a). Therefore, further research is needed to evaluate the association between diets that improve energy balance at early lactation, carryover effects, and reproductive performance.

CONCLUSIONS

In conclusion, corn grain-processing method interacts with CSPO supplementation on production responses and has a carryover effect in grazing cows. When CSPO was fed in the FGC diet, milk production increased more than when fed in the SFC diet, but also caused greater mobilization of reserves at early lactation. Furthermore, both supplementation with CSPO and SFC were effective strategies to increase energy intake and yields of milk and milk solids. The carryover effect on milk production was greater for CSPO supplementation than altering corn grain-processing method, whereas SFC diets had lower mobilization of reserves and less BW and BCS variation throughout lactation.

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