J. Dairy Sci. 105:5714–5722
https://doi.org/10.3168/jds.2021-21682

Dry malt extract from barley partially replacing ground corn in diets of dairy cows: Nutrient digestibility, ruminal fermentation, and milk composition

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ABSTRACT

Dry malt extract (DME) has been used in animal nutrition as an alternative source of rapidly fermentable carbohydrate. An experiment was conducted to evaluate the partial replacement of ground corn with DME in diets of dairy cows on apparent digestibility, ruminal fermentation, predicted rumen microbial protein supply, N excretion, serum urea-N concentration, and milk yield and composition. Twenty-eight Holstein cows (35.3 ± 5.88 kg/d milk yield and 148 ± 78 d in milk), 4 of which were rumen cannulated, were blocked according to the presence of rumen cannulas, parity, milk yield, and days in milk and enrolled into a crossover design experiment. Experimental periods lasted 21 d, of which the first 14 d were allowed for treatment adaptation and 7 d were used for data collection and sampling. Treatment sequences were composed of control (CON) or DME from barley (Liotécnica Tecnologia em Alimentos) replacing ground corn at 7.62% diet dry matter (~2 kg/d). Data were analyzed using the MIXED procedure of SAS (SAS Institute Inc.) modeling the fixed effects of treatment, period, and their interaction, in addition to the random effect of animal. Ruminal fermentation data were analyzed as repeated measures including time and its interaction with treatment in the previous model as fixed effects. Treatments did not affect nutrient intake or feed sorting. Dry malt extract increased apparent digestibility of CP. Feeding DME decreased ruminal pH and molar percentage of butyrate and increased molar percentage of acetate. No treatment effects were detected for predicted rumen microbial protein supply or N excretion. Cows fed DME had lower serum urea-N concentration than CON cows. Dry malt extract increased yields of actual milk, 3.5% fat-corrected milk, fat, and protein, and improved feed efficiency (fat-corrected milk ÷ dry matter intake). Cows fed DME had lower milk urea nitrogen content in comparison with CON cows. Dry malt extract can partially replace ground corn in the diet while improving milk yield and feed efficiency.

Key words: carbohydrate, malting barley, rapidly fermentable carbohydrate, sugar

INTRODUCTION

Barley (*Hordeum vulgare* L.) is the primary cereal used in world malt production and contains (on DM basis) 65 to 68% starch, 10 to 17% CP, 4 to 9% β-glucan, 2% to 3% free lipids, and 1.5% to 2.5% minerals (Czuchajowska et al., 1998; Izydorczyk et al., 2000). About two-thirds of barley production is used for feed and one-third for malting, and about 2% for food directly (Li et al., 2001; Baik and Ullrich, 2008). During malting, barley undergoes an incomplete natural germination process that involves a series of enzyme degradations of kernel endosperm. As a result of enzymatic activity (especially of amylolytic and proteolytic enzymes), endosperm cell walls are degraded, starch granules are released from the matrix of the endosperm in which they are embedded (Gupta et al., 2010), increasing contents of soluble protein and simple sugars (Hoseney, 1994).

Malt extracts can be obtained after barley malt passes through a series of processes, which include moisturizing, extruding, cooling, crushing malt, preparation of mash (extraction process), hydrolysis of the mash, subsequent separation (filtration), and evaporation of wort to produce the liquid malt extract (Safonova et al., 2018); the liquid malt extract can be further dried to produce the dry malt extract (**DME**), which is a crystalline form similar to common sugar. During the mashing process, polysaccharides of the malt extract are degraded and fermentable carbohydrates (maltose, isomaltose, maltotrioese, and so on) are produced (Paik et al., 1991). Nonstarch polysaccharides are also degraded

Received December 9, 2021.
Accepted March 10, 2022.
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during the mashing process into smaller carbohydrates (Gupta et al., 2010). Thus, the malt extract is generally composed of smaller carbohydrates and is more fermentable than malt. Malted barley contains around 63.0% starch, 10.1% soluble carbohydrates, and 3.2% reducing sugars, whereas a commercial malt extract contains 17.0% starch, 92.1% soluble carbohydrates, and 35.9% reducing sugars (Bhatty, 1996).

Malt extracts from barley have half of the sweetness of sugar syrup and are widely used in the food industry in the preparation of various additives in dough for baking, breakfast cereals, and brewing (Safonova et al., 2018). Malt extracts have also been tested in diets of poultry (Sedghi and Akbari Moghaddam Kakhki, 2018) and dairy cows (Biagi et al., 2007) without influencing animal performance. Because of its high content of readily fermentable carbohydrates, malt extract can replace sources of starch and sugars in diets of ruminants such as ground corn and molasses, depending on costs and availability. Malt extracts can be used to supplement diets with relatively low starch content. Malted barley has also shown antioxidant properties derived from its vitamin E content (Do et al., 2015). However, partially replacing ground corn, barley, and sorghum with malt extracts during the transition period and early lactation had no effect on milk yield and composition during the first 120 d of lactation (Biagi et al., 2007).

To the best of our knowledge no peer-reviewed studies have been published on the effects of a DME from barley on ruminal fermentation and performance of mid-lactation cows. The objective of this study was to determine the effects of partially replacing ground corn with DME (at 7.6% diet DM) on total apparent nutrient digestibility, ruminal fermentation, predicted rumen microbial protein supply, milk yield and composition, and concentrations of urea-N in blood of dairy cows. We hypothesized that partially replacing ground corn with DME would alter ruminal fermentation and improve performance of cows.

MATERIALS AND METHODS

This study was carried out between May and July 2020 in the Laboratório de Pesquisa em Bovinos de Leite (Laboratory on Dairy Cattle Research; Pirassununga, Brazil) under the approval of the Ethics Committee on Animal Use from the School of Veterinary Medicine and Animal Sciences, University of São Paulo (São Paulo, Brazil; protocol #5986020620).

Treatments and Design

Twenty-eight Holstein cows (4 primiparous and 24 multiparous, 35.3 ± 5.88 kg/d milk yield, 148 ± 78 DIM, and 696 ± 80.6 kg of BW), 4 of which (30.7 ± 1.87 kg/d milk yield, 171 ± 112.3 DIM, and 706 ± 85.6 kg of BW) were rumen cannulated, blocked according to parity, milk yield, and DIM, and enrolled into a crossover design experiment. Experimental periods lasted 21 d of which the first 14 d were allowed for treatment adaptation and 7 d were used for data collection and sampling purposes. Treatment sequences were composed of control (**CON**) or DME from barley (Liotécnica Tecnologia em Alimentos) replacing ground corn at 7.62% diet DM (~2 kg/d). Dry malt extract was weighed for each cow (twice daily at feeding times) and hand mixed into the concentrate prepared for the DME treatment (which had lower inclusion of ground corn than CON concentrate). The DME is a hygroscopic compound derived from malting barley hydrolysis, followed by concentration, vacuum dehydration, and grinding. According to the manufacturer's information, for every kilogram of barley malt processed, 590 g of DME is obtained. The DME is a granular powder of brownish color with density 0.300 to 0.450 g/cm^3, 85% total carbohydrates (minimum), 5 to 8% protein, 0.6% fat, and 60% reducing sugars (minimum). Dry malt extract chemical composition (Table 1) was determined by wet chemistry analyses and liquid chromatography.

Animals were individually fed twice daily (0700 and 1300 h) in equal amounts and the DME was mixed into the concentrate before TMR preparation. Total mixed ration was individually prepared for each cow in the feed bunk. Corn silage and concentrate for each cow were individually weighed, placed in the feed bunk, and hand mixed to form the TMR. Feeding rate was adjusted to allow refusals between 5 and 10% on as-fed basis. Diets (Table 2) were formulated according to the NRC (2001) targeting the nutrient requirements estimates of cows. Cows were housed in a barn with individual pens (17 m^2 of area), sanded beds, fans, and free access to water. Samples of feed ingredients were collected during the last 5 d of each experimental period and

Table 1. Dry malt extract (DME; Liotécnica, Tecnologia em Alimentos) chemical composition (% of DM, unless stated)

Item	DME
Chemical	
DM (% as-fed)	86.8
OM	98.2
NDF	2.12
Ether extract	0.45
Starch	—
CP	8.17
Reducing sugars	71.0
Fructose	0.84
Glucose	3.54
Saccharose	0.94
Maltose	31.7

analyzed for contents of DM (method 930.15; AOAC International, 2000), ash (method 942.05; AOAC International, 2000), OM (DM − ash), and CP (N × 6.25; Kjeldahl method 984.13; AOAC International, 2000). Neutral detergent fiber (Van Soest et al., 1991) was analyzed using α-amylase and sodium sulfite added to the detergent (TE-149 fiber analyzer; Tecnal Equipamentos para Laboratório Inc.), and ADF and ADL (method 973.18) were analyzed according to AOAC International (2000). Feed ingredients were also analyzed for contents of starch using an enzymatic degradation method (Amyloglicosidase, Novozymes Latin America Ltda.) and absorbances measured on spectrophotometer (SBA-200, Celm) according to Hendrix (1993).

Nutrient Intake, Sorting Index, and Apparent Digestibility

Feed offered and refusals were recorded daily to determine feed intake. Refusals were sampled during the last 5 d of each experimental period, pooled by cow per period, and frozen for further chemical analysis according to the methods described earlier. Samples of TMR and refusals were collected for 2 consecutive days during the collection period for determination of particle size distribution (Maulfair and Heinrichs, 2012) and sorting index (Silveira et al., 2007). Feed particles were stratified using the Penn State particle size separator to the following fractions: long (>19 mm), medium (19 to 8 mm), short (8 to 4 mm), and fine (<4 mm) particles. The sorting index was calculated using the following equations:

$$\text{Expected intake}\left(\text{kg/d}\right) = \text{intake}\left[\left(\text{kg as-fed}\right)/\text{d}\right] \times \text{P}_{\text{TMR}}\ \left(\text{kg/kg}\right),$$

$$\text{Observed intake}\left(\text{kg/d}\right) = \left[\text{offered}\left(\text{kg/d}\right) \times \text{P}_{\text{TMR}}\ \left(\text{kg/kg}\right)\right] - \left[\text{refusals}\left(\text{kg/d}\right) \times \text{P}_{\text{refusals}}\ \left(\text{kg/kg}\right)\right],$$

$$\text{Sorting index} = \frac{\text{observed intake}\left(\text{kg/d}\right)}{\text{expected intake}\left(\text{kg/d}\right)}.$$

The intake corresponding to each sieve was expressed as the percentage of the total estimated intake, where P_{TMR} is the TMR particle size, and $\text{P}_{\text{refusals}}$ is the particle size distribution of refusals. The sorting index equaling 1 means no sorting, <1 indicates sorting against the particular particle size, and values >1 shows that cows sorted for a specific particle size.

Indigestible NDF (iNDF) contents in feeds, refusals, and feces were used to estimate fecal DM output. Fecal samples were collected directly from the rectum of cows every 9 h for 3 consecutive days (d 15, 16, and 17) and pooled for analyses. For indigestible NDF analysis, ground samples (2 mm) of feeds, refusals, and feces were placed in nonwoven fabric bags (5 × 5 cm at 20 mg of DM/cm^2) and incubated in the rumen of 2 cannulated dry cows for 288 h (Huhtanen et al., 1994; Casali et al., 2008). After removal from the rumen, bags were washed in running tap water until bleached; then, bags were dried and NDF content was determined. Digestibilities of DM and nutrients were calculated using following equations:

$$\text{DM digestibility (\%)} = 100 - \left[100 \times \left(\frac{\text{\% iNDF intake}}{\text{\% iNDF in feces}}\right)\right],$$

$$\text{Nutrient digestibility (\%)} = 100 - \left[100 \times \left(\frac{\text{\% iNDF intake}}{\text{\%iNDF in feces}}\right) \times \left(\frac{\text{\% nutrient in feces}}{\text{\% nutrient intake}}\right)\right].$$

Table 2. Ingredients and chemical composition of diets

Item	Diet[1]	
	CON	DME
Ingredient (% DM)		
Corn silage	48.0	48.0
Ground corn	18.7	10.1
Citrus pulp	8.20	8.20
Dry malt extract[2]		7.62
Soybean meal 48% CP	11.8	12.8
Whole raw soybean	6.42	6.42
Bypass soybean meal	4.01	4.01
Urea	0.15	0.15
Sodium bicarbonate	0.80	0.80
Minerals and vitamins[3]	1.50	1.50
Limestone	0.20	0.20
Salt	0.20	0.20
Chemical (% DM)		
DM	47.3	47.3
OM	92.8	93.0
Starch	29.9	24.6
CP	16.9	16.4
Lignin	3.11	3.01
NDF	33.9	32.8
Neutral detergent insoluble CP	3.24	2.99
ADF	26.7	26.4
Net energy of lactation[4] (Mcal/kg)	1.57	1.57

[1]Control (CON) or dry malt extract (DME; Liotécnica Tecnologia em Alimentos) partially replacing ground corn at 7.62% diet DM.

[2]Liotécnica, Tecnologia em Alimentos.

[3]Content per kilogram of product: 215 g of Ca, 15 g of Co, 700 mg of Cu, 10 mg of Cr, 20 g of S, 600 mg of F, 40 mg of I, 20 g of Mg, 1,600 mg of Mn, 20 mg of Se, 70 g of Na, 200,000 IU of vitamin A, 50,000 IU of vitamin D_3, 1,500 IU of vitamin E, and 2,500 mg of Zn.

[4]Estimated according to NRC (2001).

Ruminal Fermentation

Rumen fluid samples were collected from cannulated cows on the last day of each period, before the morning feeding (0 h), and after 2, 4, 6, 8, 10, 12, 14, and 16 h. Digesta were collected from different sites within the rumen (dorso-cranial, ventral-cranial, ventral, caudo-ventral, and caudo-dorsal regions) and strained through 4 layers of cheesecloth to extract rumen fluid (250 mL). Rumen fluid pH was measured by a glass electrode and a reference electrode (MB-10, Marte Científica). Rumen fluid samples were centrifuged (2,000 × *g* for 15 min at room temperature) and 1.8 mL of the supernatant was pipetted into a centrifuge tube containing 400 μL of orthophosphoric acid solution (1 *N*) for short-chain fatty acids (**SCFA**) analysis. Peaks of SCFA were measured on a gas chromatograph (Shimadzu GC-2010 Plus) equipped with an automatic flame injector (AOC-20i, Stabilwax-DA 30 m capillary column, 0.25 mm i.d., 0.25 μm df; Restek) and a flame ionization detector, as described by Del Valle et al. (2018). Another aliquot from the supernatant (800 μL) was mixed with sulfuric acid solution (400 μL at 1 *N*) for NH_3-N determination using the phenol-hypochlorite method (Broderick and Kang, 1980) and absorbances were measured on microplate reader (Biochrom Asys, Biochrom).

Excretion of Purine Derivatives and Nitrogen

Rumen microbial protein supply was predicted based on the excretion of purine derivatives (**PD**) in urine (uric acid and allantoin) and milk (allantoin) according to Chen and Gomes (1992). Urine samples (20 mL) were collected by stimulation of urinating at the same time points as feces. Urine samples were diluted (1:4 ratio) into a sulfuric acid solution at 0.036 *N* (Chen and Gomes, 1992) to preserve PD. Samples were stored frozen for total nitrogen, allantoin, uric acid, and creatinine analyses. Daily urine volume was estimated considering a daily creatinine excretion of 24.05 mg/kg BW (Chizzotti et al., 2008). Body weights were measured at the start of experiment and at the end of each experimental period for 2 consecutive days (d 20 and 21), always before the morning feeding (after milking) using an electronic livestock scale for large animals. Urine creatinine concentration was assessed using commercial kits (kinetic creatinine catalog no. K-067, Bioclin) and absorbances measured on a spectrophotometer (SBA-200, Celm). Allantoin concentrations in urine and milk were assessed according to Fujihara et al. (1987). Uric acid concentration in urine was analyzed using a commercial kit (uric acid stable liquid: catalog no. K-052, Bioclin).

Total PD was calculated as the sum of allantoin and uric acid excreted in milk and urine (Boero et al., 2001). The absorbed PD was calculated according to Gonzalez-Ronquillo et al. (2003). Predicted microbial protein was estimated according to Chen and Gomes (1992) as follows:

$$\text{Absorbed PD (mmol/d)} = \left[\text{total PD} - \left(0.512 \times \text{BW}^{0.75}\right)\right] / 0.70,$$

$$\text{Predicted microbial protein (kg/d)} = 6.25 \times [(\text{absorbed PD} \times 70) \div (0.134 \times 0.83 \times 1{,}000)]/1{,}000.$$

Nitrogen intake was calculated dividing the CP intake by 6.25 and nitrogen in milk was calculated dividing milk protein yield by 6.38. Nitrogen in feces and urine samples were determined (Kjeldahl method 984.13) according to AOAC International (2000).

Serum Urea-N and Milk Yield and Composition

Blood samples were collected on d 16 of each period, 4 h after the morning feeding in vacuum tubes (10 mL) by puncture of coccygeal veins. After clotting, blood samples were centrifuged (2,000 × *g* at room temperature for 15 min) and serum was harvested and stored frozen for urea analyses. Blood urea was measured using colorimetric commercial kits (Bioclin) and absorbances were measured on a biochemistry analyzer (SBA-200, Celm). Blood urea-N was calculated multiplying the urea concentration by 0.4667. Cows were milked twice daily (0600 and 1700 h), and milk production was electronically recorded (Alpro, DeLaval). Data from the last 7 d of milk yield were used for statistical analysis. Milk samples (300 mL) were collected for 3 consecutive days during each experimental period to assess concentrations of protein, fat, and lactose using mid-infrared method (Lactoscan, Entelbra). 3.5% Fat-corrected milk was calculated according to Sklan et al. (1992): 3.5% FCM = (0.432 + 0.165 × milk fat) × milk yield (kg/d). Milk samples were deproteinized with trichloroacetic acid solution (25%; 2:1 vol/vol; Shahani and Sommer, 1951) and stored at −20°C for allantoin and MUN analyses. Milk urea nitrogen was determined using commercial kits (catalog no. K-082, Bioclin).

Statistical Analysis

Data were submitted to ANOVA using the PROC MIXED procedure of SAS 9.4 (SAS Institute Inc.) according to the following model:

Table 3. Nutrient intake, sorting index, and total-tract apparent digestibility of mid-lactation cows fed dry malt extract replacing ground corn in diet (n = 28)

	Treatment[1]			
Item	CON	DME	SEM	*P*-value
Intake (kg/d)				
DM	27.5	27.8	0.88	0.473
OM	25.5	25.8	0.81	0.483
CP	4.79	4.84	0.152	0.521
NDF	8.78	8.99	0.294	0.174
Intake (% BW)				
DM	4.03	4.05	0.138	0.814
NDF	1.29	1.32	0.047	0.176
Sorting index[2]				
>19 mm	0.986	0.988	0.008	0.780
19–8 mm	0.975	0.973	0.004	0.799
8–4 mm	1.01	1.02	0.003	0.771
<4 mm	1.03	1.03	0.007	0.659
Total-tract apparent digestibility (%)				
DM	63.4	63.8	0.85	0.572
OM	65.6	66.1	1.00	0.672
CP	63.7	64.6	1.18	0.048
NDF	39.4	39.2	1.64	0.914

[1]Control (CON) or dry malt extract from barley (DME; Liotécnica Tecnologia em Alimentos) partially replacing ground corn at 7.62% diet DM.

[2]No sorting = 1, values <1 indicates sorting against, and values >1 indicates sorting for particles in the particular particle size range. Sorting index was calculated according to Silveira et al. (2007).

$$y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + e_{ijk},$$

where y_{ijk} represents the observation on animal k given treatment i at period j; μ is the overall mean; α_i represents the fixed effect of the ith treatment ($i = 1$ to 2); β_j represents the fixed effect of the jth period ($j = 1$ to 2); γ_k represents the random effect of animal ($k = 1$ to 28); and e_{ijk} represents the random error associated with each observation. Fermentation data were analyzed as repeated measures adding the fixed effects of time and its interaction with treatment to the previous model. For the repeated measurements analyses autoregressive covariance matrices were tested and chosen according to the Bayesian information criterion values. Means were adjusted by LSMEANS and degrees of freedom were calculated by the Kenward and Roger (1997) method. The significance level was set at $P \leq 0.05$.

RESULTS

No treatment effect ($P \geq 0.174$) on DMI (either as kg/d or % BW), nutrient intake, or feed sorting was observed in this study (Table 3). Cows fed DME had greater ($P \leq 0.048$) CP and ether extract digestibility in comparison with CON. Feeding DME increased ($P \leq 0.017$) ruminal pH (Figure 1) and molar percentage of acetate and decreased molar percentage of butyrate and valerate (Table 4). No interaction effects between treatment and time were detected for ruminal fermentation variables. Treatments neither affected the excretion of PD nor the excretion of nitrogen, but cows fed DME had lower ($P < 0.001$) BW than CON (Table 5). Cows fed DME had lower ($P = 0.003$) serum urea-N concentration in comparison with counterparts (Table 6). Feeding DME increased ($P \leq 0.026$) yields of milk, FCM, fat, protein, and lactose as well as the feed efficiency in terms of FCM (FCM ÷ DMI). Replacing ground corn with DME reduced ($P = 0.038$) MUN concentration.

DISCUSSION

We hypothesized that partially replacing ground corn with DME in corn silage-based diets would improve performance of mid-lactation cows by altering ruminal fermentation and nutrient digestion. Indeed, cows fed DME produced 1.2 kg/d more milk than counterparts and presented greater CP digestibility and different molar percentage of SCFA in ruminal fluid. Although differences in CP digestibility may partially explain the greater milk yield of cows fed DME, changes in ruminal fermentation are likely the main reason for milk yield outcomes. To the best of our knowledge, this is the first study investigating the effects of DME inclusion on ruminal fermentation of lactating cows. Feeding DME increased ruminal fluid pH and acetate molar percentage. During the malting process of barley, starch is released

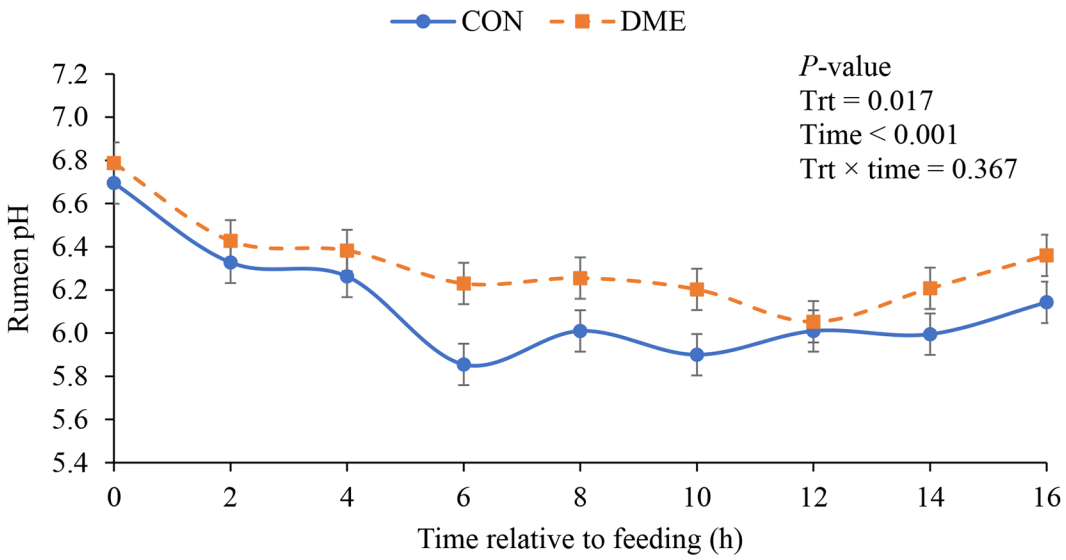

Figure 1. Ruminal pH of mid-lactation (n = 4) cows fed dry malt extract replacing ground corn in diet. Control (CON) or dry malt extract from barley (DME; Liotécnica Tecnologia em Alimentos) partially replacing ground corn at 7.62% diet DM. Trt = treatment. Error bars are SEM.

from binding components and extensively degraded by several starch-degrading enzymes into sugars that could be easily fermented by yeasts (Yu et al., 2020). Because of the relative rapid fermentation of sugar over other carbohydrate fractions, rumen pH is expected to be lower in cows fed DME. However, agreeing with the current study, authors observed an increase or a trend for increased rumen pH with the partial replacement of dietary starch sources with sugars (Heldt et al., 1999; Penner and Oba, 2009; Penner et al., 2009). A higher rumen pH likely favored rumen fiber degradation, thus increasing acetate molar percentage and supporting milk fat results. Possible reasons by which feeding sugar in place of starch may increase ruminal pH include less acid produced per mole of hexose fermented and storage of glucose as microbial glycogen (Oba, 2011). In the current study, cows fed DME had lower rumen butyrate molar percentage in comparison with CON. The effects of feeding sugar on rumen fermentation have been inconsistent; the ruminal molar proportion of butyrate was not affected (Broderick et al., 2008; Penner and Oba, 2009), increased (Kellogg and Owen, 1969a,b), or decreased (McCormick et al., 2001) by partial replacement of starch sources with sugar. We need to stress that fermentation results of the current study should be interpreted carefully because ruminal fluid samples

Table 4. Ruminal fermentation of mid-lactation cows fed dry malt extract replacing ground corn in diet (n = 4)

	Treatment[1]			*P*-value[2]		
Item	CON	DME	SEM	Trt	Time	Trt × time
pH	6.13	6.32	0.057	0.017	<0.001	0.367
NH_3-N (mg/dL)	13.4	13.9	1.67	0.750	<0.001	0.488
Short-chain fatty acid (%)						
Acetate	64.0	65.3	0.46	<0.001	<0.001	0.457
Propionate	19.0	19.2	0.16	0.347	<0.001	0.309
Butyrate	13.4	11.9	0.39	0.003	0.084	0.247
Iso-valerate	1.43	1.48	0.124	0.201	<0.001	0.430
Valerate	1.52	1.28	0.055	0.002	<0.001	0.353
Iso-butyrate	0.679	0.799	0.0372	0.055	<0.001	0.513
Branched-chain fatty acids	3.63	3.56	0.136	0.395	<0.001	0.120
Acetate-to-propionate ratio	3.39	3.43	0.038	0.453	<0.001	0.370
Total short-chain fatty acids (m*M*)	96.4	96.4	0.136	0.395	<0.001	0.120

[1]Control (CON) or dry malt extract from barley (DME; Liotécnica Tecnologia em Alimentos) partially replacing ground corn at 7.62% diet DM.
[2]Trt = treatment.

Table 5. Purine derivative excretion, predicted rumen microbial protein supply, and N excretion of mid-lactation cows fed dry malt extract replacing ground corn in diet (n = 28)

Item	Treatment[1]		SEM	*P*-value
	CON	DME		
BW (kg)	695	687	15.6	<0.001
Excretion (mmol/d)				
Urine allantoin	206	218	18.8	0.504
Urine uric acid	184	190	17.0	0.747
Milk allantoin	35.8	33.8	4.81	0.768
Total purine derivatives	425	442	31.5	0.625
Predicted rumen microbial protein supply[2] (kg/d)	1.97	2.04	0.147	0.632
N excretion (g/g N intake)				
Feces	0.370	0.357	0.0111	0.360
Milk	0.226	0.230	0.0082	0.259
Urine	0.268	0.253	0.0153	0.362

[1]Control (CON) or dry malt extract from barley (DME; Liotécnica Tecnologia em Alimentos) partially replacing ground corn at 7.62% diet DM.

[2]Estimated according to Chen and Gomes (1992).

were collected only in one day and fluctuations in DMI during the last days before the collection might have influenced results of pH and SCFA molar percentages.

Although DME altered ruminal fermentation, no treatment differences were detected for PD excretion and predicted rumen microbial protein supply. Dietary sugar may not affect microbial protein production if it dilutes dietary starch. Microbial protein production decreased (Hall and Herejk, 2001) or was not affected (Vallimont et al., 2004) when sucrose replaced starch. The reasons for higher CP digestibility when feeding DME are unclear but might be related to CP content and profile in dietary treatments; DME diet had lower contents of CP (−0.50%) and neutral detergent insoluble CP (−0.25%) in comparison with the CON diet. Differences in prolamin profile and CP degradation of DME and ground corn might have also influenced CP digestibility. Hordein (a type of prolamin) proteins are significantly reduced (~30%) during the malting process (Briggs, 1998), and thus proteins from DME are expected to be more degradable than those in ground corn. Ground corn zein proteins comprise 50 to 60% of corn CP and have relatively low degradability in rumen because of their hydrophobicity (Hamaker et al., 1995). Despite the greater CP digestibility observed for DME-fed cows, serum urea-N and MUN were decreased due to greater N excretion in milk in comparison with CON. It is worth mentioning that no differences in ruminal NH_3-N concentration were observed in this study. In the current study, the total N excreted was lower than the N consumed, raising the question of the N fate. In an extensive review, Hristov et al. (2019) discussed the potential N losses during sampling of feces and urine and using different techniques in addition to listing other N losses including those in expiration, eructation, or dermal losses. Furthermore, ruminants are able to regulate urea-N recycling to conserve N to maintain ruminal microbial protein synthesis and catabolic processes in the animal (Lapierre and Lobley, 2001). Authors have reported that ammonia losses from urine is the largest potential source of errors in measurements of N balance in ruminants (Spanghero and Kowalski, 1997). Furthermore, both daily fecal and urinary outputs were estimated based on markers (i.e., no total collection was carried out), which directly affect N excretion results.

Table 6. Serum urea-N concentration and milk yield and composition of mid-lactation cows fed dry malt extract replacing ground corn in diet (n = 28)

Item	Treatment[1]		SEM	*P*-value
	CON	DME		
Serum urea-N (mg/dL)	20.2	17.1	0.77	0.003
Yield (kg/d)				
Milk	34.4	35.6	1.17	0.003
3.5% FCM	35.5	37.5	1.03	0.001
Fat	1.26	1.35	0.039	0.004
Protein	1.09	1.13	0.034	0.026
Lactose	1.64	1.70	0.052	0.019
Composition (%)				
Fat	3.71	3.85	0.112	0.121
Protein	3.17	3.15	0.019	0.233
Lactose	4.77	4.75	0.028	0.445
MUN (mg/dL)	18.7	17.3	0.533	0.038
Efficiency				
Milk yield ÷ DMI	1.28	1.31	0.051	0.119
FCM ÷ DMI	1.31	1.37	0.043	0.015

[1]Control (CON) or dry malt extract from barley (DME; Liotécnica Tecnologia em Alimentos) partially replacing ground corn at 7.62% diet DM.

Dry malt extract partially replacing ground corn in diets improved yield of actual milk, FCM, and solids. Contrasting with the current study, Biagi et al. (2007) fed transition cows with malt extracts (at 7% diet DM)

partially replacing ground corn and barley and did not detect treatment differences for milk yield and composition until 120 DIM. Although data are lacking in the literature on feeding malt extract and its effects on performance of dairy cows, sugar supplementation has been extensively evaluated. Research data (23 scientific papers and 97 observations) of sugar dietary supplementation evaluated by nonlinear statistical analysis suggest that the optimal total dietary sugar is 6.75% diet DM, whereas optimum 3.5% FCM yield response was achieved when combining moderate starch diets (22–27% diet DM) and high soluble fiber (6.0 to 8.5% diet DM; de Ondarza et al., 2017). In line with the latter study, DME diet had starch content within the range for optimal FCM response to sugar supplementation. Improved milk yield of cows fed DME in this study is likely associated with its positive effects in ruminal fiber degradation and fermentation. The greater FCM yield of cows fed DME aligns with increased acetate proportion in rumen fluid when compared with CON. It is noteworthy that studies regarding sugar supplementation on productivity and ruminal fermentation cited earlier, used either molasses or sucrose as sugar sources and DME is mainly composed of maltose. We are not aware of studies with dairy cows, other than Biagi et al. (2007), that have evaluated the effects of maltose sources on performance. Finally, we also need to highlight that despite DME hygroscopic behavior, cows did not sort feed particles during this experiment. Because of its high hygroscopic behavior, DME had to be weighed and mixed into the concentrate immediately after packages were opened, which may hinder ration mixing. Less hygroscopic formulations should be developed and tested for dairy cattle. The costs of replacing ground corn with DME should be considered in diet formulations.

CONCLUSIONS

Dry malt extract can replace ground corn in corn silage-based diets at 7% DM with increments in yields of actual milk and FCM without altering nutrient intake. Dry malt extract increased ruminal pH and feed efficiency and reduced MUN. Further studies should be performed to evaluate doses and economics of feeding DME, as well as on handling difficulties.

ACKNOWLEDGMENTS

The authors thank Liotécnica Tecnologia em Alimentos (Embu das Artes, Brazil) for partially funding this study. The authors have not stated any conflicts of interest.

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