Faba bean (*Vicia faba*) inclusion in dairy cow diets: Effect on nutrient digestion, rumen fermentation, nitrogen utilization, methane production, and milk performance

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ABSTRACT

The objective of this study was to determine the effect of replacing on isonitrogenous and isoenergetic basis soybean meal (SBM) and corn grain with ground or rolled faba bean (FB; *Vicia faba* major var. Baie-Saint-Paul) in dairy cow diets (17% of diet dry matter) on nutrient digestion, rumen fermentation, N utilization, methane production, and milk performance. For this purpose, 9 lactating cows were used in a replicated 3 × 3 Latin square design (35-d period) and fed (ad libitum) a total mixed ration (forage:concentrate ratio = 59:41 on a dry matter basis). In the concentrate portion, SBM and corn grain (control diet) were completely and partially replaced, respectively, with either ground or rolled FB. Ruminal degradability (in sacco) of crude protein was higher for ground FB (79.4%) compared with SBM (53.3%) and rolled FB (53.2%). Including FB in the diet did not affect dry matter intake, milk production, and milk composition. Experimental treatment had no effect on total volatile fatty acid concentration, acetate-to-propionate ratio, and protozoa numbers. Compared with cows fed the control diet, ruminal NH₃ concentration increased and tended to increase for cows fed ground FB and rolled FB, respectively; however, we found no difference in ruminal NH₃ concentration between the 2 processed FB. Apparent total-tract digestibility of crude protein was similar between cows fed the control diet and cows fed rolled FB and tended to increase for cows fed ground FB compared with cows fed the control diet. Feeding rolled FB decreased CP digestibility compared with feeding ground FB. Urinary and manure (feces + urine) N excretion (g/d or as a proportion of N intake) were not affected by the inclusion of FB in the diet. Enteric

CH₄ production was similar among the experimental diets. Results from this study show that including FB (17% of dietary dry matter) at the expense of SBM and corn grain in the diet had no effect on milk production, N excretion, and enteric CH₄ production of dairy cows.

Key words: faba bean, dairy cow, N utilization, enteric methane

INTRODUCTION

Soybean meal (SBM) is the main protein source in the diet of high-producing dairy cows due to its relatively high CP and RUP concentrations and balanced AA composition. Still, demands for alternatives to SBM are increasing to reduce feeding costs and enhance farm profits. In this regard, due to their relatively high CP and starch contents (Petit et al., 1997; White et al., 2007; Crépon et al., 2010), legume seeds may represent a good alternative to SBM (as a protein source) and cereal grains (as an energy source) in dairy cow nutrition.

Faba bean (*Vicia faba*; FB) is a valuable protein source (25 to 33% CP; Yu, 2005; Larsen et al., 2009; Crépon et al., 2010) and can be a practical alternative to SBM in the diet of high-producing dairy cows. Similar to other legume seeds, ruminal solubility and degradability of CP of FB is higher than CP of SBM (Rotger et al., 2006; Zagorakis et al., 2015). Accordingly, several heat-treatment methods (e.g., extrusion, micronization) have been commonly applied to legume seeds (e.g., FB, lupin seeds) to decrease extent of CP degradation in the rumen (Aguilera et al., 1992; Benchaar et al., 1992; Goelema et al., 1999).

Faba bean also contains a substantial amount of starch (32 to 44%; Yu, 2005; Larsen et al., 2009; Crépon et al., 2010), which makes FB an excellent source of energy, thereby reducing the need for use of costly cereal grains (e.g., corn) in dairy cow diets. The inclusion of FB in dairy cow diets can increase starch supply, which would shift ruminal fermentation toward more propionogenesis and less methanogenesis given the inverse relation-

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ship between propionate formation and CH₄ synthesis in the rumen. To the best of our knowledge, no study has been yet conducted on the effects of including FB in dairy cow diets on enteric CH₄ emissions.

Ruminal degradability of feeds is largely affected by their particle size. Previous studies showed that particle size can greatly affect feed (protein or starch sources) degradability in the rumen, nutrient availability, and, consequently, milk performance (Dhiman et al., 1997; Yang et al., 2000). No information is available on the effects of particle size of FB on ruminal fermentation characteristics, nutrient digestibility and milk performance.

We hypothesized that replacing on isonitrogenous and isoenergetic basis SBM with ground or rolled FB in dairy cow diets would (1) result in similar performance (DMI and milk production) without affecting enteric CH₄ production, and (2) the type of FB processing (i.e., ground or rolled) would influence ruminal N metabolism and consequently, N excretion. Thus, the objective of our study was to determine the effects of replacing SBM with ground or rolled FB in the diet of lactating cows on digestion, ruminal fermentation, N utilization, milk performance (production and composition), and enteric CH₄ emissions.

MATERIALS AND METHODS

The study was conducted at the Sherbrooke Research and Development Centre, (Sherbrooke, Quebec, Canada). Animal procedures were conducted under the approval of the local Institutional Animal Care Committee and were in accordance with the guidelines of the Canadian Council on Animal Care (2009).

Cows, Experimental Design, and Diets

Nine multiparous (2.9 ± 0.9 parity; mean $\pm$ SD) lactating Holstein cows fitted with rumen cannula (10 cm, Bar Diamond Inc., Parma, ID) were used in a replicated 3×3 Latin square design (35-d period). The cows averaged 121 ± 28 DIM at the start of the experiment with an average BW of 660 ± 47 kg and milk yield of 41 ± 5.6 kg/d. During the experiment, cows were housed in individual tiestalls and had free access to water. Cows were fed ad libitum (5% orts, on an as-fed basis) a TMR consisting (DM basis) of 59% forages (20.2% corn silage, 35.4% alfalfa silage, and 3.5% timothy hay) and 41% concentrate. Soybean meal and corn grain (control diet) were completely and partially replaced (17% of diet DM), respectively, with either rolled or ground FB (*Vicia faba* major var. Baie-Saint-Paul). The diets (Table 1) were formulated to be isonitrogenous (CP = 16%) and isoenergetic (NE_L =

1.50 Mcal/kg of DM) and meet nutrient requirements of the cows (NRC, 2001). Chemical composition of FB, SBM, and corn grain are shown in Table 2.

Rolled FB was processed using a roller mill (Buhler Y180; Buhler industry, Winnipeg, Manitoba, Canada), whereas ground FB was processed using a hammer mill (Omega 4e, Milpro, Saint-Hyacinthe, Quebec, Canada). Rolled and ground FB were screened through 5 sieves and percentage of particles retained in each sieve was determined. Distribution of rolled FB particles retained in 4.75-, 2.00-, 1.00-, 0.50-, and 0.10-mm sieves was 0, 70.0, 20.0, 5.4, and 3.7%, respectively. Distribution of ground FB particles retained in 4.75-, 2.00-, 1.00-, 0.50-, and 0.10-mm sieves was 0, 0.4, 22.0, 34.3, and 29.1%, respectively. Geometrical mean size was calculated according to the ASABE (2017) and was 0.60 mm for ground FB and 3.03 mm for rolled FB.

After 14 d of adaptation to dietary treatments, feed intake, apparent total-tract digestibility, N excretion, milk production, milk composition (i.e., 7 d), in sacco ruminal degradability (i.e., 4 d), rumen fermentation characteristics (i.e., 2 d), BW (i.e., 3 d), and CH₄ production (i.e., 5 d) were measured. Because only 2 air flow-controlled chambers were available, cows were staggered by 5 d to facilitate measurements. In addition, measurements (i.e., digestibility, N excretion, rumen fermentation, in sacco ruminal degradability, and CH₄) were spread over the 21 d of sampling and data collection.

Intake, Apparent Total-Tract Digestibility, N Excretion, and BW

Diets were offered in equal amounts twice daily (0900 and 1930 h). Feed consumption was recorded daily by weighing feeds offered to and refused by the cows and data collected during the determination (7 consecutive days) of apparent-total digestibility and N excretion (Benchaar et al., 2013) were included in the statistical analyses. Samples of the experimental diets, feed ingredients, and refusals were collected daily and stored at -20°C . These samples were later thawed, composited by cow within period, freeze-dried, ground to pass a 1-mm screen using a Wiley mill (standard model 4; Arthur M. Thomas, Philadelphia, PA), and analyzed for DM, OM, total N, NDF, ADF, starch, ether extract (EE), and gross energy (GE). Faba bean was further analyzed for soluble N, NDIN, ADIN, and total tannins. Total collection of feces and urine was performed as described in Benchaar et al. (2013) by fitting cows with harnesses and tubes allowing the collection of feces and urine separately. Feces were analyzed for DM, OM, total N, NDF, ADF, starch, and GE. Urine was analyzed for total N content. Cows were weighed at the

Table 1. Ingredient and chemical composition of the experimental diets

Item (% of DM, unless otherwise noted)	Diets		
	Control	Ground FB ¹	Rolled FB
Ingredient			
Alfalfa silage	35.4	35.3	35.3
Corn silage	20.2	20.2	20.2
Corn grain, ground	24.0	16.2	16.2
Soybean meal, 48% solvent-extracted	9.2	0	0
Ground FB	0	17.1	0
Rolled FB	0	0	17.1
Beet pulp, dehydrated	3.73	3.72	3.72
Timothy hay, chopped	3.50	3.50	3.50
Corn gluten feed	1.88	1.87	1.87
Mineral and vitamin supplement ²	1.65	1.65	1.65
Calcium carbonate	0.51	0.51	0.51
Chemical composition			
OM	93.2	93.2	93.3
CP	16.0	16.1	15.9
NDF	27.8	28.2	29.0
ADF	19.2	19.7	20.4
Starch	25.3	25.0	24.7
Ether extract	2.58	2.55	2.52
Gross energy (Mcal/kg of DM)	4.39	4.39	4.38
NE _L ³	1.51	1.49	1.49

¹FB = faba bean.

²Contained 9.27% Ca, 4.80% P, 4.80% Mg, 1.57% S, 12.68% Na, 1.23% K, 23 mg/kg I, 2,014 mg/kg Fe, 440 mg/kg Cu, 1,797 mg/kg Mn, 2,657 mg/kg Zn, 7 mg/kg Co, 467,556 IU/kg vitamin A, 56,669 IU/kg vitamin D, 2,739 IU/kg vitamin E, and 20 mg/kg Se.

³Calculated using values from NRC (2001) tables.

beginning and end of each experimental period on 3 consecutive days before and after the morning milking.

In Sacco Ruminal Degradability

Ruminal degradability of SBM, rolled FB, and ground FB was determined over 4 consecutive days (Benchaar et al., 2013) on 6 (i.e., 2 Latin squares) of the 9 cows (i.e., 3 Latin squares) used in the experiment. Soybean meal was ground to pass a 2-mm screen using a Wiley mill, whereas ground and rolled faba bean were left

intact. Samples (5 g of DM) were weighed in quadruplicates in polyester bags (17 × 9 cm; 53-μm pore size) made of monofilament PeCAP Polyester (Sefar Nitex, Sefar AG, Heiden, Switzerland). Bags were incubated in the ventral sac of the rumen for 2, 4, 8, 16, 24, 48, and 72 h. Bags used for time 0 disappearance were soaked in water at 37°C for 5 min and then treated similar to the other bags. Residues were dried at 55°C for 48 h, ground to pass through a 1-mm screen, and stored for subsequent analysis of total N for the determination of ruminal CP degradability.

Table 2. Chemical composition of faba bean, soybean meal, and corn grain

Item	Ingredient		
	Faba bean	Soybean meal	Corn grain
OM (% of DM)	96.2	93.3	98.7
CP (% of DM)	30.16	52.03	8.17
Soluble N (% of total N)	60.8	18.8	10.9
NDIN (% of total N)	8.65	3.29	9.18
ADIN (% of total N)	0.59	1.47	3.25
Total tannins (% of DM)	0.42	ND ¹	ND
NDF (% of DM)	13.90	6.83	6.88
ADF (% of DM)	11.30	5.29	2.04
Starch (% of DM)	30.70	0.59	70.16
Ether extract (% of DM)	1.18	1.10	5.21
Gross energy (Mcal/kg of DM)	4.38	4.65	4.37

¹Not determined.

Kinetics of ruminal degradation of DM and CP of SBM, rolled FB, and ground FB were calculated using a nonlinear model of (McDonald, 1981). The NLIN procedure of SAS (SAS Institute Inc., Cary, NC) was used to fit the model

$$P = a + b[1 - e^{-c(t-L)}] \text{ for } t > L;$$

$$P = a \text{ for } t \leq L,$$

where P = percentage of nutrient (DM or CP) disappearance from the nylon bag at time t ; a = soluble and rapidly degradable fraction (%); b = slowly degradable fraction (%); c = fractional rate of disappearance of the fraction b (/h); L = lag time (h); and t = time of incubation (h). The model was fitted using ($a + b$) ≤ 100 , $b \geq 0$, $c \geq 0$, and $L \geq 0$ constraints.

The effective ruminal degradability (ERD) of DM and CP was calculated as

$$\text{ERD} = a + [bc/(c + k_p)] \times e^{(-k_p L)},$$

where k_p is the ruminal fractional passage rate, calculated from the equations suggested by the NRC (2001) for concentrates.

Ruminal Fermentation Characteristics and Protozoa Enumeration

Ruminal content was collected from each cow on 2 successive days for the determination of fermentation characteristics (pH, VFA, and NH_3) and protozoa population. For fermentation characteristics, ruminal fluid was collected before (0 h) and at 1, 2, 4, 6, and 8 h after the morning feeding, as described in Benchaar et al. (2013). A total of 250 mL was collected from several locations within the rumen using a 50-mL syringe screwed to a stainless tube ending with a probe covered by a fine metal mesh (RT Rumen Fluid Collection Tube, Bar Diamond Inc.). Ruminal fluid pH was measured immediately after sampling (Accumet pH meter; Fisher Scientific, Montreal, QC, Canada). Ruminal fluid was subsampled (15 mL) and frozen at -20°C immediately for later determination of VFA concentrations. Another subsample (15 mL) was acidified to pH 2 with 50% sulfuric acid and frozen at -20°C for later determination of NH_3 concentrations.

Protozoa were counted in ruminal content collected 4 h after the morning feeding, as described in Benchaar et al. (2013). Ruminal content (approximately 1 L) was strained through 4 layers of cheesecloth and a 5-mL portion of the strained ruminal fluid was preserved using 5 mL of methyl green formalin-saline solution

for protozoa enumeration (Ogimoto and Imai, 1981). Protozoa samples were stored at room temperature in darkness until counting. Protozoa were microscopically enumerated using a counting chamber (Neubauer Improved Bright-Line counting cell, 0.1 mm depth; Hausser Scientific, Horsham, PA), and genera were identified as outlined by Dehority (1993).

Milk Production and Milk Composition

Cows were milked twice daily at 0700 and 1900 h in their stalls. Milk production was recorded at each milking and data from the 7-d collection period of feces and urine were included in the statistical analysis. Milk samples were taken from each cow at each milking, stored at 4°C with a preservative (2-bromo-2-nitropropan-1,3-diol), and sent to a commercial laboratory (Valacta Dairy Production Center of Expertise Quebec-Atlantic, Ste-Anne-de-Bellevue, QC, Canada) for analyses of fat, protein, lactose, MUN, and SCC.

Enteric Methane Production

Only 2 air flow-controlled chambers were available for measuring CH_4 emissions in our study, which limited the number of animals that could be examined simultaneously to 2 (i.e., 1 cow per chamber). Consequently, CH_4 determination had to be staggered by 5 d within the sampling and data collection period to facilitate measurements.

The chambers measured 4.09 m in length $\times$ 2.95 m in width $\times$ 2.84 m in height. When chambers doors were closed, air entered the chamber through a ventilation duct and exited through an exhaust. Air temperature within the chamber was maintained at $18 \pm 1^\circ\text{C}$. Air flow into and out of the chamber was measured using inline mass flowmeters (FT2; Fox Thermal Instruments Inc., Marina, CA) and maintained at $180 \pm 10 \text{ m}^3/\text{h}$. Methane concentration was continuously measured at the air entrance and exhaust ducts using CH_4 analyzers (Servopro 4100; Servomex, Brighton, East Sussex, UK). The amount of CH_4 (entering and leaving the chamber) was calculated by multiplying the concentration of CH_4 by the airflow (at entrance and at exhaust). The difference between the incoming and outgoing mass of CH_4 corresponded to the amount of enteric CH_4 emitted in each chamber by the animal. The chambers were calibrated at the beginning of each experimental period by releasing known amounts of CH_4 in each chamber (with no cow inside). The recovered amounts were calculated from the difference incoming and outgoing CH_4 . The recovered amounts ranged from 96 to 106%. The calibration factors (i.e., to adjust each chamber to 100%

recovery) were used to correct CH₄ emissions data. A small positive pressure was generated inside each chamber to prevent inflow of gases into the chambers. Methane was recorded every minute over 5 consecutive days and fluxes were averaged to derive 24-h CH₄ emissions. Cows were preconditioned to the environmental chambers before the beginning of the experiment. To reduce the effect of isolation on animal behavior, the chambers were equipped with windows and speakers so the cow in the chamber could see and hear other cows. Cows entered the chambers 18 h before starting CH₄ measurements. Within each chamber, the cow was kept in a tiestall that measured 1.82 m long × 1.60 m wide, elevated from the floor by 25 cm. Manure was collected from each cow in a stainless box placed below and to the rear of each stall. Farm personnel accessed the chambers twice daily (0800 and 2000 h) to feed and milk the cows and remove the manure. The doors were kept opened for a maximum of 1 to 1.5 min to allow exchange of material in and out of the chambers. This resulted in interruptions of flux measurements for 15 to 30 min, which is the time required for gas concentrations to reach steady state. These interruptions had little effect on daily emissions because fluxes were calculated every minute and used to derive the 24-h period emissions values. Cows in the chambers were milked twice daily, had free access to water, and were fed twice daily for ad libitum intake (5% orts on an as-fed basis). Offered feed and orts were weighed daily to determine feed consumption. Samples of feed offered and orts were collected, pooled across days, and kept frozen for later determination of DM and GE concentrations.

Chemical Analyses

Dry matter content was determined by drying samples in a vacuum oven at 100°C overnight (AOAC International, 2005; method 934.01). Ash content was determined by sample incineration at 550°C overnight in a muffle furnace (AOAC International, 2005; method 942.05), and the OM content was calculated as the difference between 100 and the percentage of ash. Crude protein (N × 6.25) was determined using the macro-Kjeldahl procedure (AOAC International, 2005; method 954.01). The concentration of NDF was determined as described by Van Soest et al. (1991) with the use of sodium sulfite and with the inclusion of heat-stable α -amylase. The ADF content was determined according to AOAC International (2005; method 973.18). The NDF and ADF procedures were adapted for use in an Ankom200 Fiber Analyzer (Ankom Technology Corp., Fairport, NY). The concentration of starch was determined colorimetrically according to the procedure

of AOAC International (2005; method 996.11). Ether extract was determined using the Soxtec 2050 extraction systems (Foss, Höganäs, Sweden) according to AOAC International (2005; method 920.39). Gross energy was determined using an oxygen bomb calorimeter (model 6200, Parr Instrument Company, Moline, IL). The concentration of N in acidified urine samples was determined by micro-Kjeldahl analysis (AOAC International, 2005). For FB, nitrogen fractions (soluble N, NDIN, and ADIN) were determined according to the procedure of Roe et al. (1990), whereas total tannin (tannic acid equivalent) concentration was measured according to the procedure of Makkar et al. (1993). Analysis of VFA was performed using a GC equipped with a flame ionization detector and auto-injector (6850 network GC system, Agilent Technologies, Mississauga, ON, Canada) fitted with DB-FFAP column (30 m × 0.250 mm × 0.25 μ m; Agilent technologies) as in Benchaar et al. (2015). Ammonia concentration was determined as in Weatherburn (1967). Protein, fat, lactose, urea N, and SCC in milk samples were analyzed by infrared spectroscopy (MilkoScan FT 6000; Foss Electric, Hillerød, Denmark). Milk composition was corrected for differences in milk yield between morning and evening milking.

Statistical Analyses

Data were analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC) and the statistical model included diet and period as fixed effects, whereas cow was considered as random effect. Ruminal fermentation characteristics (i.e., pH, VFA, NH₃) and protozoa data were analyzed as repeated measures using the same model with the addition of the fixed effects of day, sampling time (i.e., hour), and all interactions. The CH₄ data were also analyzed as repeated measures with the inclusion of the fixed effects of day and day × diet interaction. The appropriate covariance structure used for repeated-measures analyses was chosen according to the type of repeated measurement (single or double), sampling distance (equal or unequal), and to achieve lowest Akaike, corrected Akaike, and Bayesian information criteria values. The covariance structure used cow within treatment × period as subject of the repeated measures. In sacco ruminal degradability data were analyzed as a 3 × 3 Latin square design and the model included the fixed effects of protein source (FB and SBM), diet (control, rolled FB, ground FB), protein source × diet interaction, and period, whereas cow was random effect. Significant effects of diet were declared at $P \leq 0.05$ and tendencies at $0.05 < P \leq 0.10$ using the Tukey test for multiple comparisons.

Table 3. In sacco degradation kinetic parameters and degradability of DM and CP of soybean meal and ground and rolled faba bean (FB)

Item ¹	Protein source			SEM	Treatment <i>P</i> -value
	Soybean meal	Ground FB	Rolled FB		
DM					
<i>a</i> (%)	39.3 ^b	58.2 ^a	29.1 ^c	0.39	<0.01
<i>b</i> (%)	60.6 ^b	37.7 ^c	69.6 ^a	0.68	<0.01
<i>c</i> (/h)	0.068 ^a	0.058 ^{ab}	0.046 ^b	0.0056	<0.01
Lag time (h)	1.77	2.94	2.45	0.469	0.15
ERD (%)	64.9 ^b	71.1 ^a	51.6 ^c	0.54	<0.01
CP					
<i>a</i> (%)	21.8 ^c	67.2 ^a	28.5 ^b	0.45	<0.01
<i>b</i> (%)	78.2 ^a	32.6 ^c	71.5 ^b	0.45	<0.01
<i>c</i> (/h)	0.067 ^a	0.063 ^a	0.054 ^b	0.0036	<0.01
Lag time (h)	2.43	3.18	3.04	0.425	0.47
ERD (%)	53.3 ^b	79.4 ^a	53.2 ^b	0.57	<0.01

^{ac}Means within rows with different superscripts differ ($P < 0.05$).

¹*a* = soluble and rapidly degradable fraction; *b* = slowly degradable fraction; *c* = fractional rate of disappearance of the fraction *b*; ERD = effective ruminal degradability.

RESULTS

Chemical Composition

Faba bean was included in the diet at the expense of SBM and corn grain on an isonitrogenous and isoenergetic basis (Table 1). Consequently, the 3 experimental diets (control, ground FB, and rolled FB) contained similar concentrations of CP (16.0%) and NE_L concentrations (1.50 Mcal/kg of DM). Likewise, starch (25.0%), NDF (28.3%), ADF (19.8%), and EE (2.55%) concentrations were similar among the experimental diets.

Data of the chemical composition (DM basis) of FB, SBM, and corn grain are presented in Table 2. Compared with SBM, FB contained less CP (30.2 vs. 52.0%) but more NDF (13.9 vs. 6.83%) and ADF (11.30 vs. 5.29%). Characterization of N fractions (percentage of total N) showed that soluble N and NDIN were higher in FB than in SBM (60.8 vs. 18.8% and 8.65 vs. 3.29%; respectively), whereas ADIN was lower in FB than in SBM (0.59 vs. 1.47%). Starch concentration was lower in FB than in corn grain (30.7 vs. 70.2%). Concentration of total tannins in FB was 0.42% tannic acid equivalent.

In Sacco Ruminal Degradability

In sacco ruminal degradability (DM and CP) parameters of SBM, ground FB and rolled FB are presented in Table 3. For ruminal degradability of DM, the soluble and rapidly degradable fraction was higher ($P < 0.01$) for ground FB and lower ($P < 0.01$) for rolled FB compared with SBM (58.2, 29.1, and 39.3% for ground FB, rolled FB, and SBM, respectively). Inversely, the

insoluble and slowly degradable fraction was higher ($P < 0.01$) for rolled FB (69.6%) and lower ($P < 0.01$) for ground FB (37.7%) compared with SBM (60.6%). The fractional rate of disappearance of fraction *b* was lower ($P < 0.01$) for rolled FB (0.046/h) compared with SBM (0.068/h), but similar between ground FB (0.058/h) and SBM. As a consequence of these changes in parameters (i.e., fractions *a* and *b* of ruminal degradation of DM), the ERD of DM was higher ($P < 0.01$) for ground FB (71.1%) and lower for rolled FB (51.6%) compared with SBM (64.9%).

Comparison between the 2 processed FB revealed that the soluble and rapidly degradable fraction of DM was lower ($P < 0.01$) for rolled FB compared with ground FB. The opposite was observed for the slowly degradable fraction of DM ($P < 0.01$), whereas the fractional rate of disappearance of fraction *b* tended ($P = 0.07$) to be lower in rolled FB compared with ground FB. Effective ruminal degradability of DM was higher ($P < 0.01$) in ground FB (71.1%) compared with rolled FB (51.6%).

The soluble and rapidly degradable fraction of CP was higher ($P < 0.01$) for ground FB (67.2%) and rolled FB (28.5%) compared with SBM (21.8%). Inversely, the insoluble and slowly degradable fraction of CP was lower ($P < 0.01$) for ground and rolled FB compared with SBM. The fractional rate of disappearance of the CP fraction *b* was similar between SBM (0.067/h) and ground FB (0.063/h), but lower ($P < 0.01$) in rolled FB (0.054/h) than SBM. The ERD was higher ($P < 0.01$) for ground FB (79.4%) compared with SBM (53.3%) and was similar between SBM and rolled FB (53.2%).

Comparing the 2 processed FB showed that the soluble and rapidly degradable fraction of CP was lower (P

< 0.01) for rolled FB compared with ground FB. The opposite was observed for the CP slowly degradable fraction ($P < 0.01$). Fractional rate of disappearance of fraction b was lower ($P = 0.03$) in rolled FB compared with ground FB. Crude protein ERD was higher ($P < 0.01$) in ground FB compared with rolled FB.

Intake, Apparent Total-Tract Digestibility, and BW

Intake of DM (25.8 kg/d), OM (24.0 kg/d), CP (4.1 kg/d), NDF (7.2 kg/d), starch (6.5 kg/d), and GE (114 Mcal/d) were similar between the experimental diets (Table 4). Likewise, apparent total-tract digestibility of DM, OM, and GE averaged 68.8, 70.2, and 67.4%, respectively, and were not affected by dietary treatments (Table 4). Apparent total-tract digestibility of CP tended to be higher ($P = 0.09$) for cows fed ground FB compared with cows fed the control diet. In contrast, CP digestibility was not different for cows fed rolled FB versus cows fed the control diet. Total-tract digestibility of CP was higher ($P = 0.01$) for cows fed ground FB compared with cows fed rolled FB.

Fiber (NDF and ADF) digestibility was not different between cows fed the control diet and those fed the FB (ground or rolled). However, apparent total-tract digestibility of fiber was higher for cows fed rolled FB compared with those fed ground FB (43.5 vs. 40.6% and 42.6 vs. 39.0% for NDF and ADF digestibility, respectively). Apparent total-tract digestibility of starch was similar between cows fed the control diet and those fed ground FB. Starch digestibility was lower ($P < 0.01$) for cows fed rolled FB compared with those fed the control diet and ground FB. Feeding SBM, ground

FB, or rolled FB to cows had no effect on initial BW (684, 680, and 682 kg, respectively; $P = 0.63$), final BW (704, 698, and 701 kg, respectively; $P = 0.37$), or BW gain (0.57, 0.54, and 0.54 kg/d, respectively; $P = 0.98$).

Ruminal Fermentation Characteristics and Protozoa Population

Interactions between treatment and sampling time or sampling day for ruminal fermentation characteristics were not significant. Therefore, only averages of the 2-d measurements at the different sampling times are presented in Table 5.

For ruminal pH, the only change observed was between cows fed rolled FB and those fed the control diet (6.20 vs. 6.09; $P = 0.07$). Total VFA concentration averaged 121 mM and was not different among cows fed the experimental diets. Likewise, acetate molar proportion averaged 62.8 mol/100 mol and was not affected by dietary treatment.

Propionate molar proportion was not different between cows fed the control diet and cows fed ground FB (average of 21.9 mol/100 mol). The proportion of this VFA tended to decrease (20.4 vs. 22.0 mol/100 mol; $P = 0.08$) when cows were fed rolled FB compared with when fed the control diet. No difference in propionate proportion was observed between cows fed the 2 processed FB. Dietary treatment had no effect on the acetate-to-propionate ratio and molar proportions of butyrate and valerate, which averaged 3.04, 11.5 mol/100 mol, and 1.41 mol/100 mol, respectively. Compared with cows fed the control diet, ruminal NH_3 concentration increased ($P = 0.01$) and tended ($P = 0.06$)

Table 4. Intake and apparent total-tract digestibility of nutrients in lactating cows fed diets without (control) or with ground or rolled faba bean (FB)

Item	Diet			SEM	Treatment <i>P</i> -value
	Control	Ground FB	Rolled FB		
Intake (kg/d, unless otherwise noted)					
DM	25.7	25.6	26.0	1.20	0.79
OM	24.0	23.8	24.2	1.09	0.65
CP	4.13	4.11	4.15	0.19	0.89
NDF	7.10	7.15	7.42	0.374	0.23
ADF	4.89	5.00	5.22	0.277	0.14
Starch	6.59	6.40	6.48	0.277	0.46
Gross energy (Mcal/d)	114	114	114	0.6	0.93
Digestibility (%)					
DM	69.0	68.7	68.6	0.41	0.52
OM	70.6	70.1	70.0	0.40	0.24
CP	66.1 ^{ab}	67.4 ^a	65.6 ^b	0.83	0.02
NDF	41.5 ^{ab}	40.6 ^b	43.5 ^a	0.90	0.06
ADF	41.9 ^{ab}	39.0 ^b	42.6 ^a	1.42	0.05
Starch	97.1 ^a	97.9 ^a	95.3 ^b	0.49	<0.01
Gross energy	67.6	67.7	67.0	1.71	0.54

^{a,b}Means within rows with different superscripts differ ($P < 0.05$).

Table 5. Ruminal fermentation characteristics and protozoa count in ruminal fluid of lactating dairy cows fed diets without (control) or with ground or rolled faba bean (FB)

Item	Diet			SEM	Treatment <i>P</i> -value
	Control	Ground FB	Rolled FB		
pH	6.09	6.15	6.20	0.083	0.08
Total VFA (mM)	123	122	119	2.9	0.43
VFA profile (mol/100 mol)					
Acetate (A)	62.2	62.5	63.7	1.08	0.12
Propionate (P)	22.0	21.7	20.4	0.99	0.07
Butyrate	11.7	11.4	11.5	0.33	0.82
Valerate	1.41	1.40	1.41	0.040	0.96
Branched-chain VFA ¹	2.76	2.96	3.05	0.093	0.07
A:P ratio	2.94	2.97	3.21	0.172	0.12
NH ₃ (mM)	9.82 ^b	11.78 ^a	11.29 ^{ab}	0.442	0.01
Protozoa					
Total ($\times 10^5$ /mL)	4.10	4.20	4.71	0.435	0.27
Entodiniomorphs ($\times 10^5$ /mL)	4.04	4.15	4.67	0.432	0.26
Holotrichs ² ($\times 10^3$ /mL)	4.95	3.80	3.70	1.15	0.58

^{a,b}Means within rows with different superscripts differ ($P < 0.05$).

¹Branched-chain = isobutyrate + isovalerate.

²Holotrichs = isotrichs and dasytrichs.

to increase when cows were fed ground FB and rolled FB, respectively. However, we found no difference in ruminal NH₃ concentration between the 2 processed FB. A similar trend of treatment effect was also observed for ruminal molar proportion of branched-chain VFA. Ruminal protozoa populations (total, entodiniomorphs, holotrichs) were unaffected by dietary treatments.

Milk Production and Milk Composition

Dietary treatments had no effect on milk production (average of 36 kg/d) and milk composition (3.9, 3.4, and 4.5% for milk fat, protein, and lactose, on average, respectively), as shown in Table 6. Consequently, no effect of dietary treatments was observed on milk

fat (1.40 kg/d) and milk protein (1.23 kg/d) yields. Feed efficiency was similar (1.41 kg of milk/kg of DMI) between cows fed the 3 dietary treatments.

Nitrogen Utilization

As experimental diets were isonitrogenous (16% CP) and dietary inclusion of FB (ground or rolled) had no effect on DMI, N intake was similar between treatments and averaged 661 g/d (Table 7). Efficiency of N use for milk protein synthesis (milk N/N intake) tended to slightly decline when cows were fed ground FB ($P = 0.08$) or rolled FB ($P = 0.09$) compared with when fed the control diet. Efficiency of N use was similar between cows fed the 2 processed FB.

Table 6. Milk production and milk composition of lactating cows fed diets without (control) or with ground or rolled faba bean (FB)

Item	Diet			SEM	Treatment <i>P</i> -value
	Control	Ground FB	Rolled FB		
Milk production (kg/d)	36.5	35.8	36.0	0.82	0.37
Composition (%)					
Fat	3.92	3.90	3.90	0.144	0.95
Protein	3.42	3.40	3.39	0.076	0.17
Lactose	4.50	4.52	4.49	0.045	0.32
MUN (mg/dL)	11.5	11.6	11.7	0.69	0.88
SCC (log ₁₀ /mL)	4.84	4.84	4.89	0.138	0.77
Yield (kg/d)					
Fat	1.43	1.38	1.40	0.051	0.24
Protein	1.25	1.21	1.22	0.033	0.11
Lactose	1.64	1.62	1.62	0.045	0.56
Feed efficiency (milk/DMI)	1.43	1.40	1.39	0.054	0.13

Table 7. Nitrogen utilization in lactating cows fed diets without (control) or with ground or rolled faba bean (FB)

Item	Diet			SEM	Treatment <i>P</i> -value
	Control	Ground FB	Rolled FB		
Intake N (g/d)	661	658	664	30.6	0.89
Milk N					
g/d	196	189	191	5.2	0.11
% of N intake	29.7	28.8	28.9	0.62	0.05
Fecal N					
g/d	224 ^{ab}	215 ^b	228 ^a	14.1	0.03
% of N intake	33.9 ^{ab}	32.6 ^b	34.4 ^a	0.83	0.02
Urinary N					
g/d	230	232	232	9.7	0.97
% of N intake	34.9	35.2	35.1	0.67	0.93
Total N excretion					
g/d	454	447	461	23.1	0.43
% of N intake	68.7	67.8	69.4	0.90	0.35

^{a,b}Means within rows with different superscripts differ ($P < 0.05$).

The amount (g/d) of N excreted in feces was not different between cows fed FB (ground and rolled) and cows fed the control diet. However, feeding ground FB to cows decreased the amount of N excreted in feces compared with feeding rolled FB (215 vs. 228 g/d; $P = 0.03$). Fecal N proportional to N intake decreased ($P = 0.01$) and tended ($P = 0.09$) to decrease when cows were fed the ground FB versus rolled FB or the control diet, respectively (32.6 vs. 34.4 and 33.9%). No effect of the dietary treatments was observed on urinary N excretion (231 g/d, 35.1%, on average) or total daily N excretion (454 g/d, 68.6%, on average). Estimated N balance was not affected by dietary treatment and averaged 15 g/d, 2.2% of N intake.

Methane Production

No interaction between treatments and measurement days was observed for CH₄ emission variables. Therefore, only averages across measurement days were reported (Table 8). The amount of CH₄ emitted daily by cows averaged 539 g/d and was not affected by the experimental diet. Likewise, CH₄ production expressed

as DMI (20.9 g/kg), GE intake (6.30%), or milk yield (15.0 g/kg) was not affected by dietary treatments.

DISCUSSION

Chemical Composition of FB

The chemical composition of FB used in our study (30% CP; 31% starch; 14% NDF) is similar to what has been reported in previous studies (Goelema et al., 1999; Yu, 2005; Larsen et al., 2009). Faba bean is widely grown in the region of Saguenay-Lac-Saint-Jean in Quebec, Canada. Several cultivars adapted to climate conditions of the region are available for seed production including Minica, Metissa, Primo, and Baie-Saint-Paul (Pilote et al., 2017). Variation in chemical composition between FB cultivars has been reported to be small (Micek et al., 2015). Among these cultivars, the Baie-Saint-Paul cultivar is more widely grown in the region of Saguenay-Lac-Saint-Jean because it is most adapted to climate conditions and has the highest yield (6.3 t/ha) compared with other cultivars (Provencher, 1984; Pilote et al., 2017). For these reasons, the choice

Table 8. Enteric methane production of lactating cows fed diets without (control) or with ground or rolled faba bean (FB)

Item	Diet			SEM	Treatment <i>P</i> -value
	Control	Ground FB	Rolled FB		
g/d	539	533	544	31.1	0.74
g/kg of DMI	21.3	20.3	21.0	0.55	0.14
% GE intake ¹	6.44	6.13	6.33	0.168	0.14
g/kg of milk	14.8	15.0	15.2	0.73	0.58

¹GE = gross energy.

of the Baie-Saint-Paul cultivar for our study was the most appropriate to evaluate the potential use of FB in dairy cow diets.

The cultivar of FB used in the present study had black spotted flowers and contained 0.42% tannins (tannic acid equivalent). This is similar to tannins concentration in 10 FB cultivars (0.43–0.54%) grown in Alberta, Canada (Oomah et al., 2011), but lower than tannin concentration (1.03–2.10%) reported for colored-flowers (high tannins) cultivars (Makkar et al., 1997). Such a low tannin concentration (corresponds to 0.07% in the TMR on DM basis) has been shown to have no effect on feed intake, ruminal fermentation characteristics, nutrient digestion, and performance (Benchaar et al., 2008; Liu et al., 2013) of dairy cows.

Intake and Apparent Total-Tract Digestibility

In the present study, including FB (rolled or ground) had no effect on DMI. Because chemical composition (i.e., nutrient concentrations) was similar among the 3 experimental diets, intake of nutrients (OM, CP, NDF, ADF, starch, EE, and GE) was not affected by the inclusion of FB in the diet at the expense of SBM and corn grain. In other studies, replacing SBM with FB in the diet did not affect DMI of dairy cows (Ingalls et al., 1980; Volpelli et al., 2010; Tufarelli et al., 2012).

Digestibility of CP was similar between cows fed rolled FB and cows fed the control diet, which is in line with similar in sacco ruminal CP degradability between SBM and rolled FB. Digestibility of CP increased when cows were fed ground FB compared with when fed SBM and rolled FB. This increase was mainly due to smaller particle size and higher degradability of CP of ground FB compared with SBM and rolled FB. Reducing particle size of peas (Vander Pol et al., 2009) and raw soybean (Naves et al., 2016) via physical processing has also been reported to enhance CP digestibility. In contrast, Zagorakis et al. (2015) reported higher CP digestibility in rams fed SBM compared with those fed ground FB. In their study, FB contained more NDF (34.4%) compared with FB used in our study (13.9%), which may explain the discrepancy. Singh et al. (1995) observed no change in CP digestibility when cows were fed SBM compared with lupine seeds (35% CP, 17% NDF) with a similar particle size (90% of particles >2 mm) as the rolled FB used in the current study.

Starch digestibility was reduced when cows were fed the rolled FB diet compared with ground FB or the control diet. Compared with grinding, rolling of seeds results in more intact and less hydrolysable starch granules and, consequently, less available for digestion. This particle size effect has been observed with peas (Petit

et al., 1997; Vander Pol et al., 2009), barley (Zhao et al., 2016), and corn (Rémond et al., 2004).

Compared with feeding rolled FB, feeding ground FB caused a decrease in fiber (NDF and ADF) digestibility. A decline in total-tract fiber digestibility has been reported when cows were fed diets made with finely ground versus cracked corn grains (Knowlton et al., 1996) or when fed diets made with steam-flaked versus dry-rolled corn grains (Joy et al., 1997), which agrees with our findings. Fredin et al. (2015) showed that reducing corn grain particle size increased NDF passage rate from the rumen. Faster ruminal passage rates have been associated with decreased fiber digestibility (Fahey and Berger, 1988; Van Soest, 1994; Huhtanen et al., 2006). Such a finding may explain the lower fiber digestibility in cows fed ground FB compared with those fed rolled FB, as observed in our study. However, Vander Pol et al. (2009) reported higher NDF digestibility with ground versus rolled peas. The discrepancy between our findings and those of Vander Pol et al. (2009) may be due to the particle size of the processed legume seeds. In the study of Vander Pol et al. (2009), peas were coarsely ground and the particle size was 1.4 mm compared with 0.60 mm of ground FB used in our study.

Ruminal Fermentation Characteristics

Inclusion of FB (rolled or ground) caused an increase of ruminal NH_3 concentration. This change is consistent with the higher solubility of CP (i.e., in sacco) of FB compared with SBM and with the higher branched-chain VFA molar proportion in cows fed FB versus cows fed SBM. Rotger et al. (2006) reported that compared with CP of SBM, CP of FB is more soluble (60 vs. 16%) and degradable in the rumen (81 vs. 64%). Zagorakis et al. (2015) also observed higher solubility (56 vs. 30%) and ruminal degradability (88 vs. 66%) of CP of FB versus SBM. In agreement with our findings, Vander Pol et al. (2009) also reported increased ruminal NH_3 concentration when processed (rolled or ground) peas, another legume seed, replaced SBM and corn grain on an isonitrogenous and isoenergetic basis in the diet of dairy cows. In the current study, ruminal NH_3 concentration was not affected by FB processing, which is in agreement with results of Vander Pol et al. (2009), when cows were fed rolled peas compared with ground peas.

Inclusion of FB (rolled or ground) had no effect on the acetate-to-propionate ratio, which agrees with Ingalls et al. (1980), who reported no change in the acetate-to-propionate ratio when replacing SBM with FB in the diet of dairy cows. Replacing SBM with

rolled or ground peas in dairy cow diets did not change molar proportions of acetate and propionate (Vander Pol et al., 2009). It has been reported that starch of FB is more degradable (i.e., in sacco) in the rumen than starch of corn grain (Offner et al., 2003: 73 vs. 68%; Moharrery et al., 2014: 77 vs. 57%). Therefore, one would expect a shift in ruminal VFA pattern toward less acetate and more propionate when FB-based diets versus the control diet were fed to the cows. Such changes in VFA pattern did not occur in the present study because only 20% of total starch of diet was from FB.

Milk Production and Milk Composition

Milk yield and milk composition were not affected by the inclusion of FB (ground or rolled FB) in the diet, which was consistent with the lack of treatment effect on DMI, DM digestibility, and ruminal fermentation characteristics. Likewise, milk production was not affected when SBM was replaced with coarsely ground and rolled FB in dairy cow diets (Ingalls et al., 1980; Volpelli et al., 2010; Tufarelli et al., 2012). In contrast, Puhakka et al. (2016) reported decreases in milk, protein, and fat yields when rapeseed meal was replaced with ground and pelleted FB in dairy cow diets. In Puhakka et al. (2016) study, lower milk performance was due a decrease in DMI of cows fed FB versus rapeseed meal.

Nitrogen Utilization and Excretion

Milk N secretion (g/d) was not affected by the inclusion of FB (rolled or ground) in the diet. However, when expressed as a proportion of N intake, efficiency of N use for milk N secretion was slightly lower for cows fed FB (ground or rolled) versus cows fed SBM. Although this difference ($P = 0.09$) is too small (-3%) to have any biological significance, it may be related to the higher ruminal CP solubility of FB versus that of SBM, as reflected by the increase in ruminal NH_3 concentration for cows fed FB versus cows fed SBM. Vander Pol et al. (2008) reported similar efficiency of N use for milk N when ground peas replaced SBM and corn grain in the diet of dairy cows (24 vs. 26%, respectively). It is equally possible that the slight decrease in N efficiency was due to the difference in AA profile between FB and SBM. Indeed, proteins from FB contain 25 to 53% less methionine than SBM (Aguilera et al., 1992; Zebrowska et al., 1997; NRC, 2001), and methionine is one of the limiting AA for milk production (NRC, 2001). In our study, FB diets provided slightly less methionine (as a percentage of MP) compared with the SBM diet (2.03 vs. 2.14%; NRC, 2001). Improved milk N efficiency

has been reported when dietary supply of methionine increased (Noftsger and St-Pierre, 2003; Broderick and Muck, 2009; Wang et al., 2010).

Urinary N excretion (g/d or % N intake) was not affected by inclusion of FB (ground or rolled) in the diet, which is consistent with absence of a treatment effect on N intake and MUN concentration. The higher CP solubility of FB compared with SBM and the consequent increase in ruminal NH_3 concentration when FB was fed compared with SBM did not result into higher urinary N losses. Although ruminal NH_3 concentrations are well correlated with MUN and urinary N excretion, such an effect was not observed in the current study. Similarly, Vander Pol et al. (2009) reported an increase in ruminal NH_3 concentration when ground peas replaced SBM in the diet of dairy cows, but without changes in MUN or urinary N excretion. In other studies, dietary treatments that increased ruminal NH_3 concentration increased MUN and urinary N excretion (Benchaar et al., 2015; Broderick et al., 2015; Hassanat et al., 2017).

Enteric Methane Production

Enteric CH_4 emissions (g/d, g/kg of DMI, % GE intake, g/kg of milk) were not affected by inclusion of FB (ground or rolled) in the TMR. The average value of 15.0 g of CH_4 /kg of milk observed in our study is within the range of emissions reported in other studies (Aguerre et al., 2011; Chung et al., 2012; Benchaar et al., 2014; Hassanat et al., 2017). In the present study, the lack of effects of dietary treatments on CH_4 emissions is consistent with the absence of treatment effects on DMI, ruminal fermentation characteristics (i.e., acetate-to-propionate ratio, protozoa), and diet DM digestibility.

CONCLUSIONS

Results from this study show that replacing SBM and ground corn with 17% of FB (rolled or ground) in the diet had no effect on DMI, milk production, N excretion, and enteric CH_4 emissions. Results of this study revealed that that FB can substitute SBM and corn grain in the diet of dairy cows on an isonitrogenous and isoenergetic basis without adverse effects on intake, milk production, N excretion, and enteric CH_4 production.

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