Effects of Feeding Camelina (Seeds or Meal) on Milk Fatty Acid Composition and Butter Spreadability

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ABSTRACT

The nutritional and rheological properties of butter depend on the fatty acid composition of milk. Therefore, feeding oilseeds rich in unsaturated fatty acids is likely to affect butter properties. The aim of this trial was to examine to what extent feeding the linolenic acid-rich cruciferous plant camelina can affect the fatty acid composition of dairy products and the properties of butter. A control diet composed of 60% corn silage-based ration and completed with high-energy and nitrogenous concentrates was compared with 2 experimental diets designed to provide the same amount of polyunsaturated fatty acids via either camelina seed (630 g/d, CS diet) or camelina meal (2 kg/d, CM diet). The diets were isoenergetic and isonitrogenous. The trial followed a double 3 × 3 Latin-square design with 4-wk periods on 6 Holstein dairy cows. The camelina diets tended to decrease dry matter intake but did not have a significant effect on milk production. They generated a slight decrease in milk protein and a strong decrease in milk fat yield and content. The CM diet led to a stronger decrease in fat content. Camelina generated a greater proportion of monounsaturated fatty acids, notably C18:1 *trans* isomers, including *trans*-10 and *trans*-11 C18:1, which increased by 11.0- and 2.6-fold, respectively, with the CM diet. Camelina also led to an increase in conjugated linoleic acids, particularly rumenic acid, *cis*-9, *trans*-11 C18:2. Camelina did not affect parameters of buttermaking except churning time with milk from CM fed cows, which was longer. The butters of camelina diets were softer at all temperatures tested, especially with the CM diet. In conclusion, feeding camelina can modify milk fatty acid profile and butter spreadability.

Key words: camelina, false-flax, fatty acid composition, butter

INTRODUCTION

The nutritional, organoleptic, and rheological (hardness, spreadability, melting) properties of dairy products are largely dependent on the fatty acid (FA) composition of milk, particularly polyunsaturated fatty acids. The FA composition can be modulated by feeding of the dairy cows. A number of trials have studied the effects on milk FA composition of supplementing diets with lipids from oilseeds, vegetable oils, or calcium soaps of vegetable oil (Chilliard et al., 2001).

Camelina, a cruciferous plant and a member of the mustard family, is a very old European oil crop; its history goes back to the Bronze Age (Putnam et al., 1993). Camelina, popularly known as false flax or gold-of-pleasure is an annual or overwintering herb originating in the region from the Mediterranean to Central Asia and is very adaptable to climate and soil type. It presents a similar FA profile to flaxseed and is rich in linolenic acid. The camelina oil contains 20 to 40% C18:3, 10 to 20% C18:2, 12 to 25% C18:1, 13 to 21% C20:1, and between 2 and 5% C22:1. Research has demonstrated further benefits of the camelina oil in skincare products, in the production of soaps and soft detergents, in the production of interesting lipopeptides and lipoaminoacids, and in the production of paints (Bonjean and Le Goffic, 1999). The plant has been shown to have only modest agro-input requirements, and can fit with in rotational strategies. The protein-rich camelina pressed cake is also a valuable livestock food. This oilseed meal still contains 10% oil, 13% fiber, 5% minerals, and 45% protein (Bonjean and Le Goffic, 1999). The aim of this trial was to quantify the effects of supplementing a corn silage-based diet with polyunsaturated FA derived from either whole-seed camelina (CS) or camelina meal (CM) on the composition and butter-making properties of the milk.

MATERIALS AND METHODS

Treatments, Experimental Design, Animals, and Feeding

The trial was conducted according to a double 3 × 3 Latin square design using 6 Holstein dairy cows. Each

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Table 1. Major fatty acid composition (%) of the lipid content of camelina seed and meal.

Fatty acid	Camelina seed	Camelina meal
Palmitic acid, C16:0	8.3	10.3
Oleic acid, C18:1	17.8	19.9
Linoleic acid, C18:2	27.6	28.5
Linolenic acid, C18:3	46.3	41.3

experiment was conducted over a 4-wk period, and measurements were taken during the final week of each period. The dairy cows were individually fed and produced 38.3 ± 2.8 kg of milk containing $3.40 \pm 0.83\%$ fat content and $2.81 \pm 0.18\%$ true protein content at trial initiation. The cows were at 70 ± 15 DIM at the start of trial.

Three diets were compared. The control diet was a corn silage-based diet supplemented with high-energy concentrate and soybean meal. The 2 experimental diets included either camelina seeds (false-flax seeds) or camelina meal (false-flax meal; Limagrain, Chappes, France). The CS diet provided 630 g/d of camelina seeds, and the CM diet provided 2 kg/d of camelina meal. Camelina seed and meal were supplied in quantities calculated to provide the cattle with the same amounts of polyunsaturated FA, that is, around 240 g/cow per d. These oilseed supplements contain, on average, 90.7% of unsaturated FA, of which 71.8% are polyunsaturated FA (Table 1). The diets consisted of 58% corn silage. The energy concentrate and soybean meal were then adjusted to cover 100% of energy and nitrogen requirements: camelina seed was added as a substitute for the energy concentrate, whereas camelina meal was added as a substitute for part of the soybean meal and the energy concentrate. Cows received supplements of 300 g/d of minerals 5-25-5 (P-Ca-Mg) to cover mineral requirements. Tables 2 and 3 give feed composition and nutritional values. The animals were fed twice daily at 0800 and 1700 h. The

camelina seed and meal were carefully mixed with the corn silage.

Measurements

The amounts of feed and orts were weighed daily. The DM content of corn silage was determined (80°C , 48 h) every 3 d to adjust the proportion of corn silage in the diets. To calculate DMI, the composition of orts was assumed similar to the offered diet. For chemical analyses, oven-dried samples of corn silage were pooled over each period, whereas concentrates, camelina seed and meal, and minerals were sampled weekly, and the samples were pooled over the whole experimental period. All the samples were ground with a 3-blade knife mill through a 0.8-mm screen. Organic matter content was determined by ashing for 6 h at 500°C . Total feed N content was determined by the Dumas method (Association Française de Normalisation, 1997). Feed ADF, NDF, and crude fiber were analyzed according to the method initially described by Van Soest et al. (1991) on a Fibersac analyzer (Ankom Technology, Fairport, NY). Fat content was measured by ether extraction (Apper-Bossard et al., 2006). Fat composition of camelina seed and meal was determined by gas chromatography with flame-ionization detector adapted from the method described by Wolff and Fabien (1989). The cows were weighed at the beginning and at the end of each experimental period.

To characterize the effects of camelina on rumen fermentation, ruminal fluid (50 mL) was pumped out from the ventral sac of the rumen, before the morning meal (0800 h) and 3 h later on the last day of each period. At each collection time, pH was measured immediately and the samples were strained through 6 layers of cheesecloth. Eight milliliters of strained rumen fluid was mixed with 0.8 mL of 5% (vol/vol) orthophosphoric acid containing 1% (wt/vol) mercury chloride and kept at -20°C until VFA analysis by gas chromatography (Jouany, 1982). For ammonia analysis, 4

Table 2. Chemical composition and nutritional value of feeds

Item	DM, %	CP	Fat	NDF	ADF	PDIN ¹	PDIE ²	NE _L , Mcal/kg of DM
g/kg of DM								
Corn silage	35.8	63	30	404	208	39	65	1.55
Energy concentrate	89.0	115	27	335	135	81	106	1.70
Soybean meal 48	88.0	527	16	162	90	374	254	2.01
Camelina meal (CM)	91.3	411	132	269	144	257	125	2.02
Camelina seed (CS)	88.7	270	378	286	151	177	108	2.58

¹PDIN = protein digested in the small intestine supplied by rumen-undegraded dietary protein and by microbial protein from rumen-degraded organic matter (INRA, 1989).

²PDIE = protein digested in the small intestine supplied by rumen-undegraded dietary protein and by microbial protein from rumen-fermented organic matter (INRA, 1989).

Table 3. Effect of camelina seed (CS) or meal (CM) on DM intake of dairy cows and on energy and protein balances

Item	Control	CS	CM	RMSE ¹	Model contrast: Camelina	Model contrast: Form
DMI, kg/d	21.0	20.6	19.8	0.79	0.089	0.118
Form, %						
Corn silage	57.8	57.9	57.8	0.52	ND ²	ND
Soybean meal	10.2	10.3	8.9	0.30	ND	ND
Energy concentrate ³	30.2	27.5	22.5	0.77	ND	ND
Camelina seed	0.0	2.9	0.0	0.13	ND	ND
Camelina meal	0.0	0.0	9.5	0.30	ND	ND
Urea	0.6	0.5	0.1	0.28	ND	ND
Minerals 5-25-5	1.3	1.4	1.1	0.09	ND	ND
NE _L , Mcal/d	31.2	31.3	30.1	1.22	0.409	0.134
PDIN, ⁴ g/d	2,075	1,976	2,065	102.0	0.341	0.207
PDIE, ⁵ g/d	2,020	2,003	1,916	79.4	0.181	0.123
Energy balance, Mcal/d	0.3	2.5	6.3	1.4	0.001	0.003
PDI balance, g/d	61.0	5.0	103.0	95.6	0.889	0.146
BW, kg	632	625	628	10.7	0.405	0.632

¹Root mean square error.²Not determined.³Contained 22% barley, 21.5% wheat, 37% beet pulp, 15% wheat bran, 2% molasses, 0.5% CaCO₃, 1% NaHCO₃, and 1% NaCl.⁴PDIN = protein digested in the small intestine (PDI) supplied by rumen-undegraded dietary protein and by microbial protein from rumen-degraded OM (INRA, 1989).⁵PDIE = PDI supplied by rumen-undegraded dietary protein and by microbial protein from rumen-fermented OM (INRA, 1989).

mL of strained rumen fluid was mixed with 4 mL of 20% (wt/vol) NaCl and kept at -20°C until analysis (Van Eenaele et al., 1969).

To characterize the effects of camelina on metabolism of dairy cows, blood was sampled at the end of each period. At each blood sampling, about 2 mL of blood was collected from the tail in heparinized syringes (S. Monovette, Sarstedt, Nümbrecht, Germany) for plasma determination of urea, NEFA, total glycerol, α -amino N, and glucose (Apper-Bossard et al., 2006).

Milk yield was recorded at each milking. Fat and protein contents were determined 4 times per week (i.e., on 8 milkings) by infrared analysis (fat B; Milkoscan, Foss Electric, Hillerød, Denmark). We conducted a detailed analysis of milk sampled (1 L) at the end of each period. Monohydrate lactose content was measured on these samples using an enzymatic method (FIL, 1991). The FA composition was determined by extracting the lipids from a 1-mL sample of milk fat according to the method described by Bauchart and Dubois (1983) using 0.5 mL of an ethanol/HCl (4:1 vol) solution followed by 0.5 mL of hexane. Milk FA were esterified with 1 mL of a butanol/HCl (100:5) solution followed by 2 mL of hexane (butyl esters). These esters were injected into a gas chromatograph (Varian 3400, Varian, Les Ulis, France) equipped with an electron ionization detector. The separation of butyl esters was performed on an OV-1 fused-silica capillary column (25 m $\times$ 0.32 mm i.d., Interchim, Montluçon,

France). The oven temperature was programmed to rise from 70 to 220°C at 100°C/min. Injector and detector were at 220 and 250°C, respectively; helium was used as gas vector. For conjugated linoleic acid (CLA) determination, the milk was freeze-dried and total lipids were extracted via a hexane/diethyl ester mixture. The samples were then analyzed chromatographically on a 100-m CP-Sil column (Varian SA, Les Ulis, France; Michalski et al., 2005).

Butter was manufactured twice per period using milk from 4 consecutive milkings. The milk was stored at 4°C immediately after milking. Milk from the 2 cows with the same diet was pooled and heated to 60°C using a plate heat exchanger, and then skimmed using a cream separator (Elecram 3, Elecram, Chatillon, France). The cream was standardized at 400 g of fat / kg. The physical ripening was as follows: storage for about 5 h at 4°C followed by storage for 18 h at 15°C. Cream was inoculated with a starter [using mixed mesophilic lactic starters (*Streptococcus lactis*, *Streptococcus cremoris*, and *Streptococcus diacetylactis*) at 4 IU/100 L and mesophilic aromatic cultures (*Leuconostoc* spp.) at 1 IU/100 L] at the beginning of the physical ripening to develop flavor, crystallize the fat, and reduce pH to a value of 4.6. The cream was then churned at 10°C in an experimental churn (Elba 50, Elecram) until butter kernels formed. The buttermilk was separated from the butter kernels and weighed. The butter kernels were washed twice with cold water

Table 4. Effect of camelina seed (CS) or meal (CM) on rumen fluid pH and VFA composition before morning feeding and 3 h later

Item	Control	CS	CM	RMSE ¹	Model contrast: Camelina	Model contrast: Form
Before feeding (0800 h)						
pH	6.98	6.80	6.55	0.16	0.019	0.051
Acidity, mol/L	66.3	72.0	93.7	16.2	0.086	0.069
VFA, mol/100 mol						
Acetic acid	63.3	62.1	54.6	2.09	0.003	0.001
Propionic acid	20.0	20.9	24.8	2.15	0.033	0.024
Butyric acid	11.9	11.2	13.9	2.17	0.537	0.087
Valeric acid	1.50	1.91	2.40	0.29	0.004	0.030
Caproic acid	0.30	0.37	0.39	0.13	0.288	0.793
Minor VFA ²	1.80	2.28	2.79	0.37	0.006	0.060
Iso-acids ³	3.09	3.39	3.84	0.57	0.118	0.251
C2:C3	3.27	3.02	2.20	0.34	0.007	0.007
After feeding (1100 h)						
pH	6.11	6.02	6.02	0.27	0.621	0.964
Acidity, mol/L	111.8	109.2	118.8	28.7	0.881	0.615
VFA, mol/100 mol						
Acetic acid	57.7	54.9	51.4	1.43	<0.001	0.007
Propionic acid	21.2	21.9	25.5	1.47	0.014	0.006
Butyric acid	15.6	16.6	16.1	1.02	0.213	0.482
Valeric acid	2.54	3.57	3.07	0.53	0.025	0.181
Caproic acid	0.57	0.82	0.57	0.17	0.206	0.045
Minor VFA ²	3.12	4.39	3.64	0.59	0.020	0.078
Iso-acids ³	2.36	2.29	3.32	0.66	0.235	0.042
C2:C3	2.74	2.55	2.02	0.239	0.008	0.010

¹Root mean square error.²Sum of valeric + caproic acids.³Sum of isobutyric + isovaleric acids.

(12°C) in the churn (except for the very soft butters, which were washed with water at 4°C). The butter was then worked in the churn into a homogeneous mass. Butter was packaged by hand with a spatula into 250- or 500-mL plastic cream cups, and stored at 4°C for physical properties.

Physical measurements were taken on the butters conserved at 4°C over 15 d. Color was measured on 3 samples of butter per treatment (at 4 measurement points per sample) using a chromameter (CR300, Minolta, Carrières-sur-Seine, France) according to the method described by Michalski et al. (2004). Butter samples (1 sample corresponded to a cup of butter) were tested for resistance to penetration using an universal testing machine (model 4501, Instron, Norwood, MA; Couvreur et al., 2006) at 2 different storage temperatures (4 and 10°C) during the 20 h preceding the measure.

Statistical Analysis

Statistical analysis was performed using the GLM procedure (SAS Institute, 1990). The results for intake and milk and butter composition were analyzed using the following statistical model:

$$Y_{ijk} = \mu + p_i + c_j + d_k + e_{ijk}$$

where Y_{ijk} = variable studied during the trial; μ = the overall mean of the population; p_i = the effect due to the period i (2 df), c_j = the effect due to the cow j (5 df) or effect due to the group for butter (2 df), d_k = the effect due to the treatment k (control, CS, and CM; 2 df); and e_{ijk} = error associated with each Y_{ijk} . The 2 series of butter produced were considered as independent data (11 df for residual error). Orthogonal contrasts were used to analyze 1) the effects of camelina compared with the control (camelina: control vs. CS + CM) and 2) the effect of the form of the camelina (seed or meal; form: CS vs. CM), according to the method described by Gill (1978). A P -value of <0.05 was considered significant and a P -value of <0.10 was considered as a trend.

RESULTS

Feed Intake

The inclusion of camelina in dairy cow feeding tended to decrease feed intake (−0.8 kg/d, $P = 0.089$; Table 3). Feed intake of the CM diet showed important day-to-day variation (up to 2 kg/d of DM). The differ-

Table 5. Effect of camelina seed (CS) or meal (CM) on plasma composition

Item	Control	CS	CM	RMSE ¹	Model contrast: Camelina	Model contrast: Form
NEFA, $\mu\text{mol/L}$	127	112	97	36.2	0.262	0.550
Glucose, mg/100 mL	72.5	70.4	65.6	3.86	0.055	0.083
Urea, mg/100 mL	25.9	27.7	34.7	5.03	0.080	0.061
Total glycerol, mg/L	52.1	46.6	63.8	11.4	0.613	0.046
α -Amino N, mg/100 mL	47.7	49.0	40.7	3.46	0.163	0.007

¹Root mean square error.

ences in energy and in protein digestible in the small intestine intakes were not significant. Energy balance was more positive in the camelina diets (+4.4 Mcal/d, $P < 0.001$). There was no effect of diet on protein balance. Camelina had no effect on the BW of the dairy cows (Table 3).

Intake of camelina seed and meal was 0.59 and 1.9 kg/d, respectively. The lipids supplied by camelina averaged 39 and 35% of total lipids supplied for CS and CM diets, respectively.

Ruminal Digestion and Energy and Nitrogen Metabolism

Before feeding, rumen pH was lower ($P < 0.05$) and total acidity tended to be higher ($P = 0.086$) under the camelina diets (Table 4). Camelina also led to changes in the fermentation profile compared with control, decreasing acetic acid content (−4.9 mol/100 mol) while increasing propionic acid (2.8 mol/100 mol) and 5- or 6-carbon minor FA (0.7 mol/100 mol). These effects were stronger in the CM diet than in the CS diet ($P < 0.05$). More specifically, the CM diet led to a lower acetic acid-to-propionic acid ratio ($P < 0.01$). There was a treatment effect on butyric acid content, although it tended to be greater in the CM diet than in the CS diet ($P = 0.087$). There was no treatment effect on isoacids. Similar effects as those described above were

also present at peak fermentation (i.e., 3 h after feeding), except for average rumen fluid pH and butyric acid, which were not affected by treatments.

Camelina had no significant effect on blood NEFA. However, camelina led to lower glycemia (−4.5 mg/100 mL, $P = 0.055$) and it tended to be lower in the CM diet than in the CS diet ($P = 0.083$). Total glycerol was increased by the CM diet but remained unchanged by the CS diet. Both camelina diets, but especially CM, tended to increase blood urea ($P = 0.080$). α -Amino N content was reduced by the CM diet and remained unchanged by the CS diet (Table 5).

Milk Production and Composition

Feeding camelina had no significant effect on milk production. However, it decreased milk fat content, milk fat yield, and FCM production (Table 6). For these parameters, the decrease was stronger in the CM diet than the CS diet ($P < 0.001$). Camelina tended to reduce milk protein content (0.09 percentage units, $P = 0.055$) and lactose content (−0.12 percentage units, $P = 0.113$), with no difference between camelina forms (seed or meal). The CM diet led to lower protein production (−78 g/d) compared with the CS diet.

Feeding camelina had an effect on milk FA composition, and the effect was more pronounced with CM than with CS (Table 7). Camelina increased the pro-

Table 6. Effect of camelina seed (CS) or meal (CM) on milk production and composition

Item	Control	CS	CM	RMSE ¹	Model contrast: Camelina	Model contrast: Form
Milk, kg/d	33.8	34.4	32.5	1.76	0.701	0.134
Fat content, %	3.14	2.51	1.44	0.244	<0.001	<0.001
Protein content, %	2.89	2.83	2.76	0.080	0.055	0.258
Fat yield, g/d	1,063	865	481	76.7	<0.001	<0.001
Protein yield, g/d	980	967	902	48.9	0.132	0.041
FCM, kg/d	29.4	26.7	19.9	1.33	<0.001	<0.001
Lactose, %	4.93	4.86	4.75	0.131	0.113	0.218

¹Root mean square error.

Table 7. Effect of camelina seed (CS) or meal (CM) on milk fatty acid (FA) composition

FA, %	Control	CS	CM	RMSE ¹	Model contrast: Camelina	Model contrast: Form
C4	2.44	2.38	1.40	0.27	0.006	0.001
C5	0.023	0.025	0.024	0.01	0.817	0.898
C6	1.95	1.84	0.99	0.20	0.002	<0.001
C7	0.020	0.022	0.019	0.004	0.886	0.348
C8	1.34	1.27	0.61	0.13	0.001	<0.001
C9	0.048	0.037	0.029	0.02	0.174	0.557
C10	3.33	3.16	1.59	0.30	<0.001	<0.001
C11	0.085	0.058	0.054	0.03	0.127	0.838
C12	4.13	4.04	2.61	0.29	0.001	<0.001
C13	0.132	0.130	0.131	0.04	0.968	0.959
C14:1	1.28	1.42	1.96	0.20	0.006	0.004
C14	12.99	12.95	11.77	0.47	0.035	0.005
Iso-C15	0.24	0.23	0.23	0.027	0.577	0.838
C15:1	0.57	0.53	0.54	0.063	0.403	0.779
C15	1.35	1.21	1.42	0.27	0.788	0.237
C16:1	2.14	2.25	4.14	0.50	0.005	<0.001
C16	37.0	32.2	31.9	1.66	0.001	0.835
Iso-C17	0.40	0.41	0.57	0.051	0.012	0.002
C17:1	0.91	0.88	1.04	0.070	0.217	0.011
C17	0.58	0.54	0.59	0.071	0.630	0.254
Trans-9, trans-12 C18:2	0.09	0.18	0.67	0.081	<0.001	<0.001
Cis-9, cis-12 C18:2	1.86	2.20	1.89	0.20	0.124	0.040
C18:3	0.20	0.32	0.36	0.12	0.054	0.596
Trans-6-8 C18:1	0.26	0.57	0.64	0.17	0.006	0.544
Trans-9 C18:1	0.26	0.55	0.58	0.14	0.004	0.742
Trans-10 C18:1	1.02	3.44	11.27	0.83	<0.001	<0.001
Trans-11 C18:1	1.26	2.19	3.34	0.17	<0.001	<0.001
Trans-12 C18:1	0.15	0.18	0.52	0.05	<0.001	<0.001
Cis-9 C18:1	16.4	17.3	14.1	1.41	0.375	0.010
Trans-15, cis-11 C18:1	0.68	1.03	1.47	0.13	<0.001	0.001
C18:1 cis-12	0.23	0.43	0.07	0.056	0.554	<0.001
C18:0	6.61	6.09	3.40	1.06	0.011	0.005
C14:1/C14:0	0.099	0.111	0.166	0.017	0.003	0.002
C16:1/C16:0	0.058	0.071	0.128	0.013	<0.001	<0.001
C18:1/C18:0	2.50	2.93	4.08	0.42	0.003	0.004
C18:1/C16:0	0.44	0.54	0.45	0.064	0.153	0.048
Saturated FA	72.7	66.6	57.4	2.22	<0.001	<0.001
Unsaturated FA	27.3	33.4	42.6	2.22	<0.001	<0.001
Monounsaturated FA	25.1	30.7	39.7	2.09	<0.001	<0.001
Polyunsaturated FA	2.16	2.70	2.92	0.29	0.004	0.261

¹Root mean square error.

portion of unsaturated FA. This effect was mainly due to an increase in monounsaturated FA content. In particular, camelina led to an increase in all *trans*-C18:1 isomers, especially *trans*-10 C18:1. Camelina also led to an increase in daily production of *trans* FA, reaching 63.5 g/d under CS and 100.3 g/d with CM diet ($P < 0.001$) despite the reduced fat yield (Table 8). Camelina also led to lower levels of shorter-chain monounsaturated FA (C14:1 and C16:1), particularly under the CM diet. Only *cis*-9 and *cis*-12 C18:1 isomers decreased with the CM diet. The camelina diet led to an increase in polyunsaturated FA, especially C18:2 isomers, and particularly CLA and rumenic acid (*cis*-9, *trans*-11 CLA; Table 9). The effects of camelina on the proportion of C18:2 isomers were always more pronounced with the CM diet than with the CS diet. Lin-

olenic acid content remained relatively low at an average 0.34%, even if the increase with camelina was significant. Camelina led to a reduction in the milk percentage of short-chain FA. There was a lower proportion and yield of 4- to 12-carbon FA with the camelina diets than with the control (respectively, control: 13.4%, 142.3 g/d vs. camelina: 10.1%, 72.6 g/d, $P < 0.001$), and the decrease was stronger with the CM diet than with the CS diet (7.3 vs. 12.8%, 116.1 vs. 29.0 g/d, $P < 0.001$ respectively). Both forms of camelina led to a decrease in C16:0 FA.

There was no significant effect of camelina diet on C18:1/C16:0 ratio, although the ratio was higher with the CS diet than with the CM diet ($P < 0.05$). The C14:1/C14:0, C16:1/C16:0, and C18:1/C18:0 ratios increased with camelina, particularly with the CM diet.

Table 8. Effect of camelina seed (CS) or meal (CM) on milk fatty acid (FA) yield

FA, g/d	Control	CS	CM	RMSE ¹	Model contrast: Camelina	Model contrast: Form
C4	25.7	21.0	5.9	3.31	<0.001	<0.001
C5	0.23	0.20	0.12	0.122	0.289	0.396
C6	20.6	16.6	4.0	2.52	<0.001	<0.001
C7	0.20	0.17	0.08	0.041	0.008	0.008
C8	14.3	11.6	2.2	1.56	<0.001	<0.001
C9	0.48	0.33	0.14	0.207	0.055	0.184
C10	35.6	29.0	5.7	3.44	<0.001	<0.001
C11	0.90	0.53	0.28	0.318	0.018	0.254
C12	44.3	36.7	10.6	3.71	<0.001	<0.001
C13	1.41	1.09	0.70	0.461	0.064	0.226
C14:1	13.6	11.7	10.1	1.17	0.003	0.066
C14	138.3	114.0	54.4	11.04	<0.001	<0.001
Iso-C15	2.48	1.99	1.04	0.253	<0.001	<0.001
C15:1	5.97	4.61	2.63	0.831	0.001	0.007
C15	14.3	10.0	7.6	3.26	0.013	0.272
C16:1	22.3	18.1	21.3	2.02	0.038	0.039
C16	395	281	149	21.0	<0.001	<0.001
Iso-C17	4.15	3.42	2.83	0.440	0.003	0.069
C17:1	9.53	7.33	5.26	1.10	0.001	0.020
C17	6.14	4.49	3.08	0.956	0.002	0.049
Trans-9, trans-12 C18:2	1.03	1.45	3.55	0.442	<0.001	<0.001
Cis-9, cis-12 C18:2	20.0	18.8	8.8	1.58	<0.001	<0.001
C18:3	2.08	2.69	1.83	0.933	0.717	0.185
Trans-6-8 C18:1	2.71	4.53	3.44	1.237	0.084	0.204
Trans-9 C18:1	2.77	4.44	3.05	0.973	0.091	0.055
Trans-10 C18:1	10.5	24.5	62.3	4.37	<0.001	<0.001
Trans-11 C18:1	13.3	18.7	17.3	3.32	0.030	0.524
Trans-12 C18:1	1.68	1.44	2.88	0.304	0.017	<0.001
Cis-9 C18:1	173	147	67	21.2	<0.001	<0.001
Trans-15, cis-11 C18:1	7.22	8.47	7.78	1.141	0.166	0.377
C18:1 cis-12	2.53	3.83	0.11	0.567	0.095	<0.001
C18:0	70.2	54.8	14.8	13.23	0.002	0.002
C4 to C12	142.5	116.1	29.0	12.9	<0.001	<0.001
C13 + C14:1 + C14	153.4	126.8	65.2	10.8	<0.001	<0.001
C15 + C17	42.6	31.9	22.4	5.9	0.002	0.037
C16:1 + C16	417.2	299.5	170.4	21.1	<0.001	<0.001
Trans-10 and trans-11 C18:1	23.9	43.2	79.5	5.80	<0.001	<0.001
C18:2 + C18:1 + C18	307.0	290.5	193.4	40.4	0.016	0.007
Saturated FA	774.4	587.3	262.7	51.9	<0.001	<0.001
Unsaturated FA	288.2	277.5	217.8	31.0	0.037	0.018
Monounsaturated FA	265.1	254.6	203.6	29.9	0.051	0.029
Polyunsaturated FA	23.1	22.9	14.2	2.39	0.007	0.001

¹Root mean square error.

Production and Properties of the Butter

There was a very significant increase in churning time for butters made from milks of the CM diet. The churning time was 2-fold longer for the CM diet than for the other treatments: 29.6 vs. 15.4 min (control) and 15.1 min (CS diet). The camelina diets led to lower butter yield and lower fat content of the butter, with no difference between CS and CM diets. However, there was no effect on butter yield when it was expressed in relation to fat content (Table 10).

The 3 butters presented significantly different rheological behaviors at both measurement temperatures (4 and 10°C). Compared with control butter, both CM

and CS butters presented less penetration resistance, particularly CM butter. The treatments had little effect on butter color, although butters from the camelina diets had a tendency to be slightly less yellow than control butter (−0.5 units, $P = 0.098$) and were whiter ($P < 0.001$; Table 10).

DISCUSSION

Despite being a cruciferous plant, camelina oil contains 45% linolenic acid, a similar content to flaxseed oil, which contains about 50% linolenic acid (INRA-AFZ, 2004). Camelina oil also contains 28% linoleic acid, which ranks it just above flaxseed oil (15%) and

Table 9. Effect of camelina seed (CS) or meal (CM) on milk lipid and conjugated linoleic acid (CLA) contents

Item	Control	CS	CM	RMSE ¹	Model contrast: Camelina	Model contrast: Form
Total lipids, mg/g of DM	165.3	148.2	72.5	25.6	0.005	0.003
C18:2n-6, mg/g of total lipids	18.9	17.1	15.7	2.61	0.095	0.429
Total CLA, mg/g of total lipids	8.99	10.26	17.37	1.70	0.001	<0.001
<i>Cis</i> -9, <i>trans</i> -11 C18:2	8.18	9.27	14.84	1.55	0.002	0.001

¹Root mean square error.

rapeseed (21%). Finally, camelina seed oil is richer in polyunsaturated FA (73%) compared with the other oilseeds (flaxseed 69%, sunflower 66%, soybean 60%, and rapeseed 31%).

Camelina Meal Tended to Reduce DMI in Dairy Cows and Reduced Milk Protein Yield

The CM diet led to strong day-to-day variation in feed intake, in contrast to the CS diet, which had no effect. This result contrasts with the results of Schori et al. (2006), Loor et al. (2005), and Gonthier et al. (2005) in studies conducted on diet supplementations with C18:3 sources including, respectively, extruded or nonextruded flaxseed, flaxseed oil or whole raw flax seeds, and micronized or extruded flaxseed. This high daily variability in DMI and the fact that one cow refused to eat the CM diet during the last experimental period suggest that the unsaturated FA in the cam-

elina meal may have progressively oxidized during the experiment, producing a dissuasive odor or taste not tolerated by dairy cows. This oxidation process would be limited in the CS diet because the seed husk would have protected the camelina oil from exposure to air. Oxidation of fat in the feed could have resulted in transfer of oxidized off-flavors to milk or caused spontaneous oxidized off-flavors (Sol Morales et al., 2000).

Both forms of camelina tended to reduce milk protein. The CM diet had a stronger effect on protein yield, most likely due to lower milk production because of the slightly lower dietary energy supply (−1.2 Mcal/d less than the CS diet). This result is not consistent with other reports when flax oil or flaxseed are added. Indeed, Schori et al. (2006), Stoll et al. (2003), and Loor et al. (2005) reported no effect on milk protein content and protein production, and Gonthier et al. (2005) reported no effect on protein content but a slightly reduced protein production. There is only one

Table 10. Effect of camelina seed (CS) or meal (CM) on butter production and on physical properties of butter

Item	Control	CS	CM	RMSE ¹	Model contrast: Camelina	Model contrast: Form
Butter making parameters						
Churning time, min	15.4	15.1	29.6	3.96	0.006	<0.001
Butter milkfat content, g/kg	22.7	16.6	16.5	5.33	0.046	0.976
Butter yield, %	48.12	43.96	42.00	4.59	0.042	0.487
Fat-corrected butter yield, %	88.38	85.50	86.95	6.94	0.528	0.804
Rheology parameters						
Measures at 4°C						
Force at 5 mm, N	33	23	16	0.4	<0.001	0.034
Force at 10 mm, N	106	77	50	1.4	<0.001	0.009
Force at 18 mm, N	251	175	126	2.9	<0.001	0.014
Slope, kN/mm	21.63	14.84	10.98	2.53	<0.001	0.031
Measures at 10°C						
Force at 5 mm, N	13	8	5	1.3	<0.001	0.014
Force at 10 mm, N	46	26	17	5.0	<0.001	0.010
Force at 18 mm, N	122	67	42	12.0	<0.001	0.005
Slope, kN/mm	10.84	5.96	3.56	1.36	<0.001	0.016
Color						
White (L) index	93.29	94.01	95.15	0.49	<0.001	0.004
Red (a) index	−2.66	−2.79	−2.42	0.22	0.590	0.017
Yellow (b) index	18.69	17.77	18.26	0.73	0.098	0.298

¹Root mean square error.

report of a decrease in protein content (Offer et al., 1999).

Camelina Influences Milk Fat Yield and Composition and Properties of the Butter

The negative effect of camelina on milk fat content (on average -1.1 percentage units) and milk fat production was more important than previously reported for flaxseed, which had no effect when added as an oil (Offer et al., 1999; Loor et al., 2005) or as whole raw or extruded seeds (Schori et al., 2006), and a slightly negative effect (-0.49 percentage units, Chouinard et al., 1998) with calcium salts and with flaxseed oil (Pottier et al., 2006). This negative effect of camelina was also stronger than the effect of other oilseeds. Schori et al. (2006) observed no difference between sunflower and flaxseed, whereas Loor et al. (2005) observed no difference among fish oil, flaxseed oil, and sunflower oil. Milk fat production also largely decreased, thereby increasing the cow energy balance.

The camelina diet led to changes in the physical properties of the butter produced, probably related to the effects of camelina on milk FA composition. The longer churning time, particularly in the CM diet, may be a direct result of the high *trans*-10 C18:1 FA content. Hurtaud et al. (2001) demonstrated a positive linear relationship between milk *trans*-10 C18:1 content and churning time. Furthermore, because the camelina led to a strong decrease in fat content, the size of the milk fat globules was probably reduced (Couvreur et al., 2006), which may have also increased churning time. Pointurier and Adda (1969) showed that small milk fat globules require a longer churning time because more pressure is required to break the milk fat globule membrane.

Feeding camelina resulted in butter that was less firm and more spreadable. These changes in the physical properties of the butter are the direct result of the increase in milk unsaturated FA content and in the spreadability index (C18:1/C16:0). It has been demonstrated that FA composition affects butter texture according to the liquid milk fat-to-solid milk fat ratio (Chen et al., 2004).

The effects of camelina on butter color were particularly mild. This was a relatively surprising finding, because camelina oil itself had a golden yellow color. The camelina lipids may have had an indirect effect on pigment metabolism of dairy cows. We did not test the organoleptic properties of the butters, but the butters produced from camelina diets, and especially the CM diet, appeared relatively oily. This apparent defect may have been due to the fat being too rich in low-

melting triglycerides rich in unsaturated FA (Pointurier and Adda, 1969).

The camelina increased the milk content of total CLA, particularly rumenic acid (*cis*-9, *trans*-11 C18:2). Numerous previous studies have shown that dietary lipid supplementation can be used to modulate the concentrations of rumenic acid, which is noted for its anticarcinogenic, antilipogenic, and antiatherogenic properties (Williams, 2000). Dietary supplementation of plant oils (sunflower, soybean, corn, canola, flaxseed) results in substantial increases in milk fat CLA concentrations. Plant oils high in linoleic acid give the greatest response. Pasture feeding has been shown to increase milk fat content of CLA.

The increase in CLA content is associated with an increase in other *trans* FA, particularly *trans*-10 C18:1, and to a lesser extent *trans*-11 C18:1, which acts as a precursor of rumenic acid (Williams, 2000) via the enzymatic action of Δ^9 -desaturase. Indeed, in the present study, CLA concentrations were very tightly correlated with *trans*-11 C18:1 concentrations ($r = 0.71$). Chilliard et al. (2000) reported a linear relationship between milk CLA and *trans* C18:1 FA that tended to become asymptotic above 5.5% of *trans* C18:1 and 1.5% of *cis*-9, *trans*-11 CLA.

However, the increase in *trans*-10 C18:1 concentration is not a desirable goal because research suggests relationships between dietary intake of *trans* FA and coronary heart disease (Hayakawa et al., 2000). Camelina led to a much stronger increase in *trans*-10 C18:1 than in CLA and in *trans*-11 C18:1. The decrease in acetic acid-to-propionic acid ratio in the CM diet suggests that the meal-based diet affected rumen function. Significant deviations in fermentation are widely reported in studies on oil-based forms of lipid supplementation (Sauvant and Bas, 2001), which provide available FA directly in the rumen fluid. This effect is often associated with a strong reduction in protozoa populations and in fiber digestibility (Sauvant and Bas, 2001).

Furthermore, the camelina did not increase milk C18:3 concentrations despite a daily intake of 104 g/d, corresponding to a calculated passage rate from 1.7 to 2.6%, which is less than for flax (3.3% with flax to 6.8% with extruded flax; Schori et al., 2006). Therefore, camelina as either meal or whole raw seed is less efficient than flax in increasing milk C18:3 content. This is very likely due to substantial hydrogenation of C18:3 in the rumen, especially under the CM diet, and perhaps due to incomplete digestibility of oils in the seed form with CS diet.

Fatty Acids are Likely More Digestible in the CM Diet than in the CS Diet, Which Explains the Stronger Effects of CM Compared with CS

The weaker effects of the CS diet could be due to the protective role of the seed husk, which would reduce rumen microbe access to lipids. According to Chilliard et al. (2001), lipids can be delivered in seed form to limit ruminal hydrogenation. The husk surrounding whole raw seeds would also have limited the total quantity of FA available to the body. Although we did not measure the digestibility of the oils in the CS and CM diets, this hypothesis is supported by the fat contents of feces (ether extraction). The fat content of feces was lower under the CM diet than under the CS diet (2.7 vs. 4.3%, respectively), with the control intermediate at 3.2%. Supposing that digestibility of organic matter was 0.70, which is standard for the control diet, then the quantity of fat digested would have been 360, 490, and 570 g/d for the control, CS, and CM diets, respectively. The difference between the CS and CM diets could be narrower if we accept that, despite the reduction in intake, CM digestibility decreased in relation to the fiber content of diet due to changes in the conditions of ruminal digestion (Sauvant and Bas, 2001). Nevertheless, even a 4-point decrease in rumen digestibility (i.e., a 10-point decrease in NDF digestibility) would still lead to >540 g/d of fat digested with the CM diet. Given this probable fecal loss of fat, it would be better to provide the camelina as either micronized or extruded seed.

These differences in FA digestion between CS and CM and the digestive effects of the meal form explain the more marked effects of the CM diet on the production of milk fat and on the properties of butter. Compared with the seed form, the CM diet led to a very substantial reduction in short-chain FA (29 vs. 116 g/d) due to the decrease in plasma precursors, especially acetate. This decrease may also be related to a direct effect of long-chain FA, particularly the *trans* forms (Palmquist et al., 1993). The CM diet also reduced the quantity of medium-chain FA partially synthesized by the udder, particularly C14:0 and C16:0. This decrease was also likely due to the formation of *trans* FA in the rumen, because the milk *trans* FA content had increased. This production of *trans* FA could have been reduced by increasing ruminal pH with buffers such as bicarbonate (J. L. Peyraud, unpublished data). More specifically, the CM diet led to a very strong increase in *trans*-10 C18:1 as well as C18:2 conjugated FA (except *cis*-9, *trans*-11 CLA) such as, perhaps, *cis*-12, *trans*-10 C18:2. According to Baumgard et al. (2002), these FA, particularly *cis*-12, *trans*-10 C18:2, can inhibit the mammary synthesis of medium-chain FA.

Figure 1. Relationship between milk fat content and percentage *trans*-10 C18:1.

Both Loor and Herbein (2003) and Palmquist et al. (1993) claimed that a large portion of the reduction in *de novo* synthesis due to feeding unsaturated oils occurs as a result of greater uptake and secretion of dietary and ruminally derived FA. Exogenous FA competes for esterification with newly synthesized short-chain FA in mammary cells and could lead to feedback inhibition of lipogenic enzymes. In our trial, changes in milk fat content correlated strongly with changes in *trans*-10 C18:1 and all other CLA except *cis*-9, *trans*-11 CLA (Figures 1 and 2). The CLA gave a significantly greater slope of the correlation line. This specific effect of CLA other than *cis*-9, *trans*-11 C18:2 is probably related to one CLA in particular; that is, *cis*-12, *trans*-10 C18:2 (Loor and Herbein, 2003).

Figure 2. Relationship between milk fat content and percentage conjugated linoleic acids (total CLA excluding *cis*-9, *trans*-11 CLA).

CONCLUSIONS

This trial showed that a diet containing a cruciferous plant can affect milk FA composition and the properties of butter. The use of camelina led to significant changes in milk fat composition and yield, and resulted in softer and probably more spreadable butter. The diet utilizing the meal form of camelina led to particularly strong effects, and it is therefore advisable to keep camelina input to below a threshold of 2 kg/cow per d to limit certain adverse effects such as a decrease in milk fat content or an increase in the concentrations of potentially unhealthy *trans* C18:1 isomers. Camelina seed represents an interesting compromise because it has a more moderate effect on fat content while improving the physical qualities of butter. Some questions remain about the sensorial properties of the butter produced with camelina.

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