Production Performance and Milk Composition of Dairy Cows Fed Whole or Ground Flaxseed With or Without Monensin^{1,2}

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ABSTRACT

Eight multiparous Holstein cows averaging 570 ± 43 kg of body weight and 60 ± 20 d in milk were used in a double Latin square design with four 21-d experimental periods to determine the effects of feeding ground or whole flaxseed with or without monensin supplementation (0.02% on a dry matter basis) on milk production and composition, feed intake, digestion, blood composition, and fatty acid profile of milk. Intake of dry matter was similar among treatments. Cows fed whole flaxseed had higher digestibility of acid detergent fiber but lower digestibilities of crude protein and ether extract than those fed ground flaxseed; monensin had no effect on digestibility. Milk production tended to be greater for cows fed ground flaxseed (22.8 kg/d) compared with those fed whole flaxseed (21.4 kg/d). Processing of flaxseed had no effect on 4% fat-corrected milk yield and milk protein and lactose concentrations. Monensin supplementation had no effect on milk production but decreased 4% fat-corrected milk yield as a result of a decrease in milk fat concentration. Feeding ground compared with whole flaxseed decreased concentrations of 16:0, 17:0, and *cis*6-20:4 and increased those of *cis*6-18:2, *cis*9, *trans*11-18:2, and *cis*3-18:3 in milk fat. As a result, there was a decrease in concentrations of medium-chain and saturated fatty acids and a trend for higher concentrations of long-chain fatty acids in milk fat when feeding ground compared with whole flaxseed. Monensin supplementation increased concentrations of *cis*9 and *trans*11-18:2 and decreased concentrations of saturated fatty acids in milk fat. There was an interac-

tion between flaxseed processing and monensin supplementation, with higher milk fat concentration of *trans*11-18:1 for cows fed ground flaxseed with monensin than for those fed the other diets. Flaxseed processing and monensin supplementation successfully modified the fatty acid composition of milk fat that might favor nutritional value for consumers.

Key words: dairy cow, flaxseed, protein, milk production

INTRODUCTION

Flaxseed is an excellent source of n-3 fatty acids (FA), which are reported to be anticarcinogenic, and which contribute to prevention of cardiovascular diseases and to improved vision (Wright et al., 1998). Infusion of flaxseed oil in the abomasum, which avoids ruminal biohydrogenation of polyunsaturated fatty acids (PUFA), increased milk concentration of linolenic acid to 13.9% of total FA as compared with 2.0% when whole flaxseed (WF) was fed in the diet of dairy cows (Petit et al., 2002). Therefore, methods to decrease ruminal biohydrogenation would increase the transfer of PUFA from flaxseed into milk. Experiments carried out with flaxseed used ground (Goodridge et al., 2001; Gonthier et al., 2004, 2005) or whole (Petit, 2002; Petit et al., 2002; Ward et al., 2002) seeds. No comparison has been found on the effect of grinding flaxseed, although processing would increase availability of oil in the rumen. As a result, greater biohydrogenation of flaxseed PUFA by rumen microbes may occur, thus increasing milk conjugated linoleic acid (CLA) concentration. Milk CLA is derived from rumen CLA and from endogenous synthesis of CLA in the mammary gland from *cis*9, *trans*11-18:2 (Griinari et al., 2000).

Monensin (MO), which is an ionophore, has been used extensively in the diet of dairy cows, and effects on milk production and composition are well documented (Van der Werf et al., 1998; Phipps et al., 2000; Duffield et al., 2003). Monensin is also known to decrease in vitro

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ruminal biohydrogenation of PUFA (Van Nevel and Demeyer, 1995) and to increase in vitro total CLA concentration (Fellner et al., 1997), thus suggesting that dietary supplementation of MO could increase milk concentration of CLA and other PUFA. Concentrations of CLA, PUFA, and n-3 FA in milk after feeding MO could be greater with ground than WF due to a decrease in ruminal biohydrogenation of PUFA and a greater availability of oil in the rumen following grinding of flaxseed. Therefore, the objective of the present experiment was to determine the effects of feeding ground or WF with or without MO on feed intake, milk production, milk composition, milk FA profile, digestion, and blood composition of lactating dairy cows.

MATERIALS AND METHODS

Animals and Diets

A total of 8 multiparous Holstein cows averaging 570 ± 43 kg of BW and 60 ± 20 DIM were assigned to a replicated 4×4 Latin square design to determine the effects of flaxseed processing and MO supplementation on total tract apparent digestibility, feed intake, milk production, milk composition, and milk FA profile. Each experimental period consisted of 14 d of adaptation to the diets and 7 d for daily data collection of milk yield and feed intake. The 4 TMR (Table 1) consisted of supplements based on WF with no MO (CO), WF with 0.02% MO on a DM basis, ground flaxseed (GF) with CO, and GF with MO. Flaxseed was ground through a 10-mm screen using a Nogueira dpm-2 chopper (Irmãos Nogueira S.A. Máquinas Agrícolas e Motores, Itapira, São Paulo, Brazil).

Diets were formulated with similar chemical composition to meet nutrient requirements of a 570-kg cow producing 25 kg/d of milk containing 3.9% of fat (NRC, 2001). The experiment was conducted at the Iguatemi Experimental Farm, Maringa State University, Brazil. Cows were housed in tie stalls, fed individually, and milked twice daily at 0645 and 1530 h. Milk production was recorded at each milking. Yield of FCM was calculated according to the equation of Tyrrell and Reid (1965). Cows were weighed on the first and last day of each experiment period.

Sample Collection

Feed consumption was recorded daily. Diets were fed twice daily at 0800 and 1600 h and adjusted for 100 g oforts/kg as fed. Samples of each diet were collected daily from d 15 to 20, frozen, and pooled on a period basis. Composite samples were mixed thoroughly and subsampled for chemical analyses. Samples of feces were collected for 6 consecutive days at 0800 h on d 15,

1000 h on d 16, 1200 h on d 17, 1400 h on d 18, 1600 h on d 19, and 1800 h on d 20 of each experimental period. Fecal samples were dried in a forced draft oven (60°C ; 72 h), then ground through a 1-mm screen (Wiley mill model 4, Arthur H. Thomas, Philadelphia, PA). Equal DM from each fecal subsample was mixed to obtain a single composite for each sampled cow during each period. Milk samples were obtained from the 4 consecutive milkings on d 15 and 16 of each experimental period and pooled within cow and period relative to production to obtain one composited milk sample per cow per period for chemical analysis. Milk samples were kept at room temperature with a preservative, 2-bromo-2-nitropropane-1,3 diol (Bronopol, D&F Control Systems Inc., San Ramon, CA), for determination of protein, fat, and lactose concentrations. One sample without preservative was kept frozen to determine milk FA profile and MUN concentration. On d 18 of each experiment period, blood samples were withdrawn before the a.m. feeding from the jugular vein into Vacutainer tubes (Becton Dickinson and Cie, Rutherford, NJ) containing heparin for determination of total cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, triglycerides, and glucose concentrations. The plasma was separated by centrifugation ($2,500 \times g$ for 20 min).

Chemical Analyses

Dry matter of the diets was determined in a forced-air oven according to method 934.01 (AOAC, 1990). Total mixed diets were ground to pass a 1-mm screen in a Wiley mill before analyses of N, ether extract, ADF, and NDF. Total N determination used a Tecnal TE-036/1 (Tecnal, Piracicaba, São Paulo, Brazil) following method 990.03 of AOAC (1990). Concentrations of NDF and ADF inclusive of residual ash were measured according to the nonsequential procedures of Van Soest et al. (1991) with the use of amylase but without sodium sulfite. Ether extraction in diets was conducted with Tecnal TE-044/1 according to the method no. 7.060 (AOAC, 1990). Period fecal, orts, and TMR composites were analyzed for indigestible NDF (the NDF remaining after 144 h of in vitro fermentation). Indigestible NDF was used as an internal marker to estimate apparent nutrient digestibility and fecal output (Cochran et al., 1986). Coefficients of apparent digestion of dietary components were determined by comparing dietary indigestible NDF concentration (corrected for orts) with fecal indigestible NDF concentration as outlined by Cochran et al. (1986). The N, fat, and lactose concentrations in milk were determined by infrared spectroscopy (Bentley model 2000; Bentley Instrument Inc., Chaska, MN). Concentration of MUN was deter-

Table 1. Chemical composition of total mixed diets of Holstein cows fed whole flaxseed without monensin (WFCO), whole flaxseed with monensin (WFMO), ground flaxseed without monensin (GFCO), or ground flaxseed with monensin (GFMO)

Item	Treatment				SE	P-value		
	WFCO	WFMO	GFCO	GFMO		Flaxseed	Monensin	Flaxseed × monensin
Ingredient, % of DM								
Corn silage	60.0	60.0	60.0	60.0				
Ground corn	8.8	8.8	8.8	8.8				
Soybean meal	17.7	17.7	17.7	17.7				
Whole flaxseed	12.0	12.0	0	0				
Ground flaxseed	0	0	12.0	12.0				
Mineral and vitamin								
Supplement ¹	1.50	1.48	1.50	1.48				
Monensin	0	0.02	0	0.02				
Chemical analysis								
DM, %	54.0	54.0	53.9	53.9	0.1	0.15	0.57	1.0
CP, % of DM	16.4	16.5	16.4	16.5	0.1	0.87	0.05	1.0
Ether extract, % of DM	6.4	6.4	6.4	6.4	0.1	0.51	0.49	1.0
NDF, % of DM	40.4	40.0	40.4	40.0	0.3	0.98	0.13	1.0
ADF, % of DM	23.5	23.6	23.4	23.6	0.04	0.51	0.001	1.0
NE _L , ² Mcal/kg	1.44	1.45	1.47	1.49				
NSC, ² % of DM	30.3	31.1	30.4	31.2				
Fatty acid, ³ % of total								
C16:0	15.7	15.5	15.8	15.6	0.2	0.69	0.19	1.0
C18:0	4.4	4.4	4.6	4.6	0.1	0.05	0.70	1.0
C18:1	28.6	28.9	29.0	29.3	0.4	0.40	0.20	1.0
C18:2	36.1	35.8	36.1	35.9	0.2	0.96	0.20	1.0
C18:3	10.2	10.2	9.5	9.4	0.2	0.003	0.77	1.0
Others	5.0	5.2	5.0	5.2	0.1	0.84	0.14	1.0

¹Contained 27.0% Ca, 8.0% P, 2.0% Mg, 2.0% S, 2,200 mg/kg of Fe, 2,800 mg/kg of Zn, 800 mg/kg of Cu, 801 mg/kg of F, 60 mg/kg of I, 50 mg/kg of Co, 40 mg/kg of Se, 216,000 IU/kg of vitamin A, 67,600 IU/kg of vitamin D₃, and 500 IU/kg of vitamin E.

²Calculated using published values of feed ingredients (NRC, 2001).

³Mean of 7 daily samples collected and accumulated during the digestibility trial.

mined according to the method of Marsh et al. (1965). Milk SCC were obtained using an electronic counter (Somacount 500, Chaska, MN) as described by Voltolini et al. (2001).

Fat in milk was separated by centrifugation as described by Murphy et al. (1995), and FA were methylated according to method 5509 of ISO (1978) using KOH/methanol (Synth, São Paulo, Brazil) and n-heptane (Vetec, Rio de Janeiro, Brazil). Fatty acid methyl ester profiles were measured at a split ratio of 1:80 by GLC on a Varian chromatograph (Palo Alto, CA) with a G1315A autosampler equipped with a flame-ionization detector and a CP-7420 fused silica capillary column (100 m and 0.25 mm i.d., 0.25-μm film thickness). The column parameters were as follows: initial column temperature of 65°C was maintained for 8 min; the temperature was then programmed at 50°C per min to 170°C. This temperature was maintained for 40 min, then increased 50°C per min to 240°C, and remained at this temperature for 28.5 min. Injector and detector temperatures were 220 and 245°C, respectively. The carrier gas was hydrogen at 1.4 mL/min. Hydrogen flow to the detector was 30 mL/min, airflow was 300 mL/min, and

the flow of N₂ make-up gas was 30 mL/min. Fatty acid peaks were identified using pure methyl ester standards (Sigma, São Paulo, Brazil).

Plasma triglycerides (Triglycerides FS, DiaSys, Holzheim, Germany), HDL cholesterol (HDL-C Immuno FS, DiaSys), LDL cholesterol (LDL-C Select FS, DiaSys), total cholesterol (Cholesterol FS, DiaSys), and glucose (Glucose GOD FS, DiaSys) concentrations were analyzed by colorimetric methods.

Statistical Analysis

All results were analyzed using the MIXED procedure of SAS (2000) within a 2 × 2 factorial arrangement of treatments. Data on digestion, milk production, milk composition, blood composition, and feed intake were analyzed using a replicated 4 × 4 Latin square design with the following general model:

$$Y_{ijkl} = \mu + S_i + C_{j(i)} + P_k + T_l + e_{ijkl},$$

where Y_{ijkl} = the dependent variable, μ = overall mean, S_i = random effect of square ($i = 1$ to 2), $C_{j(i)}$ = random

Table 2. Feed intake, milk production, and milk composition of Holstein cows fed whole flaxseed without monensin (WFCO), whole flaxseed with monensin (WFMO), ground flaxseed without monensin (GFCO), or ground flaxseed with monensin (GFMO)¹

Item	Treatment				SE	P-value		
	WFCO	WFMO	GFCO	GFMO		Flaxseed	Monensin	Flaxseed × monensin
DMI, kg/d	16.1	16.0	16.4	16.1	0.2	0.31	0.43	0.61
DMI, % of BW	2.91	2.78	2.88	2.80	0.06	0.95	0.12	0.66
CP intake, kg/d	2.70	2.70	2.76	2.73	0.03	0.28	0.72	0.67
Milk production, kg/d	21.3	21.5	22.8	22.7	0.7	0.07	0.98	0.82
4% FCM, kg/d	22.7	20.8	22.5	21.9	0.6	0.47	0.05	0.31
Milk composition, %								
Protein	3.13	3.10	3.11	3.10	0.05	0.91	0.77	0.91
Fat	4.44	3.81	3.90	3.75	0.18	0.11	0.04	0.21
Lactose	4.57	4.62	4.61	4.66	0.03	0.15	0.10	0.88
Urea N	16.9	17.1	18.8	18.5	0.7	0.03	0.92	0.77
Total solids	13.4	12.6	12.7	12.5	0.1	0.04	0.009	0.07
SCC, × 10 ³ /mL	2.46	2.42	2.56	2.34	0.13	0.91	0.33	0.49
SCS ²	540.8	779.9	573.6	396.7	253.8	0.49	0.90	0.42
Milk yield, kg/d								
Protein	0.66	0.65	0.69	0.69	0.02	0.21	0.80	0.87
Fat	0.95	0.82	0.89	0.86	0.03	0.84	0.02	0.17

¹Least squares means with pooled SE.²SCS = log₁₀ SCC.

effect of cow within square ($j = 1$ to 4), P_k = fixed effect of period ($k = 1$ to 4), T_l = fixed effect of treatment ($l = \text{WFCO, WFMO, GFCO, GFMO}$), and e_{ijkl} = random residual error. Treatments were compared with provide factorial contrasts: 1) WF vs. GF, 2) with vs. without monensin, and 3) the interaction between flaxseed processing and monensin supplementation. Significance was declared at $P < 0.05$ and a trend at $0.5 < P < 0.10$, unless otherwise stated.

RESULTS AND DISCUSSION

The chemical composition of the TMR (Table 1) was generally similar among diets. Ground flaxseed had higher and lower percentage of 18:0 and 18:3 FA, respectively, than WF, which may suggest partial modification of long-chain FA during processing of the seeds. Similarly, Gonthier et al. (2004) reported that extruded and micronized flaxseed had lower concentration of 18:3 and higher concentration of 18:0 than raw flaxseed. There was no significant interaction between flaxseed processing and monensin supplementation for DMI, CP intake, milk production, 4% FCM yield, milk composition, and milk yield of components (Table 2). Intake of DM, expressed as kilograms per day or as a percentage of BW, was similar among treatments. Monensin was fed at 0.02% of the DM and DMI of cows fed MO averaged 16.1 kg/d, thus resulting in an average intake of 320 mg of monensin per d. Similarly, feeding monensin at 22 mg/kg of DM (Plaizier et al., 2000; Osborne et al., 2004), 24 mg/kg of DM (Bell et al., 2006), or 300 mg/d

(Van Der Werf et al., 1998; Phipps et al., 2000) had no effect on DMI of dairy cows. Moreover, cows fed ground (Ward et al., 2002; Gonthier et al., 2005) or whole (Kennelly, 1996; Petit et al., 2004) flaxseed had similar DMI compared with those fed no flaxseed, thus suggesting that grinding of flaxseed does not affect DMI.

Intake of CP, expressed as kilograms per day, was similar among treatments as a result of similar DMI. Milk production tended ($P = 0.07$) to be 6.5% greater (+1.4 kg/d) for cows fed GF compared with those fed WF. Similarly, Kennelly (1996) reported higher milk production (+2.0 kg/d) for cows fed rolled flaxseed compared with those fed WF. Processing of flaxseed had no effect on 4% FCM yield. Milk protein and lactose concentrations were similar for cows fed WF and GF. Milk fat concentration tended ($P = 0.11$) to decrease with flaxseed processing, which may indicate a greater release of oil in the rumen (Mohamed et al., 1988) due to grinding. Milk urea N concentration was higher for cows fed GF compared with WF. Physical breakdown of seeds is known to increase ruminal CP degradability (Stern et al., 1994). Therefore, greater ruminal CP degradability for GF rather than WF may contribute to increase urea N concentration in milk; DePeters and Cant (1992) reported that feeding high compared with low ruminal degradable protein increases ($P = 0.08$) milk NPN concentration. The greater oil release with ground rather than WF could also contribute to affect milk urea N concentration, although the effects of feeding protected and unprotected fat supplements on milk urea N concentrations are still unclear (DePeters and

Cant, 1992). Feeding WF compared with GF increased concentration of milk total solids but the increase was more important when cows were fed no monensin, which tended ($P = 0.07$) to result in an interaction between flaxseed processing and monensin supplementation. Somatic cell count and SCS were not affected by flaxseed processing. Milk yields of protein and fat were similar for cows fed WF and GF.

Monensin supplementation had no effect on milk production. This disagrees with earlier trials establishing that the inclusion of 300 mg of monensin/d in dairy cow diets for the first 25 wk of lactation would increase milk yield (Van der Werf et al., 1998; Phipps et al., 2000). However, feeding monensin at 24 and 22 mg/kg of DM, respectively, for 15- (Bell et al., 2006) and 35-d (Osborne et al., 2004) periods had no effect on DMI and milk yield of dairy cows. Discrepancies between studies could be related to factors such as stage of lactation, diet composition, and length of the trial. Moreover, Sauer et al. (1998) suggested that some adaptive changes occur in the rumen microflora following monensin supplementation and cows that had previously received monensin no longer respond. The response to monensin regarding milk production and composition also differs with genetic line, cows with the highest capacity of milk production responding best to monensin supplementation (Van der Werf et al., 1998). The lack of any effect on milk production in the present experiment where cows averaged 20 kg/d would corroborate this finding.

Cows fed monensin had lower 4% FCM yield as a result of the decrease in milk fat concentration. This agrees with the well-documented decrease in milk fat concentration reported when adding monensin to a dairy cow diet (Sauer et al., 1998; Dhiman et al., 1999; Phipps et al., 2000; Bell et al., 2006) due to the reduction of molar proportions of acetate and butyrate and the increase of propionate (Sauer et al., 1998). Moreover, monensin supplementation reduced milk fat percentage in cows receiving diets with less than 40% NSC (Duffield et al., 2003), which is in the range of values observed for the present experiment (Table 1). Milk lactose concentration tended ($P = 0.10$) to be higher with than without MO supplementation. Feeding monensin had no effect on milk protein and MUN concentrations, SCC, SCS, and milk yield of protein. In general, milk protein concentration is little affected by monensin supplementation (Sauer et al., 1998; Ruiz et al., 2001; Bell et al., 2006), although it decreased (Phipps et al., 2000) or increased (Duffield et al., 1998, 2003) in some cases.

In general, there were no interactions between flaxseed processing and monensin supplementation on milk concentrations of individual FA with the exception of *trans*11-18:1 (Table 3). Feeding ground compared with WF decreased concentrations of *cis*10-15:1, 16:0, 17:0,

and *cis*6-20:4, and it increased those of *cis*6-18:2, *cis*9, *trans*11-18:2, *cis*3-18:3, and n-3 FA. Moreover, flaxseed processing tended ($P < 0.10$) to decrease concentrations of *cis*7-16:1 and n-6 and to increase those of *cis*3-20:5 and unidentified FA. As a result, there was a decrease in concentrations of medium-chain and saturated FA and a trend for higher ($P = 0.06$) concentrations of long-chain FA following grinding of flaxseed. Similar differences in concentrations of milk FA were generally observed when rolled flaxseed was compared with WF (Kennelly, 1996). Physical breakdown of flaxseed may contribute to increase availability of FA for absorption and transfer in milk partly as a result of more rapid passage rate out of the rumen with ground than WF, which would increase concentrations of linolenic acid and n-3 FA in milk. Moreover, grinding of flaxseed may also increase partial ruminal biohydrogenation of C18:3 as shown by the greater *cis*9, *trans*11-18:2 concentration in milk fat of cows fed ground compared with WF. Long-chain PUFA (18:2 and 18:3) are subjected to biohydrogenation processes in the rumen, and the intermediate steps for converting C18:2 to CLA have been suggested by Kepler and Tove (1967). Other results (Dhiman et al., 1999) suggest that C18:3 might be also a substrate for conversion to CLA in the rumen. Although the C18:3 FA can be biohydrogenated in the rumen, they do not appear to increase the secretion of CLA into milk, as is the case with C18:2 FA (Lock and Garnsworthy, 2002). It is believed that the C18:3 FA might limit the formation of the *trans*11-18:1, which is converted to CLA in the mammary gland (Griinari and Bauman, 1999). On the other hand, Chilliard et al. (2000) reported that flaxseed oil greatly increases milk fat CLA content and is at least as efficient as C18:2-rich vegetable oils, thus suggesting that feeding flaxseed oil results in a large increase in the production of ruminal *trans*11-18:1, which can be used by the mammary gland for CLA synthesis. In the present experiment, cows fed the GFMO diet had the highest *trans*11-18:1 concentration and the trend for the highest ($P = 0.11$) CLA concentration, thus suggesting that C18:3 does not always interfere with the conversion of CLA in the mammary gland.

Monensin supplementation decreased concentrations of *cis*6-20:4, *cis*6-22:4 and increased those of *cis*9, *trans*11-18:2, *trans*10-18:2, and unidentified FA. Supplementation with monensin tended ($P < 0.10$) to increase concentrations of 17:0, *iso*17:0, *cis*6-18:2, and n-6 and to decrease concentrations of *cis*3-22:6, thus resulting in lower concentrations of saturated FA for cows fed MO compared with those fed no MO. Similarly, Sauer et al. (1998) reported an increase in *trans*11-18:1 and C18:2 FA with monensin supplementation. There was an interaction between flaxseed processing and

Table 3. Fatty acid concentrations in milk of Holstein cows (percentage of total fatty acids) fed whole flaxseed without monensin (WFCO), whole flaxseed with monensin (WFMO), ground flaxseed without monensin (GFCO), or ground flaxseed with monensin (GFMO)¹

Item ²	Treatment				SE	P-value		
	WFCO	WFMO	GFCO	GFMO		Flaxseed	Monensin	Flaxseed × monensin
6:0	0.45	0.40	0.43	0.41	0.09	0.95	0.72	0.85
8:0	0.52	0.45	0.48	0.44	0.08	0.77	0.52	0.87
10:0	1.72	1.52	1.60	1.43	0.18	0.58	0.33	0.93
11:0	0.04	0.04	0.04	0.03	0.01	0.32	0.83	0.33
12:0	2.17	2.03	2.06	1.90	0.16	0.46	0.37	0.95
13:0	0.07	0.09	0.08	0.07	0.01	0.47	0.51	0.29
14:0	9.18	8.96	8.93	8.32	0.38	0.26	0.28	0.60
<i>cis</i> 10-15:1	0.83	0.93	0.79	0.79	0.04	0.05	0.26	0.23
16:0	26.38	26.43	24.62	23.27	0.64	0.001	0.32	0.28
<i>iso</i> 16:0	0.22	0.20	0.19	0.20	0.02	0.41	0.79	0.42
<i>cis</i> 9-16:1	0.32	0.31	0.30	0.31	0.03	0.69	0.85	0.71
<i>cis</i> 7-16:1	1.36	1.34	1.16	1.24	0.11	0.07	0.71	0.52
17:0	0.49	0.53	0.47	0.48	0.01	0.01	0.06	0.40
<i>iso</i> 17:0	0.57	0.60	0.50	0.58	0.02	0.11	0.07	0.39
<i>cis</i> 10-17:1	0.23	0.22	0.18	0.24	0.03	0.70	0.45	0.34
18:0	17.34	17.36	18.84	16.76	0.73	0.54	0.17	0.16
<i>trans</i> 11-18:1	1.40	1.59	1.71	3.33	0.06	0.0001	0.0001	0.0001
<i>cis</i> 9-18:1	29.08	28.37	29.01	29.30	0.85	0.61	0.80	0.56
<i>cis</i> 6-18:2	1.70	1.90	1.91	2.09	0.10	0.04	0.05	0.93
<i>cis</i> 9, <i>trans</i> 11-18:2	0.47	0.55	0.56	1.01	0.11	0.02	0.02	0.11
<i>trans</i> 10-18:2	0.06	0.06	0.05	0.07	0.01	0.40	0.02	0.17
<i>cis</i> 3-18:3	0.66	0.67	1.05	0.80	0.07	0.004	0.14	0.12
<i>cis</i> 6-20:4	0.13	0.11	0.11	0.10	0.01	0.03	0.02	0.94
<i>cis</i> 3-20:5	0.05	0.05	0.07	0.06	0.01	0.07	0.14	0.56
<i>cis</i> 6-22:4	0.03	0.02	0.03	0.02	0.01	0.24	0.02	0.29
<i>cis</i> 3-22:6	0.08	0.08	0.09	0.08	0.01	0.50	0.06	0.48
Total <i>trans</i>	1.93	2.20	2.32	4.40	0.15	0.01	0.01	0.01
Unidentified	4.47	5.19	4.75	6.66	0.44	0.06	0.007	0.18
MUFA	33.2	32.8	33.2	35.2	0.9	0.19	0.37	0.17
PUFA	3.1	3.4	3.9	4.2	0.2	0.001	0.11	0.82
SFA	59.1	58.6	58.2	53.9	1.1	0.02	0.04	0.10
PUFA/SFA	0.053	0.061	0.067	0.080	0.004	0.002	0.04	0.56
SCFA	5.0	4.5	4.7	4.3	0.5	0.61	0.44	0.96
MCFA	36.6	36.5	34.5	32.6	0.8	0.003	0.25	0.29
LCFA	53.9	53.7	56.0	56.4	1.2	0.06	0.92	0.80
n-3 ³	0.80	0.79	1.20	0.94	0.1	0.003	0.10	0.11
n-6 ⁴	1.84	2.03	2.04	2.20	0.1	0.07	0.09	0.92
n-6:n-3	2.4	2.7	1.8	2.4	0.1	0.007	0.008	0.37

¹Least squares means with pooled SE.²MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; SFA = saturated fatty acids; SCFA = short-chain fatty acids; MCFA = medium-chain fatty acids; LCFA = long-chain fatty acids.³*Cis*3-18:3 + *cis*3-20:5 + *cis*3-22:6.⁴*Cis*6-18:2 + *cis*6-20:4 + *cis*6-22:4.

monensin supplementation as a result of higher concentration of *trans*11-18:1 and total *trans* FA in milk fat of cows fed GF with monensin than in milk fat of those fed the other diets. In parallel, highest ($P = 0.11$) numerical concentrations of *cis*9, *trans*11-18:2 and a trend ($P = 0.10$) for lower concentration of saturated FA in milk fat were observed for cows fed GF with monensin compared with those fed the other 3 diets. It was suggested that MO can modify milk FA profile by inhibiting biohydrogenation of linoleic acid (C18:2) and increasing the content of C18:1 (Fellner et al., 1997; Sauer et al., 1998). Moreover, higher concentrations of linoleic acid (C18:2), *trans*11-18:1, and CLA in continuous cultures

of ruminal bacteria following infusion of monensin were reported by Fellner et al. (1997). Therefore, this would suggest that monensin supplementation was successful in decreasing complete ruminal biohydrogenation of FA of GF as indicated by the trend ($P = 0.10$) for lower concentrations of saturated FA in milk fat and by the highest concentration of *trans*11-18:1 and the trend ($P = 0.11$) for the highest concentration of *cis*9, *trans*11-18:2 in milk fat.

The n-6 to n-3 FA ratio in milk fat was significantly lower for cows fed ground compared with WF and cows fed no monensin had a lower ratio than those fed monensin. The n-6 to n-3 FA ratios were within the range

Table 4. Digestion of Holstein cows fed whole flaxseed without monensin (WFCO), whole flaxseed with monensin (WFMO), ground flaxseed without monensin (GFCO), or ground flaxseed with monensin (GFMO)¹

Item	Treatment				SE	P-value		
	WFCO	WFMO	GFCO	GFMO		Flaxseed	Monensin	Flaxseed × monensin
Digestibility, %								
DM	58.6	59.7	58.7	59.6	0.7	0.99	0.19	0.87
ADF	36.3	36.4	31.5	34.6	1.5	0.04	0.29	0.34
NDF	38.7	39.8	37.4	37.5	1.3	0.18	0.66	0.70
CP	65.9	67.9	69.4	69.3	1.6	0.003	0.20	0.16
Ether extract	73.1	73.6	87.4	89.3	3.4	0.0001	0.34	0.55
OM	49.8	49.6	51.3	50.8	0.7	0.07	0.61	0.81

¹Least squares means with pooled SE.

usually reported when feeding flaxseed (Petit, 2002; Petit et al., 2002).

There was no interaction between flaxseed processing and monensin supplementation for digestibility (Table 4). Cows fed WF had higher digestibilities of ADF but lower digestibilities of CP and ether extract than those fed GF. Lower fiber digestibility is associated with process such as grinding (Scott et al., 1991) and is consistent with the release of oil from the seed into the rumen (Murphy et al., 1990). That cows fed GF had higher milk CLA concentration than those fed WF agrees with a higher release of oil in the rumen and ruminal biohydrogenation of PUFA and the decrease in fiber digestibility observed with feeding of GF. On the other hand, grinding could contribute to increase digestibility of fat by releasing a greater amount of oil in the rumen and the intestine as discussed previously. Rumen protection of CP usually parallels fat as a protein-rich matrix surrounds the fat droplets of oilseeds (Khorasani et al., 1992); therefore, greater availability of protein will parallel that of oil, thus increasing digestibility of fat and protein as observed in the present experiment. There was a trend ($P = 0.07$) for flaxseed processing to increase digestibility of OM.

Monensin supplementation had no effect on digestibilities of DM, ADF, NDF, CP, ether extract, and OM. Similar results have been reported by Benchaar et al. (2006) and Plaizier et al. (2000), although monensin increased CP digestibility in both studies. Discrepancies between studies could partly be due to differences in diet composition. According to Plaizier et al. (2000), MO supplementation increases CP digestibility in cows fed high concentrate diets, whereas it has no effect in those fed high forage diets. Diets used in the experiments of Benchaar et al. (2006) and Plaizier et al. (2000) contained, respectively, 52.0 and 57.4% concentrate, and MO supplementation increased CP digestibility. On the other hand, diets used by Haimoud et al. (1995) and in the present experiment contained, respectively,

35.4 and 40.0% concentrate, and MO had no effect on CP digestibility, which would corroborate that hypothesis.

Flaxseed processing had no effect on plasma concentrations of glucose, triglycerides, total cholesterol, HDL, and LDL cholesterol (Table 5). Similar plasma concentrations of total cholesterol, HDL and LDL cholesterol, and glucose have been reported when feeding calcium salts of palm oil, micronized soybeans, or WF (Petit et al., 2004). Plasma concentration of glucose tended ($P = 0.09$) to be higher for cows fed monensin than for those fed no monensin as previously reported by Duffield et al. (1998), although others found no difference (Abe et al., 1994; Sauer et al., 1998). According to Duffield et al. (1998), monensin supplementation has positive effects on energy indicators and blood concentration of glucose mediated through different ways such as increased propionate concentration in the rumen and reduced methane production in the rumen and rate of ketone oxidation. The LDL cholesterol concentration in plasma was significantly greater for cows fed monensin than for those fed no monensin, but there was no effect of monensin supplementation on plasma concentrations of triglycerides, total cholesterol, and HDL cholesterol.

CONCLUSIONS

In conclusion, flaxseed grinding and monensin supplementation at 0.02% of the DM had no effect on DMI of lactating cows. Grinding of flaxseed had no effect on 4% FCM yield and milk protein and lactose concentrations, and it decreased digestibility of ADF and increased that of CP and ether extract. Monensin had no effect on digestibility of the diet and milk production, but it decreased 4% FCM yield as a result of a decrease in milk fat concentration. Feeding ground compared with WF increased concentrations of *cis*6-18:2, *cis*9, *trans*11-18:2, *cis*3-18:3 and decreased those of medium-chain and saturated FA in milk fat, which would improve milk FA profile from a human health perspective. Monensin supplementation increased concentrations of

Table 5. Blood composition of Holstein cows fed whole flaxseed without monensin (WFCO), whole flaxseed with monensin (WFMO), ground flaxseed without monensin (GFCO), or ground flaxseed with monensin (GFMO)¹

Item	Treatment				SE	P-value		
	WFCO	WFMO	GFCO	GFMO		Flaxseed	Monensin	Flaxseed × monensin
Glucose, mg/100 mL	53.6	67.1	62.4	64.9	4.4	0.47	0.09	0.23
Triglycerides, mg/100 mL	12.5	15.0	13.3	15.4	1.4	0.70	0.13	0.90
Total cholesterol, mg/100 mL	119.5	140.0	142.4	157.9	16.2	0.22	0.28	0.88
HDL cholesterol, mg/100 mL	99.0	110.6	119.6	129.0	13.3	0.16	0.44	0.93
LDL cholesterol, mg/100 mL	18.0	26.4	20.1	25.8	3.2	0.81	0.04	0.68

¹Least squares means with pooled SE.

*cis*9, *trans*11-18:2 and decreased concentrations of saturated FA in milk fat, thus also improving milk FA profile for human health. Concentration of *trans*11-18:1 was higher and that of saturated FA tended to be lower in milk fat of cows fed GF with monensin than for those fed the other diets, thus suggesting that monensin supplementation was successful in decreasing ruminal biohydrogenation of FA of GF and increasing concentrations of beneficial FA in milk fat. Monensin supplementation and flaxseed processing are 2 useful dietary tools to modify milk FA profile.

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