Oxidation and Textural Characteristics of Butter and Ice Cream with Modified Fatty Acid Profiles

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ABSTRACT

The primary objective of this study was to evaluate oxidation and firmness of butter and ice cream made with modified milkfat containing enhanced amounts of linoleic acid or oleic acid. The influence of the fatty acid profile of the HO milkfat relating to product properties as compared with the influence the fatty acid profile of the HL milkfat was the main focus of the research.

Altering the degree of unsaturation in milkfat may affect melting characteristics and oxidation rates, leading to quality issues in dairy products.

Three milkfat compositions (high-oleic, high-linoleic, and control) were obtained by modifying the diets of Holstein cows. Ice cream and butter were processed from milkfat obtained from cows in each dietary group. Butter and ice cream samples were analyzed to determine fatty acid profile and firmness. High-oleic milkfat resulted in a softer butter. Solid fat index of high-oleic and high-linoleic milkfat was lower than the control. Control ice cream mix had higher viscosity compared with high-oleic and high-linoleic, but firmness of all ice creams was similar when measured between –17 and –13°C. Nutritional and textural properties of butter and ice cream can be improved by modifying the diets of cows.

(Key words: oleic acid, linoleic acid, conjugated linoleic acid (CLA), firmness)

Abbreviation key: HO = high-oleic; HL = high linoleic; CLA = conjugated linoleic acid, TVA = trans-vaccenic acid.

INTRODUCTION

Coronary heart disease is a leading cause of death in America (American Heart Association, 2000) and most industrialized countries (Gurr, 1995). In 1997, cardio-

vascular diseases were responsible for 41.2% of all deaths in the US. Unfortunately whole milk and some dairy products have been listed as one of the risk factors in coronary heart disease due to their high content of saturated fatty acids (Noakes et al., 1996). Modification of the fatty acid profile in milkfat to yield lower saturated fatty acid content and greater polyunsaturated fatty acid content has been a major research focus for the dairy industry. A modified fatty acid profile may influence several physical and chemical properties of milkfat such as firmness, melting point, solid fat and liquid fat content, viscosity, oxidative stability, and flavor. The number of double bonds in fatty acids influences melting behavior and oxidative stability (off-flavors), whereas distribution of the fatty acids in the triglyceride structure influences crystallization behavior, melting behavior and nutritional aspects (Hawke and Taylor, 1995; Kaylegian and Lindsay, 1995).

Several studies indicated that a high content of unsaturated fatty acids in milkfat increases the risk of oxidation and production of off-flavors (Lin et al., 1996a; Ashes et al., 1997; Focant et al., 1998; Im and Marshall, 1998). For example, milk with a high polyunsaturated fatty acid content can develop oxidized flavors within 24 h of refrigerated storage (McDonald and Scott, 1977). Off-flavors in butterfat can be carried to second products, such as ice cream, and affect consumer acceptance (Abd El-Rahman et al., 1997). However, milkfat with a high monounsaturated fatty acid content compared with a high polyunsaturated fatty acid content did not exhibit oxidation problems (Lin et al., 1996a; Lin et al., 1996b). Unsaturated fatty acids are oxidized to form hydroperoxides, which are very unstable. Secondary oxidation products, including saturated and unsaturated aldehydes, ketones, hydrocarbons, semialdehydes and alcohols, may be perceptible to consumers even at low concentrations (Fox and Mc Sweeney, 1998).

The melting point of fat also is influenced by fatty acid profile. The higher the number of double bonds in a fatty acid chain, the lower the melting point (Walstra, 1995). Solid fat content, which measures the percentage of solid fat at a specific temperature, is usually used to

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Table 1. Ingredient composition of diets containing high-oleic or high-linoleic safflower oil.

Ingredient	% of DM
Corn silage	11.0
Alfalfa silage	28.1
Orchard grass hay (chopped)	13.4
Corn grain (ground)	31.6
Soybean meal	11.9
Mineral/vitamin mix	0.9
Dicalcium phosphate	0.1
Limestone	0.5
Safflower oil ¹	2.5
Total	100.00

¹High oleic safflower oil contained 79% oleic acid and 13% linoleic acid; high linoleic safflower oil contained 76% linoleic acid and 15% oleic acid.

evaluate dairy products (Kaylegian and Lindsay, 1995).

When milkfat was modified to contain more unsaturated fat (35% of cis C18:1 and 8% C18:2), the softer milkfat influenced properties such as melting point and processes such as churning (Ashes et al., 1997). When milkfat was modified to contain a higher percentage of unsaturated triglycerides, both high and low molecular weight, melting point of the fat decreased and produced a softer butter at any temperature (Ashes et al., 1997). The objective of the present study was to analyze the influence of milkfats with modified fatty acid profiles (High-oleic (HO) or High-linoleic (HL)) on chemical and textural properties of butter and ice cream. Primary focus was placed on the influence of the fatty acid profile of the HO milkfat relating to product properties as compared with the influence the fatty acid profile of the HL milkfat.

MATERIALS AND METHODS

Four Holstein cows were randomly assigned to one of two diets during three 2-week periods. The diets (Table 1) were formulated to meet NRC (1989) requirements, and included HO safflower oil or HL safflower oil (Columbus Food Co., North Albany, IL) at 2.5% of diet DM (Table 1). Dietary sequences during the three periods were HO-HL-HO or HL-HO-HL. During both milkings (0100 and 1300 h) on the last 2 d of each feeding period, milk from each cow was weighed and placed into stainless steel cans. Milk was commingled by diet (HO or HL) and stored at 4°C prior to processing. Bulk tank milk was obtained to provide a control for comparison with milk from cows fed HO or HL in each period. The tank held milk produced by approximately 135 cows fed a typical TMR without supplemental fat. Thus, control milk, high-oleic milk, and high-linoleic milk were collected and processed into butter and ice cream each of the three 2-wk periods.

Table 2. 10% Ice cream formulation.¹

Ingredient	Percentage
Milkfat	10.00
Nonfat dry milk	10.50
Sweetener ²	16.66
Stabilizer ³	0.20

¹Formulation calculated using DAYSYS, Penn State Dairy Formulation System, Komputerwerk, Inc., 1988.

²Sweetener = sucrose (60%), corn syrup (40%).

³Stabilizer = Kontrol 0.25 (mono-diglycerides, cellulose gum, guar gum, polysorbate 80, carrageenan).

Butter and ice cream production. Milk was preheated at 55°C and separated into 30 to 35% cream and skim milk by a pilot plant separator (Elecram separator, model IG. Bonanza Industries, Inc., Calgary, Alberta). Creams were pasteurized at 68.8°C for 30 min and cooled to 13°C in an ice bath. A portion of each treated cream was churned using electric churns, until butter kernels were formed (13°C; 30 to 45 min). The buttermilk was separated from the butter kernels by draining through cheesecloth. Butter was pressed, washed with cold water and worked with a spatula to remove excess buttermilk. Butter samples were packaged in 5 oz. plastic cups or sterile plastic bags for further analyses. Butter was analyzed for color, firmness and fatty acid profile. Butteroil was extracted by melting the butter at about 55 to 60°C, and refrigerated at 3.3°C for 30 min to separate the butteroil from the aqueous phase (Elling and Duncan, 1996). Butteroil was used to determine solid fat content.

The remaining portion of cream was used in the formulation of ice cream (10% fat) (Table 2). Ice cream mix was preheated at 54.4°C, homogenized, pasteurized at 68.3°C for 30 min and aged (−4°C) for 24 h. Ice cream mixes were frozen in a batch freezer (Emory Thompson Freezer 2HSC A, Emory Thompson Machine and Supply Co., New York) with 75% overrun. Ice cream samples were packaged in 4.6-L plastic containers or 5 oz (140 ml) plastic cups and stored at −20°C until textural and chemical analyses.

Compositional analyses. Composition of ice cream was determined to verify that all treatments had similar characteristics except for variation in fatty acid composition. Fat content of ice cream was determined by the Pennsylvania test (Marshall, 1993). Protein was determined by a dye-binding method (Bio-rad, Hercules, CA) using a spectrophotometer (Spectronic 1001 Split Beam Spectrophotometer; Milton Roy Company, Rochester, NY). Moisture and total solids content were measured using an infrared analyzer (Infrared Analyzer 115 Vac; Denver Instrument Company, Arvado, CO). Ash was determined by gravimetric analysis (AOAC 920.117; AOAC, 1997).

Fatty acid profile. Fatty acid content of ice cream mixes and butteroil was determined to evaluate the effect of dietary treatments on oleic acid, linoleic acid, medium chain fatty acids, trans-vaccenic acid (TVA), and conjugated linoleic acid (CLA) content. Milkfat was extracted from ice cream mix samples (Bligh and Dyer, 1959). Fatty acids were methylated by in situ transesterification with 0.5N methanolic NaOH (Park and Goins, 1994). Fatty acid methyl esters were injected by an auto sampler into a Hewlett-Packard 5890A gas chromatograph with a flame ionization detector (Hewlett-Packard, Sunnyvale, CA) (Loor, 2001). Methyl esters were separated on a 100 m $\times$ 0.25 mm i.d. fused silica capillary column (CP-Sil 88; Chrompack, Middleburg, The Netherlands). An 80 to 1 split ratio was used for injection of 0.5 μ l hexane containing the methyl esters of milkfat fatty acids. The carrier gas was hydrogen (ultra pure) and inlet pressure was maintained at 23.1 psi. The injector temperature was maintained at 250°C, while the detector temperature was maintained at 255°C. The initial oven temperature was set at 70°C and held for 1 min with increases of 5°C per min until 100°C was reached and held for 2 min. An increase of 0°C/min was set until 175°C was reached and held for 40 min and then increased 5°C/min to 225°C and held for 15 min (Loor, 2001).

Oxidation rate. Milkfat was extracted (AOAC 960.32; AOAC, 1997) from ice cream mixes (fresh product within one week of mix processing) and stored frozen ice cream samples to obtain the oil and analyze peroxide and free fatty acids. Initial products of oxidation were measured with the determination of the peroxide value (AOAC CD 8-53; AOAC, 1997). Free fatty acids were assessed using the AOAC method Ca 5a-40 (AOAC, 1997). Both analyses were determined at different stages during the process: 1) Ice cream mix after homogenization and before pasteurization (0 month); 2) Ice cream after freezing and packaging: peroxides and free fatty acids were measured on all replications after 1 and 2 months of storage. Peroxide values were measured subsequently at different intervals of storage to evaluate the peroxide behavior through storage time.

Color. Color of butter and ice cream samples was measured after 3 to 5 months of storage. A Minolta (CR-2000, Japan) colorimeter was used to determine a, b, and L values.

Firmness. Firmness was measured by compression (Model 100; Instron, Canton, MA) using a cylindrical probe. A 50-kg transducer with a 20% load range was used at a speed of 100 mm/min. Firmness was measured as kilograms of force. Product temperature was between -17 and -13°C for ice cream and between 4.2 and 5.5°C for butter. Ice cream and butter samples used to mea-

sure firmness were stored in 5-oz (140 ml) cups (9.0-cm diameter $\times$ 3.5-cm deep) (Sweetheart Plastic Food Cups; Sweetheart Cup Company, Inc., Chicago, IL).

Solid fat index. The solid fat index was measured by the dilatometric method (Method Cd 10-57; AOCS, 1996). Calibrated dilatometers (Kontes, Vineland, NJ) were used to measure the solid fat index at a temperature range from 10 to 40°C.

Viscosity of ice cream mix. Viscosity of ice cream mix samples during the processing week of every replication was measured at 7°C with a Haake Rotovisco Rv-12 viscometer equipped with a Haake NV spindle and cup (Elling et al., 1995). Hysteresis curves were plotted to compare the viscoelastic nature of ice cream mixes with different fatty acid profile. The shear rates at which apparent viscosity (mPa) was measured to plot hysteresis curves were: 173, 364.24, 692.5, 1384.96, 692.5, 364.5, 346.24 and 173 s⁻¹.

Sensory analyses. A paired comparison test was used to determine which ice cream treatment (HO, HL or control ice cream) was easiest to dip. Samples of each treatment were packaged in 4.6-L plastic containers and tempered in a chest freezer at -18°C. Twenty-four panelists were instructed to dip the ice cream samples in a specified order from the containers stored within the freezer. Each panelist completed the test individually, but all individual panelists completed the test from the same containers for each replication. The method of dipping was explained to the panelists as described in Arbuckle (1986), to be done from one extreme of the container to the end of it. Finally each panelist had to determine which ice cream sample was the easiest to scoop (Matak, 1999). 72 observations were recorded for each comparison (HO vs. Control, HO vs. HL and HL vs. Control) and the number of agreeing answers to obtain significant difference based on 72 observations at a $P = 0.05$ was 45, based on Table T-12 in Meilgaard et al. (1999).

Statistical analyses. The commingled milk from each 2-d collection from each treatment (HO, HL) and the bulk milk (control) sample collected simultaneously represented the initiation of each period from which each product was subsequently processed. Three periods were completed. Measurements were completed in duplicate on each sample. The randomized block design was analyzed by JMP (SAS Institute, Cary, NC) to determine differences in chemical and physicochemical properties due to treatment. A Tukey's test was used to determine significance ($P < 0.05$) of differences due to the treatment. Statistical contrasts were assessed on firmness analyses. The relationship between ice cream peroxide values and storage time (months) was analyzed as repeated measures of analysis of covariance.

Table 3. Fatty acid profile of milkfat from cows fed control, high-oleic or high-linoleic diets (n = 6).

Fatty acid ¹	Diet (g/100 g of total fatty acids)					
	Control	SE ²	Oleic ³	SE	Linoleic	SE
SC ⁴	15.61	0.27	16.07	0.19	15.79	0.40
12:0	2.88	0.06	2.82	0.05	2.83	0.11
14:0	10.17	0.14	9.94	0.10	9.70	0.21
16:0	28.83 ^b	0.27	22.71 ^a	1.06	21.12 ^a	0.65
18:0	12.74	0.39	13.86	0.38	13.98	0.96
18:1 w9	18.22 ^a	0.32	22.45 ^b	0.41	19.92 ^a	0.48
18:2 w6	2.81 ^a	0.01	3.41 ^a	0.17	5.99 ^b	0.09
18:3 w3	0.49	0.03	0.41	0.04	0.41	0.01
TVA ⁵	1.12 ^a	0.03	1.10 ^a	0.02	1.73 ^b	0.04
CLA ⁶	0.62 ^a	0.02	0.61 ^a	0.17	1.00 ^b	0.02
Saturated ⁷	69.27 ^b	0.46	64.11 ^a	0.64	62.15 ^a	0.41
Unsaturated ⁸	30.72 ^b	0.46	35.90 ^a	0.63	37.85 ^a	0.41
PLC ⁹	4.87 ^a	0.04	5.21 ^a	0.19	8.38 ^b	0.11

^{a,b} = means within rows with different letters are significantly different ($P < 0.05$; n = 6).

¹Expressed as number of carbons: number of double bonds.

²SE = Standard Error on duplicate samples for the three replications of each treatment.

³Oleic = high-oleic treatment; linoleic = high-linoleic treatment.

⁴SC = short-chain fatty acids (C4:0–C10:0).

⁵TVA = Transvaccenic acid (C18:1 t11).

⁶CLA = conjugated linoleic acid (C18:2 cis9,t11).

⁷Saturated = saturated fatty acids from C4:0–C20:0.

⁸Unsaturated = unsaturated fatty acids from C14:1–C22:6.

⁹PLC = polyunsaturated long-chain fatty acids (C18:2 w6–C22:6 w3).

A second-degree polynomial (quadratic) was used to describe the response.

RESULTS AND DISCUSSION

Milkfat fatty acid profile. The addition of the HO or HL oils to the diet of the cows provided an effective method for altering the fatty acid profile of milkfat (Table 3). The percentage of unsaturated fatty acids was greater ($P < 0.05$) for both treatments compared with the control. The concentration of short chain fatty acids (C4:0 to 12:0) did not differ among treatments. Concentration of medium chain fatty acids (C12:0 and C14:0) also did not differ due to dietary treatments. However C16:0 content of milkfat was lower (approximately 24%) due to HO and HL treatments compared with control. The decrease in concentration of C16:0 may be an important factor in human health issues, because C16:0 content of whole milk products is directly related to increases in low-density lipoprotein (LDL) cholesterol in plasma (Denke and Grundy, 1992).

In a previous study (Noakes et al., 1996), decreases in human total plasma cholesterol (4.3%) were related to consumption of modified fat products (milk and butter). Linoleic and oleic acid contents (6.9% and 35.3% of total fatty acids) were increased, while myristic and palmitic acid contents (6.7% and 15.5% of total fatty acids) were decreased due to a reduction in roughage and diet and addition of a protected lipid supplement

to the cow's diet (Noakes et al., 1996). Lin et al. (1996b) also showed a decrease in palmitic acid content (from 27.2 to 20.9%) when feeding cows a diet containing calcium-protected high-oleic sunflower oil. The above changes are greater than those observed in the current study, which used an unprotected oil supplement.

The C18:1 (cis-9 18:1) content of milkfat increased, due to the HO dietary treatment, compared with the control and HL, as was expected. The C18:2 w6 (linoleic acid) content of milkfat was increased in milkfat only when cows were fed the HL oil, however. Having established that the dietary manipulation yielded a different fatty acid composition than the control milkfat, subsequent references to treatment will be HO milkfat or HL milkfat.

Trans-vaccenic acid (TVA, C18:1 Δ 11 trans) and conjugated linoleic acid (CLA, C18:2 Δ 9 cis Δ 11 trans; also called rumenic acid) were increased in HL milkfat compared with HO and control milkfat. Typical rumenic acid intake by humans is approximately 150 mg/day (Ritzenthaler et al., 2001). If daily intake of dairy fat is estimated at 20 g/d and dairy products with a modified fatty acid profile (HL milkfat) were consumed, the daily rumenic acid intake should increase to approximately 200 mg/d. Consumption of rumenic acid delivered by other types of fat (beef fat) and transformation of TVA to rumenic acid in human tissues were not taken into consideration. This calculated intake of rumenic acid (200 mg/d), however, is not high enough to deliver

Table 4. Butter and ice cream firmness expressed in (kg-force) measured at specific temperature ranges.

Product	Firmness mean (kgf)	SE
Butter (4.2 to 5.5°C)		
Control	107.54	8.65
High-oleic	62.13	8.62
High-linoleic	70.83	8.62
Ice cream (-17 to -13.3°C)		
Control	12.73	5.88
High-oleic	11.74	5.88
High-linoleic	7.50	5.88

the optimal amount needed for anticarcinogenic properties (620 and 441 mg/d for men and women, respectively) (Ritzenthaler et al., 2001).

Color of butter. Slight differences in color between the highly unsaturated butters and the control were visually observed while churning and pressing the butter. After storage, the color differences seemed more pronounced. The unsaturated butters were less yellow than the control butter; however differences between the HO butter and HL butter were not observed. Color variation was subsequently measured analytically in butter samples stored for 3 to 5 months at -20°C. Control butter had a higher b value (yellow) when compared with HO and HL butter (27.73, 18.75 and 19.44, respectively; $P < 0.05$). The HO butter had a higher L (white) value than the control butter (92.40 versus 87.39; $P < 0.05$) but not the HL butter (90.95). Processing conditions were controlled as much as possible but may have contributed to color variations. In addition, color differences between the unsaturated butters and the control could be due to factors such as color of supplemented oils in the diet, source of dietary fatty acids and oxidation reactions. Noakes et al. (1996) observed slight color differences in dairy products (milk, butter, cheese and ice cream) with a higher unsaturated fatty acid content. Kaya (2000) related color change in butteroil to oxidation reactions. At peroxide values higher than 10 meq/kg the color of butteroil changed from yellow to light yellow; this color change was attributed to oxidation of chromophors (Kaya, 2000).

Firmness of butter and ice cream. Butter samples with HO and HL milkfat showed significant differences in firmness when compared to the control butter ($P = 0.0086$). The control butter was firmer (124.84 N; 10.54 J) than the HO butter, whereas HL butter firmness was intermediate between control and HO butter (Figure 1, Table 4). When comparing HL butter and control butter, no significant difference was found when using Tukey's test ($P > 0.05$) (Figure 1), but when using a less conservative test (Student's T-test), the difference was significant. However, the HO butter was significantly different when compared with control butter. Fatty acid

Figure 1. Butter firmness (kgforce) in a temperature range between 4.2 and 5.5°C. (1 kgforce = 9.80665 N).

composition affects textural properties like firmness. Increasing low melting species (short-chain saturated fatty acids and long chain unsaturated fatty acids) and decreasing the content of long-chain saturated fatty acids in milkfat decreases the melting point and solid fat index (Kaylegian and Lindsay, 1995). Changes in fatty acid composition of the HO butter support the observed decreases in firmness as well as the solid fat index of the unsaturated treatments.

The solid fat index for the control butter was significantly higher ($P < 0.05$) than the HO and HL butters (Figure 2), at 10, 20, 25 and 30°C, specifically. At 10°C, the percentage of solid fat ranged between 35 (control) and 26% (HO and HL). Lin et al. (1996a) found similar values (20 to 24% SFI) at 10°C for modified butter with HO acid content.

Figure 2. Solid fat index of control, high-oleic and high-linoleic butters.

Figure 3. Hysteresis curve for ice cream mixes. (Control; high-oleic = Oleic; high-linoleic = Linoleic).

Other studies (Stegeman et al., 1992; Lin et al., 1996b; Ashes et al., 1997; Bayourthe et al., 2000; Baer et al., 2001) also indicated that modification of the fatty acid profile of milkfat by adding unsaturated fat supplements to the bovine diet yields softer butters. Ashes et al. (1997) reported changes in churning temperature and time because the butter was soft. In the present study, buttermilk had to be removed carefully during the churning of unsaturated butters because they were very soft. It was also observed that butter produced with HO milkfat and HL milkfat needed longer churning time to reach the consistency and texture typically achieved in our dairy processing laboratory, when processing traditional butter (control butter).

Firmness of ice cream (Table 4) made with control and modified milk fats were similar. Apparent viscosities for the control ice cream mix were higher ($P = 0.0003$) than those for the HO and HL treatments, however (Figure 3, Table 5). Viscosity of milkfat depends to a great extent on the ratio of solid to liquid fat (Kaylegian and Lindsay, 1995).

Sensory analyses on firmness of ice cream were also measured to support the analytical firmness results. Differences in firmness between ice creams with different fatty acid profile, based on dipping tests, were not found ($P > 0.05$). The temperature at which the dipping

test was completed was approximately -18°C . At this temperature, ice cream samples were very hard and difficult to dip according to some observations made by the panelists.

Oxidative stability of ice cream. Free fatty acid content or acid values remained constant for milk, cream and ice cream throughout the storage period. The values were low and indicated no hydrolytic rancidity occurred in the milk products.

The peroxide value estimates peroxides produced by autoxidation reactions (Rossell, 1989). Initial peroxide values of the three types of fats extracted from the ice cream mixes varied in a range between 2.91 to 4.12 meq/kg (Table 6). According to deMan (1999), a low peroxide value, especially after several months of storage, does not mean that oxidation has not taken place. The peroxide value increased numerically ($P > 0.05$) after 2 mo of storage for all treatments but no significant difference was found for any treatments.

Peroxides increase slowly at initial stages, but at the end of the induction period, the concentration of peroxides increases rapidly and then declines to almost zero (Labuza, 1975). This behavior was observed when peroxide values were measured at advanced stages of storage (3 to 9 mo) for all the ice cream treatments. However, high peroxide values (>15 meq/kg oil) were observed in HL ice cream compared with peroxide values from HO and control ice cream during some measurement periods. Conclusions about the different behavior from HL ice cream cannot be drawn from this research; however it will be taken into consideration for further research, specifically in oxidation studies that involve extended storage.

According to some authors (Hoffmann, 1962; Rossell, 1989), fats should have a peroxide value of less than 1 meq/kg/oil to be considered fresh. At this level, no off-flavor can be perceived in milkfat. After refining and storage, a peroxide value of 10 meq/kg/oil is accepted in oils and fats, before off-flavors develop (Rossell, 1989). The threshold peroxide value for off-flavor is 20 to 50 meq per kilogram of oil (Hoffman, 1962). According to the International Dairy Federation the standard per-

Table 5. Apparent viscosity (millipascals) of ice cream mixes at increasing and decreasing shear rates.

Shear rate (s^{-1})	Control	SE	Oleic	SE	Linoleic	SE
· Apparent viscosity (mPa) ·						
173	41.34	12.44	24.66	4.88	27.31	10.27
346.24	71.48	10.60	57.56	5.92	51.42	8.91
692.5	83.08	9.16	71.34	4.89	60.92	8.06
1384.96	83.18	7.89	73.24	3.60	65.52	6.51
692.5	19.16	2.33	15.18	1.14	14.50	2.00
346.24	16.14	2.69	11.04	1.41	11.74	2.20
173	9.16	2.99	4.88	0.62	8.44	1.88

Table 6. Peroxide values (meq of peroxide/kg oil) of ice cream treatments stored at 0, 1, and 2 mo after processing.

Months	Control	SE	Oleic	SE	Linoleic	SE
	Peroxide value (meq/kg oil)					
0	4.12	0.64	2.91	0.64	3.25	2.97
1	5.19	2.01	4.50	1.65	7.07	2.97
2	8.06	2.90	7.77	2.95	8.09	2.97

oxide value for milkfat is 0.2 meq of oxygen per kilogram of fat (Kaylegian and Lindsay, 1995).

Stegeman et al. (1992) showed no increase in peroxide values in modified butter between 0 and 3 mo of storage (4°C). In their study, sunflower or safflower seeds were added to cow's diet to obtain modified butter. Ramaswamy et al. (2001) found normal peroxide and acid degree values in modified butters stored at 4°C between 0 and 3 months. Their modified milk came from cows fed fish oil or fish oil with extruded soybeans or extruded soybeans and no difference in peroxide values was found between the treatment butters.

Informal sensory sessions after 3 mo of storage were assessed to determine differences in oxidation flavor, but no significant difference was found among the ice cream treatments.

CONCLUSIONS

Manipulation of the cow's diet resulted in production of milkfat with a modified fatty acid profile quality, and differences in physicochemical properties of butter and ice cream. Both HL and HO milkfat had higher percentage of unsaturated fatty acids than the control milkfat, decreasing the solid fat index. The fatty acid profile decreased viscosity of ice cream mix and provided a less firm HO butter. Changes in viscosity may be important from an engineering prospective during processing. Changes in firmness of butter and modification to improve nutritional profile may increase perceived product value. HL milkfat had a higher content of CLA and TVA, potentially making it more desirable than standard milkfat or HO milkfat from a nutritional point of view. Further research needs to be done in the oxidative stability of highly unsaturated dairy products during storage.

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REFERENCES

- Abd El-Rahman, A. M., S. I. Shalabi, R. Hollender, and A. Kilarara. 1997. Effect of milkfat fractions on the sensory evaluation of frozen desserts. *J. Dairy Sci.* 80:1936–1940.
- American Heart Association. Cardiovascular disease statistics. Heart and Stroke Guide. 2000. <http://www.americanheart.org>. Accessed April 17, 2001.
- Arbuckle, W. S. 1986. Ice Cream. 4th ed. Van Nostrand Reinhold, New York.
- Association of Official Analytical Chemists. 1997. Official Methods of Analysis, 16th ed. Association of Official Analytical Chemists, AOAC. Gaithersburg, MD.
- Ashes, J. R., S. K. Gulati, and T. W. Scott. 1997. Potential to alter the content and composition of milk fat through nutrition. *J. Dairy Sci.* 80:2204–2212.
- Baer, R. J., J. Ryali, D. J. Schingoethe, K. M. Kasperon, D. C. Donovan, A. R. Hippen, and S. T. Franklin. 2001. Composition and properties of milk and butter from cows fed fishoil. *J. Dairy Sci.* 84:345–353.
- Bayourthe, C., F. Enjalbert, and R. Moncoulon. 2000. Effects of different forms of canola oil fatty acid plus canola meal on milk composition and physical properties of butter. *J. Dairy Sci.* 83:690–696.
- Bligh, E. G., and W. J. Dyer. 1959. A rapid method for total lipid extraction and purification. *Can. J. Biochem. Physiol.* 37:911–917.
- DeMan, J. M. 1999. Lipids. Pages 33–38 in *Principles of Food Chemistry*. Aspen Publishers, Inc., Maryland.
- Denke, M. A., and S. M. Grundy. 1992. Comparison of effects of lauric acid and palmitic acid on plasma lipids and lipoproteins. *Am. J. Clin. Nutr.* 56:895–898.
- Elling, J., J. Harris, and S. E. Duncan. 1995. Incorporation of modified butteroil into high-fat dairy products: ice cream manufactured with reduced-cholesterol reformulated cream. *Dairy, Food and Environmental Sanitation* 15(12):738–744.
- Elling, J. L., and S. E. Duncan. 1996. Physical properties of 20% milkfat reformulated creams manufactured from cholesterol reduced butteroil. *J. Food Sci.* 61(2):375–378.
- Focant, M., E. Mignolet, M. Marique, F. Clabots, T. Breyne, D. Dalemans, and Y. Larondelle. 1998. The effect of vitamin E supplementation of cow diets containing rapeseed and linseed on the prevention of milk fat oxidation. *J. Dairy Sci.* 81:1095–1101.
- Fox, P. F., and P. L. H. McSweeney. 1998. *Dairy Chemistry and Biochemistry*. Blackie Academic and Professional, New York.
- Gurr, M. I. 1995. Nutritional significance of lipids. Pages 349–402 in *Advanced Dairy Chemistry: Lipids*, P. F. Fox, ed. Chapman & Hall, Great Britain.
- Hawke, J. C., and M. W. Taylor. 1995. Influence of nutritional factors on the yield, composition and physical properties of milkfat. Pages 37–88 in *Advanced Dairy Chemistry: Lipids*, P. F. Fox, ed. Chapman & Hall, Great Britain.
- Hoffman, G. 1962. Vegetable oils. Pages 215–226 in *Symposium of Foods: Lipids and Their Oxidation*, Schultz, H.W., ed. AVI Publishing Company, Inc., Westport, CT.

- Im, Ji-Soon, and R. Marshall. 1998. Effects of homogenization Pressure on the physical, chemical and sensory properties of formulated frozen. *Food Sci. Biotechnol.* 7(2):90–94.
- Kaya, A. 2000. Properties and stability of butter oil obtained from milk and yoghurt. *Nahrung* 44(2):126–129.
- Kaylegian, K. E., and R. C. Lindsay. 1995. *Handbook of Milkfat Fractionation Technology and Application*. AOCS Press, Champaign, IL.
- Labuza, T. O. 1975. Oxidative changes in foods at low and intermediate moisture levels. Pages 455–472 in *Food Science and Technology. A Series of Monographs "Water Relations of Foods"*. Duckworth, R. B., ed. Academic Press, New York.
- Lin, M.-P., C. R. Staples, C. A. Sims, and S. F. O'Keefe. 1996a. Modification of fatty acids in milk by feeding calcium-protected high oleic sunflower oil. *J. Food Sci.* 61(1):24–27.
- Lin, M. P., C. A. Sims, C. R. Staples, and S. F. O'Keefe. 1996b. Flavor quality and texture of modified fatty acid high monoene, low saturated butter. *Food Research International* 29(3–4):367–371.
- Loor, J. J. 2001. Alterations in mammary gland synthesis and secretion of fatty acids in response to trans isomers of octadecenoic acid or conjugated linoleic acid isomers. Ph.D. Diss., Virginia Tech, Blacksburg, Virginia.
- Marshall, R. T., ed. 1993. *Standards Methods for the Examination of Dairy Products*. 16th ed. American Public Health Association, Washington, D.C.
- Matak, K. 1999. Lactose hydrolysis by fungal and yeast lactase: influence on freezing point and dipping characteristics of ice cream. Master's Thesis, Virginia Tech, Blacksburg, VA.
- McDonald, I. W., and T. W. Scott. 1977. Food of ruminant origin with elevated content of polyunsaturated fatty acids. *World Rev. Nutr. Diet.* 26:144–207.
- Meilgaard, M., G. V. Civille, and B. T. Carr. 1999. Overall Difference Tests. Pages 60–73 in *Sensory Evaluation Techniques*. 3rd ed. CRC Press, New York.
- National Research Council. 1989. Pages 90–110 in *Nutrient Requirements of Dairy Cattle*. 6th rev. ed. Natl. Acad. Sci., Washington, DC.
- Noakes, M., P. J. Nestel, and P. M. Clifton. 1996. Modifying the fatty acid profile of dairy products through feedlot technology lowers plasma cholesterol of humans consuming the products. *Am. J. Clin. Nutr.* 63:42–46.
- Park, P. W., and R. E. Goins. 1994. In situ preparation of fatty acid methyl esters for analysis of fatty acid composition in foods. *J. Food Sci.* 59:1262–1266.
- Ramaswamy, N., R. J. Baer, D. J. Schingoethe, A. R. Hippen, K. M. Kasperson, and L. A. Whitlock. 2001. Composition and flavor of milk and butter from cows fed fish oil, extruded soybeans, or their combination. *J. Dairy Sci.* 84:2144–2151.
- Ritzenthaler, K. L., M. K. McGuire, R. Falen, T. D. Shultz, N. Dasgupta, and M. A. McGuire. 2001. Estimation of conjugated linoleic acid intake by written dietary assessment methodologies underestimates actual intake evaluated by food duplicate methodology. *J. Nutr.* 131:1548–1554.
- Rossell, J. B. 1989. Measurement of rancidity. Pages 23–30 in *Rancidity in Foods*, Allen, J.C., and R.C. Hamilton, ed. Elsevier Science Publishers LTD.
- Stegeman, G. A., R. J. Baer, D. J. Shingoethe, and D. P. Casper. 1992. Composition and flavor of milk and butter from cows fed unsaturated dietary fat receiving bovine somatotropin. *J. Dairy Sci.* 75:962–970.
- Walstra, P. 1995. Physical chemistry of milkfat globules. Pages 131–178 in *Advanced Dairy Chemistry: Lipids*, Fox, P.F., ed. Chapman & Hall, Great Britain.