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Physical and Sensory Properties of Dairy Products from Cows with Various Milk Fatty Acid Compositions

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Dairy products from milk of cows fed diets rich in polyunsaturated fatty acids have a more health-promoting fatty acid composition and are softer but often have oxidized flavors. Dairy products made from cow's milk that has more- or less-unsaturated fatty acid compositions were tested for differences in texture and flavor from those made from bulk-tank milk. The milk was manufactured into butter, vanilla ice cream, yogurt, Provolone cheese, and Cheddar cheese. The products were analyzed for fatty acid composition, physical properties, and flavor. Milk of cows with a more monounsaturated fatty acid composition yielded products with a more monounsaturated fatty acid composition that were softer and had a satisfactory flavor. Thus, selection of cows for milk fatty acid composition can be used to produce dairy products that are probably more healthful and have a softer texture.

KEYWORDS: Bovine milk; dairy products; fatty acid composition; flavor; texture

INTRODUCTION

Milk fat is an important dietary source of nutrients and energy (*1*, *2*). Typically, milk fat contains 66% saturated fatty acids, 30% monounsaturated fatty acids, and 4% polyunsaturated fatty acids (*3*). The high ratio of saturated fatty acids, particularly 12:0, 14:0, and 16:0, to unsaturated fatty acids in milk fat has caused concern about the effects of its consumption on human health (*2*, *4*). An increase in the ratio of saturated to unsaturated fatty acids is associated with an increased risk for cardiovascular disease and increases concentrations of total and low-density lipoprotein (LDL) cholesterol (*4*, *5*).

On the basis of current information about the effect of different fatty acids on serum cholesterol and high-density lipoprotein (HDL) and LDL concentrations, the atherogenic index was proposed as a dietary risk indicator of lipids for cardiovascular diseases (*4*). The atherogenic index is the sum of concentrations of 12:0, 16:0, and 4 × 14:0 divided by the concentration of total unsaturated fatty acids (*4*). According to this equation, all unsaturated fatty acids, regardless of their double-bond number, position, or configuration, are considered to be equally effective in decreasing the risk for atherogenicity, primarily for lack of reliable information to assign more suitable coefficients to the individual acids. In the current study, we named the inverse of the atherogenic index the health-promoting index (HPI).

Stage of lactation, breed of cow, genetics, and diet composition affect milk fatty acid composition (*6*). Cow nutrition has been considered to be the primary factor influencing milk fatty acid composition and has been researched most extensively (*6*). Dairy products from milk of cows that were fed diets rich in unsaturated fatty acids have a more unsaturated fatty acid profile with HPI values between 0.47 and 0.78 in comparison to HPI values between 0.30 and 0.42 for the control group (*7*−*9*). Consumption of those products promotes human health by decreasing concentrations of plasma cholesterol (*9*, *10*).

Milk fatty acid composition also affects the texture and flavor of its food products (*1*, *2*). The effects that feeding diets rich in unsaturated fatty acids to dairy cows have on texture and flavor of their dairy products vary depending on the degree of unsaturation of the milk fatty acid profile. Dairy products from milk of cows fed diets rich in unsaturated fatty acids are softer and less viscous (*8*, *11*, *12*). Dairy products with a highly polyunsaturated fatty acid profile, however, are so fluid that they "oil off" at higher temperatures (*13*−*15*), which can result in a mealy taste and a loss of structure (*14*−*16*).

Dairy products from milk of cows fed diets rich in polyunsaturated fatty acids are prone to oxidation if no precautions against oxidation are taken, such as adding tocopherol to the fresh milk (*8*, *12*). Oxidation causes in dairy products with a highly unsaturated fatty acid profile, especially after storage, oxidized, metallic, oily, or stale flavors and a paler color (*13*, *14*, *17*). Additionally, cheese with a highly unsaturated fatty acid profile tends to taste flat (*14*, *16*, *18*).

Our group has demonstrated that selection of cows with high HPI could alter the HPI of their butter to an extent similar to

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Table 1. Ingredient Composition of Cows' Diet

ingredient	% on dry matter basis
alfalfa hay	15.9
alfalfa haylage	11.4
canola meal	3.1
corn silage	25.2
cracked corn	16.5
dried distillers grain with solubles	3.6
linseed meal	1.4
Megalac[a]	0.88
mineral/vitamin premix	3.02
molasses	0.3
QLF 4-19[b]	4.8
soybean meal (48% crude protein)	6.8
soy hulls	0.7
SurePro[a]	1.3
wheat middlings	1.0
whole cottonseed	4.1

[a] Megalac and Surepro are products of Land O'Lakes (St. Paul, MN). [b] QLF is a product of Quality Liquid Feeds (Hinton, IA).

that caused by feeding cows diets rich in unsaturated fatty acids (*19*). The butter resulting from our selection had a more desirable fatty acid composition and decreased hardness and adhesiveness. The objective of this study was to determine whether dairy products, specifically butter, vanilla ice cream, yogurt, Provolone cheese, and Cheddar cheese, from the milk of cows whose lipid profile was identified as having a more- or less-unsaturated fatty acid composition, differed in texture and flavor from the corresponding products of bulk-tank milk.

MATERIALS AND METHODS

Animal Selection and Milk Collection. Individual milk samples were collected from two commercial herds with approximately 150 and 60 lactating Holstein dairy cows, respectively. All cows were fed ad libitum twice daily a total mixed ration that was formulated to meet NRC requirements (**Table 1**). Milk collected separately from individual cows was frozen until analyzed.

For analysis of the fatty acid composition, 200 μL of milk or samples of dairy products containing a similar amount of fat were suspended in 300 μL of 1-butanol containing 0.4 mg of the two internal standards, 5:0 and 11:0, and 0.4875 mg of 19:0 (Sigma Chemical Co., St. Louis, MO). Next, 500 μL of additional 1-butanol and 50 μL of acetyl chloride were added. The vial was filled with nitrogen gas, sealed, mixed on a Vortex mixer (Fisher Scientific, Pittsburgh, PA) for 3 min, and heated on a steam bath for 1.5 h. Then, 3.3 mL of 6% aqueous K_2CO_3 and 630 μL of hexane were added, mixed for 1 min, and centrifuged for 15 min at 400*g* in a Centrific model centrifuge (Fisher Scientific). The lower, aqueous layer was discarded, and the hexane phase was washed with 3.3 mL of distilled water and centrifuged again. To remove butanol, 100 μL of the hexane layer was applied to a 1-g silica cartridge (Chrom Tech. Inc., Apple Valley, MN) that had been washed with 5 mL of hexane. The cartridge was eluted with 5% diethyl ether in hexane. The first 2.3 mL of eluate was discarded, and the butyl esters were collected in the next 1.7 mL.

The butyl esters were analyzed on a Hewlett-Packard 5890 (Avondale, PA) gas chromatograph equipped with a flame ionization detector, a 3396A integrator, and a 30-M 2330 fused-silica capillary column with a 0.25 mm i.d. and 0.2 μm film thickness (Supelco, Bellefonte, PA). The injector and detector were at 250 °C, and the oven was held for 4 min at 70 °C and programmed at 20 °C/min to 230 °C and held for 5 min. The carrier gas was helium at 3 mL/min. The weight percentage of each fatty acid was calculated by using 5:0 as a standard for 4:0−8:0, 11:0 for 10:0−14:0, and 19:0 for those longer than 14:0. External standards GLC74 and GLC79 (Nu-Chek Prep, Elysian, MN) of known compositions were tested to verify the accuracy of the correction factors obtained with the internal standards.

The HPI was calculated from the weight percentages. For selection of milk samples for manufacturing of each dairy product, all cows in the two herds were screened for the HPI values of their milk and the four cows with the highest HPI and the four cows with the lowest HPI were selected for collection of milk samples. The HPI values for the cows of the low- and high-HPI groups were between 0.21 and 0.32 and between 0.64 and 1.65, respectively. For manufacturing, equal amounts of milk were collected from each of the selected cows, and samples from cows with a similar HPI at selection were pooled. The pooled milk samples for manufacturing were labeled as low-HPI sample and high-HPI sample, respectively. The time period between selection of cows and collection of milk for manufacture was 3−7 weeks for butter, 2−5 weeks for ice cream, 2 weeks for yogurt, 2 weeks for Provolone cheese, and 7 weeks for Cheddar cheese. Additionally, a milk sample was collected from the bulk tank and was labeled as bulk-tank sample. The purpose of the bulk-tank sample was twofold. First, it was used to test whether low- or high-HPI products differ significantly from a dairy product that is manufactured without segregation of milk. Second, it was used to evaluate whether the changes between textural and sensory properties were linear with changes of milk fatty acid composition. The amount of the pooled milk samples was ∼80 kg for butter, 30 kg for ice cream, 9 kg for yogurt, and 112 kg each for Provolone and Cheddar cheeses.

Manufacture. Each pooled milk sample was manufactured separately into duplicate dairy products after vat pasteurization at 63 °C for 30 min with agitation by using an electric heated kettle (model TDC/TA/40, Groen Inc., Elk Grove, IL) or a 180-kg custom-made cheese vat.

For butter, cream (1.82 kg) was separated using an Elecrem model 1 separator (Elecrem, Vanves, France), adjusted to 30% fat with the skimmed milk, and stored overnight at 4 °C. The next day the cream temperature was adjusted to 10 °C and churned in a 4-L electric churn (Gem Dandy, Alabama Manufacture Co., Birmingham, AL) for ∼40 min. The churn was operated at room temperature, and the cream temperature was allowed to rise from 10 °C until the butter came. To minimize texture changes, the butter sample was kept in cold water near the final churning temperature when the fat determination was performed. The fat content of the butter was adjusted to 80% by mixing water back into the butter using a heavy duty mixer (KitchenAid, Troy, OH) while keeping the speed as low as possible to prevent air from being incorporated into the butter. The butter samples (520−580 g) were stored at 4 °C in closed plastic containers until further analyses.

For ice cream, milk was separated using an Elecrem model 1 separator. The cream was adjusted to 10% fat, 11% nonfat milk solids, 15% sucrose, and 0.3% stabilizer−emulsifier through the addition of the skim milk, nonfat dry milk (Carnation, Nestlé, Solon, OH), cane sugar, and a commercial stabilizer−emulsifier (Continental Colloids Inc., Minneapolis, MN). The mix (5.9−6.2 kg) was repasteurized under conditions described previously, homogenized at 8−10 MPa for the first stage and at 3 MPa for the second stage using a two-stage homogenizer (model 16M, Gaulin, Everett, MA), cooled to 4 °C overnight, and flavored with 0.4% vanilla extract. Then, the mix was frozen to a draw temperature of −6.2 °C in an Emery-Thompson 38-L freezer (Bronx, NY) and stored at −20 °C in closed plastic 1-L containers that were filled completely with tight lids until further analyses.

For yogurt manufacture, pasteurized milk was adjusted to 2% fat and 12% nonfat milk solids by separation and the addition of skim milk and nonfat dry milk to the unseparated milk. The mix was homogenized at 3.3 and 8.3 MPa and 60 °C using a two-stage homogenizer and then heated at 90 °C for 30 min. After the mix was cooled to 40 °C, it was inoculated with a freeze-dried starter culture of *Streptococcus salivarius* spp. *thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* (YC-180, Chr. Hansen, Milwaukee, WI; 137.5 mg/L) and incubated at 42 °C until the pH reached 4.6−4.7, which took 5−6.25 h. The yogurt (8.8 kg) was immediately stored at 4 °C in closed plastic 1-L containers until further analyses.

Provolone cheese and long-hold Cheddar cheese were prepared according to the methods of Reinbold (*20*) and Wilson and Reinbold (*21*), respectively, using 1% of R-704 lactic type culture from Ch. Hanson for both cheeses and 1% of *S. salivarius* subsp. *thermophilus* AC2 and 1% of *L. delbrueckii* subsp. *bulgaricus* AR2 from the Iowa State University collection for the Provolone. Provolone and Cheddar cheeses were cured at 10 °C until they were ripe, which took 4 and 7 months, respectively, and then were stored at 4 °C until further analysis. The yields for Provolone and Cheddar were 8.98−10.43 and 8.28−9.43 kg/100 kg of milk, respectively.

Textural Analysis. For all dairy products except yogurt, texture analysis was done using a TA-XT2i texture analyzer (Stable Microsystems, Surrey, U.K.). Texture was analyzed at 4 °C 1 week after manufacture for butter and at −20 °C 3 and 15 weeks after manufacture for ice cream. For textural analysis of butter and ice cream, a conical probe with an angle of 40° and at the temperature of the sample was advanced at 0.5 mm/s until it reached 300 g force, and the penetration distance was recorded. Additionally for textural analysis of butter, the speed by which the probe penetrated at 300 g force for an additional 30 s was recorded as creep compliance. The measurements were replicated six times for each sample.

The textures of Provolone and Cheddar cheeses were measured around 5 and 8 months after manufacture, respectively. A standard texture profile was done on cheese cubes (2.5 × 2.5 × 2.3 cm) compressed to 80% of their original height at 3.3 mm/s at 23 °C using a plate. Once the cheese was compressed, the plate was immediately reversed to full height and then compressed again at the same speed as before. Hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience of the cheese samples, as defined by Bourne (*22*), were calculated by using a texture analysis program (version V1.22), which was coupled to the texture analyzer. The measurements were replicated 10 times for each sample. Additionally, the texture of Provolone cheese blocks was measured with and across the grain.

Yogurt texture was measured at 4 °C 3−6 weeks after manufacture with a Haake Viscotester VT550 (Karlsruhe, Germany) by using a vane that was 3 × 1.6 cm that was pushed into the yogurt until it was just covered and moved at 0.5 rpm. The yield stress was calculated from the torque. Measurements for each yogurt sample were replicated four times.

Sensory Analysis. The 13 sensory panelists, who consisted of students, faculty, and staff of Iowa State University, were trained in two 1-h sessions on each product tasted. In the training session, the panelists examined all product samples and agreed on the flavor parameters necessary to describe the differences among the samples. Panelists were presented at each tasting session no more than five or six coded samples in random order in a partitioned booth. Each panelist evaluated each sample in duplicate trials. Panelists evaluated the strength of the flavor on a continuous scale from 0 (undetectable) to 14 cm (very strong). One of the samples was provided as a mouth-conditioning sample at the beginning of each session.

Sensory analysis for each product was done over a 5-day time period. Butter samples were evaluated at 23 °C 1 week after manufacture. Ice cream samples were evaluated 14−16 weeks after manufacture and were tasted in small individual cups that had been prepared at the time of freezing and which were allowed to temper at room temperature for 10−15 min before tasting. Yogurt samples were tasted 1−4 weeks after manufacture and were served in individual cups, in which they had been fermented, 10−15 min after their removal from 4 °C storage. Provolone and Cheddar cheese samples were presented as several cubes and evaluated at 23 °C around 4 and 7 months after manufacture, respectively.

Statistical Analysis. Textural and sensory data were analyzed by using PROC MIXED of SAS version 8.2 (*23*). The fixed effect was treatment group (low HPI, bulk tank, high HPI). For Provolone textural data, additional fixed effects were direction of measurement (with grain, across grain) and the interaction between treatment group and direction of measurement. To account for correlations between dairy product samples from the same milk, a variance−covariance structure with equal variance and equal covariance (compound symmetry) for samples from the same milk was used. Additionally, for statistical analysis of sensory data, evaluations of subsamples of the same dairy product sample were averaged, and a covariance structure with equal variance and equal covariance was used to account for correlations between evaluations of the same panelist. Differences between treatment groups were determined by using a one-sided t test for textural data and a two-sided t test for composition and sensory data. Statistical differences were judged to be significant at $P \leq 0.10$. Means and standard errors (SE) presented in tables are least-squares means and pooled SEs.

Table 2. Fatty Acid Compositions in Weight Percent of Butters That Differ in Health-Promoting Index (HPI)[a]

fatty acid	low HPI ($n = 2$)	bulk tank ($n = 2$)	high HPI ($n = 2$)	SEM
4:0	3.67	3.92	3.84	0.18
6:0	2.18b	2.09ab	1.87a	0.07
8:0	1.29b	1.16ab	1.00a	0.06
10:0	2.87b	2.45ab	2.01a	0.18
12:0	3.07b	2.69b	2.10a	0.18
14:0	9.70b	9.23b	6.95a	0.21
14:1	1.29	1.41	0.96	0.18
16:0	34.24b	29.91a	29.74a	1.05
16:1	3.61	4.28	3.57	0.81
18:0	9.72a	11.98b	13.24c	0.23
18:1	25.22a	26.80a	31.42b	0.94
18:2	2.72	3.00	2.87	0.13
18:3	0.43	1.09	0.43	0.42
saturated	66.73b	63.43ab	60.75a	1.57
monounsatured	30.12a	32.48ab	35.95b	1.15
polyunsaturated	3.15	4.09	3.30	0.54

[a] Means with different letters within a row differ at $P \leq 0.10$.

Table 3. Properties[a] of Butters That Differ in Health-Promoting Index (HPI)

property	low HPI ($n = 2$)	bulk tank ($n = 2$)	high HPI ($n = 2$)	SEM
HPI	0.44a	0.53a	0.66b	0.04
texture				
penetration (mm)	5.15a	5.29ab	5.39b	0.10
creep (mm/s)	0.0873a	0.0919b	0.0918b	0.018
taste (scale 0–14)				
milky	5.10	5.48	5.95	0.75
aftertaste	2.93	3.15	3.30	0.56

[a] Textural properties were measured at 4 °C six times for each sample with a TA-XT2 texture analyzer. Sensory properties were determined at 23 °C by 11 trained panelists using a continuous scale from 0 (undetectable) to 14 (strong). Means with different letters within a row differ at $P \leq 0.10$.

RESULTS

Butter. Butter fat from milk of high-HPI cows had higher HPI values than did butter from milk of low-HPI cows (**Table 2**). For butter fat from milk of high-HPI cows, concentrations of 18:0 and 18:1 were higher, whereas concentrations of saturated fatty acids 6:0−16:0 were lower. Butter from milk of high-HPI cows had at 4 °C a longer penetration distance and a larger creep compliance than did butter from milk of low-HPI cows (**Table 3**). No significant differences could be detected for flavor perception between the three treatment groups at 23 °C (**Table 4**).

Vanilla Ice Cream. The fat from ice cream made from the high-HPI cows had higher HPI values than that of low-HPI cows with intermediary values for that from the bulk tank (**Table 4**). Vanilla ice cream from milk of high-HPI cows had at −20 °C a longer penetration distance than did vanilla ice cream from milk of low-HPI cows (**Table 4**). Ice cream from bulk-tank milk tasted sweeter than that from milk of high-HPI cows with intermediary values for ice cream from low-HPI cows (**Table 4**). No significant differences could be detected for the perception of vanilla, oxidized, and off-flavor flavor deficiencies among the three groups. Ice cream from milk of high-HPI cows had numerically higher values for oxidized taste because one

Table 4. Properties[a] of Vanilla Ice Creams That Differ in Health-Promoting Index (HPI)

property	low HPI ($n = 2$)	bulk tank ($n = 2$)	high HPI ($n = 2$)	SEM
HPI	0.31a	0.42b	0.62c	0.01
texture				
penetration (mm)	6.10a	6.63ab	6.81b	0.23
taste (scale 0–14)				
vanilla-like	5.86	5.59	5.45	0.71
sweet	8.05b	8.35c	7.38a	0.81
oxidized	2.20	1.73	4.18	1.11
off-flavor	0.18	0.11	0.30	0.12

[a] Texture was measured at –20 °C six times for each sample with a TA-XT2 texture analyzer. Sensory properties were determined 10–15 min after removal from storage at –20 °C by 11 trained panelists using a continuous scale from 0 (undetectable) to 14 (strong). Means with different letters within a row differ at $P \leq 0.10$.

Table 5. Properties[a] of Yogurts That Differ in Health-Promoting Index (HPI)

property	low HPI ($n = 2$)	bulk tank ($n = 2$)	high HPI ($n = 2$)	SEM
HPI	0.30a	0.45b	0.62c	0.01
texture				
yield stress (Pa)	370b	356b	297a	14
taste (scale 0–14)				
acidic	6.04ab	4.87a	6.71b	0.93
sweet	2.23	2.39	1.94	0.43
bitter	0.92	0.75	0.94	0.39
yogurt-like	7.48a	7.89ab	8.37b	0.69
buttery	2.79	2.48	2.84	0.80
astringent	2.91	2.68	2.99	0.75
earthy	1.24	1.40	1.28	0.80
vanilla-like	0.63	0.79	1.20	0.39

[a] Texture was measured at 4 °C in quadruplicate for each sample with a Haake Viscotester VT550. Sensory properties were determined 10–15 min after removal from storage at 4 °C by 11 trained panelists using a continuous scale from 0 (undetectable) to 14 (strong). Means with different letters within a row differ at $P \leq 0.10$.

ice cream sample of the high-HPI group had an oxidized taste (results not shown).

Yogurt. Yogurt from milk of high-HPI cows had higher HPI values than did yogurt from milk of low-HPI cows with intermediary values of yogurt of the bulk-tank milk (**Table 5**). Concentrations of 18:1–18:2 were higher in yogurt fat from high-HPI cows, whereas concentrations of saturated fatty acids 12:0–16:0 were lower (results not shown). Yogurt from milk of high-HPI cows had at 4 °C lower values for yield stress than did the other two groups (**Table 5**). Yogurt from bulk-tank milk tasted less acidic than did yogurt from milk of high-HPI cows (**Table 5**). Yogurt from milk of high-HPI cows had a more yogurt-like taste than did yogurt from milk of low-HPI cows. No significant differences could be detected for the perception of sweet, bitter, buttery, astringent, earthy, and vanilla-like flavors among the three groups.

Provolone Cheese. Fat from the cheese of high-HPI cows had higher HPI values than from the other two groups (**Table 6**). Concentrations of 18:1 were higher in cheese from high-HPI cows, whereas concentrations of saturated fatty acids, particularly of 12:0 and 14:0, were lower than those in the other two groups (results not shown). Provolone cheese from milk of high-HPI cows had lower values for hardness, gumminess, and chewiness than did Provolone cheese from milk of low-HPI cows (**Table 6**). These differences were significant only when cheese samples were measured across the grain (results not shown). No significant differences could be detected for flavor perception among the three groups except that Provolone cheese from bulk-tank milk tasted more buttery than did Provolone cheese from the other two groups (**Table 6**).

Table 6. Properties[a] of Provolone Cheeses That Differ in Health-Promoting Index (HPI)

property	low HPI ($n = 2$)	bulk tank ($n = 2$)	high HPI ($n = 2$)	SEM
HPI (ratio)	0.38a	0.48a	0.63b	0.05
moisture (wt %)	47.1	46.4	45.7	1.1
fat (% on DM basis[b])	44.9	44.4	47.6	2.0
pH	5.48	5.52	5.48	0.04
texture				
hardness (g)	2012b	1707ab	1402a	165
adhesiveness (g·s)	35	40	48	17
springiness (cm)	0.7827	0.7839	0.7800	0.0076
cohesiveness (ratio)	0.7326	0.7328	0.7372	0.0144
gumminess (g)	1470b	1252ab	1037a	139
chewiness (g·cm)	1158b	987ab	816a	116
resilience (ratio)	0.4095	0.4051	0.4061	0.0141
sensory properties (scale 0–14)				
oily	4.79	4.82	5.00	0.41
sour	3.14	3.12	3.25	0.31
salty	4.51	4.77	5.21	0.55
buttery	2.71a	3.34b	2.49a	0.41
astringent	1.09	1.20	1.20	0.36

[a] Texture was measured at 23 °C 10 times for each sample with a TA-XT2 texture analyzer with and across the grain. Sensory properties were determined at 23 °C by 13 trained panelists using a continuous scale from 0 (undetectable) to 14 (strong). Means with different letters within a row differ at $P \leq 0.10$. [b] Weight percent on a dry matter basis.

Table 7. Properties[a] of Cheddar Cheeses That Differ in Health-Promoting Index (HPI)

property	low HPI ($n = 2$)	bulk tank ($n = 2$)	high HPI ($n = 2$)	SEM
HPI (ratio)	0.29a	0.40b	0.46c	0.02
moisture (wt %)	6.7	37.2	36.7	0.6
fat (% on DM basis[b])	49.3a	50.1ab	51.6b	0.5
pH	5.33b	5.16a	5.35b	0.04
texture				
hardness (g)	1441	1418	1229	121
adhesiveness (g·s)	70	53	98	25
springiness (cm)	0.7769c	0.7622a	0.7668b	0.0017
cohesiveness (ratio)	0.7113	0.7081	0.7072	0.0068
gumminess (g)	1027	1001	867	93
chewiness (g·cm)	798	763	665	70
resilience (ratio)	0.3465	0.3433	0.3385	0.0079
sensory properties (scale 0–14)				
sweet	1.93	1.55	1.55	0.39
sour	4.96	5.64	5.48	0.65
salty	4.86a	5.25b	5.03ab	0.34
bitter	2.15	2.58	2.28	0.54
nonvolatile cheddary	5.60	5.60	6.07	0.49
volatile cheddary	6.00b	5.30a	5.81ab	0.39
astringent	1.73	1.82	1.78	0.46

[a] Texture was measured at 23 °C 10 times for each sample with a TA-XT2 texture analyzer. Sensory properties were determined at 23 °C by 13 trained panelists using a continuous scale from 0 (undetectable) to 14 (strong). Means with different letters within a row differ at $P \leq 0.10$. [b] Weight percent on a dry matter basis.

Cheddar Cheese. Cheddar cheese made from the milk of high-HPI cows had the highest HPI values, and that from low-HPI cows had the lowest HPI values (**Table 7**). The differences can be explained by lower concentrations of the saturated fatty acids 10:0–16:0 and higher concentrations of the unsaturated fatty acids 18:1 and 18:2 in the fat of cheese from high-HPI cows (results not shown). Cheddar cheese from milk of low-HPI cows had the highest values for springiness, and Cheddar cheese from milk of high-HPI cows had the lowest values, whereas other textural parameters were not significantly influenced (**Table 7**). Cheddar cheese from milk of low-HPI cows was less salty and had a more volatile cheddary taste than did Cheddar cheese from bulk-tank milk (**Table 7**).

DISCUSSION

Fatty Acid Composition. Genetics has been considered of minor importance in influencing milk fatty acid composition (*6*). Repeatability estimates of 0.25−0.40 and 0.10−0.23 for concentrations of major fatty acids in milk fat within herd (*24*) and overall (*25*), respectively, and heritability estimates of 0.08−0.25 and 0.06−0.17 within herd (*24*) and overall (*25*), respectively, demonstrate, however, that selection of individual cows within a herd or breeding programs could be used to alter fatty acid composition to a profile that is more beneficial for human health. We showed in a previous study (*19*) that selection of individual cows with a naturally more unsaturated fatty acid composition could be used to produce butter with a fatty acid composition similar to that of butter made from the milk of cows fed diets rich in unsaturated fatty acids (*3*, *7*, *8*).

In the current study, the differences in fatty acid composition of butter (**Table 2**), vanilla ice cream (**Table 4**), yogurt (**Table 5**), Provolone cheese (**Table 6**), and Cheddar cheese (**Table 7**) were half the magnitude of those of butter in the previous study (*19*). A possible reason is that in the current study only cows of the Holstein breed were used for selection, whereas in the previous study different dairy breeds were used. Another reason is that in the current study the time between selection of cows and collection of milk samples for manufacture of dairy products was longer (2−7 weeks versus 1 week). We observed that, as the time length between selection of cows and collection of milk samples for manufacture increased, the HPI differences between the milk defined as bulk tank and the milk defined as high HPI would decrease. A good example is Cheddar cheese, which had for all of the products the smallest numerical difference between its high-HPI group and its bulk-tank samples (**Tables 3−7**), but also the longest time, 7 weeks, between milk collection for cow selection and for cheese manufacture.

Differences in the length of time between milk collection for cow selection and for making products could explain the differences in HPI values for various dairy products (**Tables 3−7**). Also, the differences in HPIs could be caused by differences in milk fatty acid composition of the cows available for selection because the selection process extended over a 1.5-year period, and for each product different cows were selected. Both reasons could explain also why the high-HPI group for Cheddar cheese had HPI values similar to those of the bulk-tank samples from other dairy products (**Tables 3−7**).

Although the numerical differences in fatty acid composition of dairy products were smaller than those previously reported, the differences in fatty acid composition were still significant among butter (**Table 2**), vanilla ice cream (**Table 4**), yogurt (**Table 5**), Provolone cheese (**Table 6**), and Cheddar cheese (**Table 7**) from bulk-tank milk and milk of cows with high HPI. These results suggest that selection of dairy cows can be used to manufacture dairy products with probably a more health-promoting fatty acid composition.

Physical Properties. Milk fatty acid composition affects the texture of the food products by determining the amount of fat that is in the solid or liquid state (*1*, *2*). Because the structure of dairy products is determined primarily by lipid−lipid and protein−lipid interactions, they can lose their structure ("oil off") at higher temperatures when there are insufficient concentrations of solid fatty acids in the dairy product, for example, in products with highly unsaturated fatty acid composition (*13*, *14*, *16*). Milk fatty acid composition also affects the texture by influencing the size of the milk fat globules. The globules are larger and have attenuated interactions with each other and with proteins in dairy products with a more unsaturated fatty acid composition (*13*, *18*).

In a previous study (*19*), we demonstrated that selection of individual cows with a naturally more unsaturated fatty acid composition can be used to manufacture butter with a softer texture and better spreadability similar to that reported previously for butter from cows fed diets rich in unsaturated fatty acids (*8*, *12*, *15*). In the current study, only the texture of butter from milk of low- and high-HPI cows was significantly different (**Table 3**), which can be explained by the smaller differences in fatty acid composition among the three groups. A strongly unsaturated fatty acid composition, however, is also not desirable, because it causes oiling off at higher temperatures and a loss of structure (*13*, *15*). We did not observe visual oiling-off in the current study.

Similar to the results for butter, the textures of ice cream from milk of only low- and high-HPI cows were significantly different at −20 °C (**Table 4**). Feeding cows diets rich in unsaturated fatty acids did not affect firmness at −13 to −17 °C but decreased viscosity of ice cream at 7 °C (*8*). The lower ratio of solid to liquid lipids at 4 °C also could explain why yogurt from milk of high-HPI cows had a lower yield point than did yogurt from bulk-tank milk and from low-HPI cows (**Table 5**).

Provolone cheese from milk of high-HPI cows was softer and less gummy and chewy when measured across the grain than was Provolone cheese from milk of low-HPI cows (**Table 6**). Differences in resistance of the grain against compression could explain the results because the measurements of gumminess and chewiness are products of the measurement for hardness. The lack of differences in springiness and cohesiveness also indicates that the cheese did not lose its structure after compression (**Table 7**). A softer structure of cheese was reported also in studies in which cheese was made from milk of cows fed diets rich in polyunsaturated fatty acids (*11*, *16*, *18*). The structure of the cheeses with the most polyunsaturated fatty acid composition was, however, so weak that at higher temperature the cheese tended to be rubbery (*18*) and to taste mealy and curdy (*14*, *16*).

Differences in texture decreased numerically and had lesser significance values with increasing age of cheese (*11*, *18*). The only significant difference between groups in texture measurements was springiness, which was greatest for Cheddar cheese from milk of low-HPI cows (**Table 7**). These results, however, were not correlated with fat unsaturation because the springiness of Cheddar cheese from bulk-tank milk was lower than that from milk of low-HPI cows.

Overall, the results indicate that fatty acid composition of milk affects the structure of butter, ice cream, yogurt, and Provolone cheese. These dairy products were softer or less firm when manufactured from milk of low-HPI cows. These dairy products, however, were not so soft and weak that they seemed to have texture deficiencies or poor structure at higher temperatures, which would limit their appeal in commerce. Therefore, selection of individual cows with a naturally more unsaturated milk fatty acid composition could be used to produce dairy products with a softer structure.

Flavor Evaluation. Milk fatty acid composition can affect the flavor of its food products (*1*, *2*). Unsaturated fatty acids, in particular the polyunsaturated ones, are susceptible, especially after longer storage and prolonged light and oxygen exposure, to oxidation, which can cause a more oxidized, metallic, oily, or stale flavor in milk (*17*), butter (*13*), and cheese (*14*, *16*, *18*) from high-HPI cows. These flavor deficiencies were either not detected for any sample of the dairy product as was the case for yogurt (**Table 5**) and Cheddar cheese (**Table 7**) or not significantly different between groups as was the case for butter (**Table 3**), ice cream (**Table 4**), and Provolone cheese (**Table 6**). Only one sample for ice cream from milk of high-HPI cows seemed to have an oxidized taste that could be detected by the more experienced panelists.

Polyunsaturated fatty acids can inhibit lipases that are important for the generation of cultured dairy product flavor by releasing free fatty acids (*16*, *18*). A problem with a flat or bland taste and a lack of milky, creamy, or dairy-product-typical taste has been reported for butter (*16*) and cheese (*13*, *14*, *16*) from milk of cows fed diets rich in polyunsaturated fatty acids. In the current study, similar flavor deficiencies could not be detected by the sensory panel in dairy products from milk of high-HPI cows (**Tables 3−7**), suggesting that the polyunsaturated fatty acids of milk in the current study did not affect significantly the flavor development of dairy products.

When there were significant differences between groups for flavor components, dairy products from bulk-tank milk had either higher or lower values than did dairy products from milk of low- and high-HPI cows. These kinds of differences were for the sweet taste of ice cream (**Table 4**), the acidic taste of yogurt (**Table 5**), the buttery taste of Provolone cheese (**Table 6**), and the salty and volatile cheddary taste of Cheddar cheese (**Table 7**). This nonlinear change of taste with fatty acid composition suggests that these differences between groups were not associated with differences in degree of unsaturation of milk fatty acid composition but rather are associated with other flavor-generating components of milk that are influenced by cows' genetics (*26*). The only exception was the yogurt-like flavor of yogurt, which was highest for yogurt from milk of high-HPI cows and lowest for yogurt from milk of low-HPI cows (**Table 5**), which suggests that a more unsaturated milk fatty acid composition could have a beneficial effect on yogurt flavor development.

Overall, there were only minor differences in flavor among dairy products from milk of cows with different milk fatty acid composition. All but one of those detected differences in flavor did not seem to be associated with fatty acid composition of milk and caused major flavor deficiencies, which would preclude consumer acceptance of low-HPI dairy products. The lack of major differences in flavor is similar to results of studies in which moderate changes in fatty acid composition were achieved by feeding cows diets rich in unsaturated fatty acids (*3*, *11*, *12*), which suggest that flavor deficiencies can be expected only of dairy products that are rich in polyunsaturated fatty acids. Moreover, Aigster et al. (*3*) reported that panelists preferred cheeses with a more unsaturated fatty acid composition.

There is a demand by consumers for dairy products with a more unsaturated fatty acid composition, and they may be willing to pay a premium for such products if the products have no flavor deficiencies (*27*). The current study indicates that one potential way to manufacture such dairy products is to segregate milk from cows with a more unsaturated milk fatty acid composition, which could be done short-term by selection of individual cows and long-term by breeding programs.

Conclusion. The current study demonstrates that milk from cows with a more unsaturated fatty acid composition could be used to manufacture dairy products, specifically butter, ice cream, yogurt, and Provolone and Cheddar cheeses. These products probably have a more health-promoting fatty acid composition and a softer but acceptable texture and are similar in flavor to dairy products from bulk-tank milk. Such products possibly could be sold commercially at a premium as health-promoting products.

ABBREVIATIONS USED

DM, dry matter; HDL, high-density lipoprotein; HPI, health-promoting index; LDL, low-density lipoprotein; SE, standard error.

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