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Milk quality as affected by feeding regimens in a country with climatic variation

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ABSTRACT

To investigate the influence of climatic conditions and season on milk composition, bulk tank milk was sampled on 5 occasions during a period of 15 mo from 20 Swedish dairy farms. These farms included 5 organic and 5 conventional farms in central Sweden and 7 traditional conventional farms and 3 conventional farms growing maize for silage in southern Sweden. Feed data and milk yield were recorded and milk was analyzed for content of fatty acids, carotenoids, and tocopherol. Differences between milk from the 2 regions and between summer and winter seasons were shown. Milk from central Sweden differed from milk from southern Sweden in that it had a higher content of carotenoids, tocopherol, short-chain fatty acids (C4–C14), C18:0, and C18:3 n-3 and a lower content of C16. Summer milk samples had a lower fat content and contained higher amounts of C18:1 *cis*-9 and conjugated linoleic acid *cis*-9,*trans*-11, and lower amounts of C4 to C16 compared with winter milk. Differences between farm types from central Sweden were lower content of conjugated linoleic acid *cis*-9,*trans*-11 and higher content of C18:3 n-3 in organic milk compared with conventional milk. In southern Sweden the use of maize silage caused lower milk content of carotenoids and C18:3 n-3 when compared with traditional feeding. Differences in milk composition could be related to climatic differences because legumes are more dominating in the leys of central Sweden and maize growing is limited to southern Sweden.
Key words: milk fatty acid, milk carotenoid, climatic variation

INTRODUCTION

There is an increasing interest among consumers to buy dairy products with a specific history or composition or from a specific region, and consumers are often willing to pay a higher price for such perceived high-end products. In some countries like Sweden there is a large variation in the climate between the southern, central, and northern regions, and because climate affects the types of plant species that can be grown for feed production it has an indirect influence on milk composition. A major part of feed consumed by cattle consists of grass and other forage products, and legumes may occur at higher proportions of the swards in central Sweden compared with the south, whereas ryegrass cultivars are more dominant in leys in the south of Sweden, which is the only region of Sweden where it is possible to grow forage maize. In central Sweden, barley is the most common grain crop, whereas all temperate cereals are produced in the southern part of the country. Barley and wheat are the most widely used crops in the feeding of dairy cattle, but some farms also use oats. The composition of Swedish dairy bulk milk is affected by season and geographic region of origin although, whereas the majority of compounds are affected by season, less than one-third shows geographical variation; this variation is not systematic (Lindmark-Mansson et al., 2003).

Numerous studies have been carried out to investigate how milk composition is influenced by the feed components. Recently, the fatty acid composition of milk has received much attention, especially because of human health considerations. Further, fatty acids and other fat-soluble constituents and their metabolites may also influence milk flavor as well as the texture and flavor of processed dairy products such as cheese and butter.

Milk fatty acid composition is affected by feed components, and higher contents of C18:3 n-3 and conjugated linoleic acid (**CLA**) have been related to the use of grass-based forage (pasture, silage, hay) rather than maize silage (Havemose et al., 2004; Couvreur et al., 2006; Ferlay et al., 2006) and to higher proportions of clover and other legume species than grasses (Dewhurst et al., 2003; Vanhatalo et al., 2007). Grazing of fresh pasture also gives higher concentrations of C18:3 n-3 and CLA in milk compared with conserved forage (Dewhurst et al., 2006).

Several studies have examined the variation in milk fatty acid composition over 1 yr. Generally, the content

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of CLA is significantly higher in summer months than in winter months (Toledo et al., 2002; Lock and Garnsworthy, 2003; Thorsdottir et al., 2004; Ellis et al., 2006; Zegarska et al., 2006), a variation that is ascribed to be an effect of pasturing. Similar but lower effects on C18:3 n-3 in milk are found (Ellis et al., 2006; Zegarska et al., 2006; Butler et al., 2008). Another effect of pasturing has been reported as a seasonal variation in the content of C18:3 n-3 in organic milk compared with lower constant levels of conventional milk (Slots et al., 2008).

Antioxidant content in milk is also affected by feed composition: 2 to 6 times higher milk concentrations of carotenoids as well as tocopherols have been found when cows are fed grass silage instead of maize silage (Havemose et al., 2004). Compared with conventional milk, the content of α-tocopherol and carotenoid has been reported as 33% higher in organic milk and 50 and 90% higher, respectively, in milk from UK low input dairy farms (Butler et al., 2008), and the content of carotenoids in Danish organic milk is reported to be twice as high as the content in conventional milk (Slots et al., 2008). In commercial organic dairy products, 50% higher tocopherol concentrations and 80% higher β-carotene concentrations have been reported when compared with conventional products (Bergamo et al., 2003). In Sweden, higher concentrations of α-tocopherol and β-carotene have been reported in summer milk compared with winter milk, whereas no geographical variation is found (Lindmark-Månsson et al., 2003).

The purpose of the present study was to collect milk from a range of dairy farms in Sweden to study to what extent differences in milk composition, especially fatty acid composition and content of fat-soluble antioxidants, could be related to dairy diet composition, and to what extent these differences could be related to geographical and seasonal influence as well as the influence of organic farming compared with conventional farming. Based on these results, characteristics of milk from different parts of the country and different production systems could be described. This knowledge may be used to create a greater diversity of Swedish milk products. The present study was a part of the Quality Low Input Food (**QLIF**) project in which a survey of effects of dairy management on quality characteristics of milk was performed. Sweden was included in the project as a country representing intensive milk production with a large variation in climate.

MATERIALS AND METHODS

Farm Details and Milk Survey Design

Milk samples from 20 dairy herds were collected 5 times over 15 mo to obtain a total of 100 samples. To ensure geographical and climate variation, 10 farms were selected from central Sweden (the counties of Dalarna, Gästrikland, and Hälsingland) and 10 were selected from the south of Sweden (the county of Blekinge). The distance between south and central regions is about 800 to 1,000 km. The 10 farms from central Sweden consisted of 5 certified organic farms and 5 conventional farms, whereas all 10 farms from southern Sweden were conventional and 3 of these were growing maize for silage. For central Swedish farms, 1 conventional and 2 organic herds were mixtures of Swedish Red breed (**SRB**) and Swedish Holstein (**SH**), whereas the remaining herds were entirely SRB. For the 10 south Swedish farms, 1 herd was a mixture of SRB and SH, 5 herds were entirely SRB, and the last 4 herds were entirely SH. The 3 herds that were fed maize silage were all SH.

Milk Sampling

Milk samples were taken in April-May 2004, August-September 2004, December 2004-January 2005, March-April 2005, and June 2005. Based on the use of pasture grazing, samples taken in December-January and March-April were classified as winter samples and those taken in April-May, August-September, and June were classified as summer samples. According to Swedish legislation all dairy cows (conventional as well as organic) have to be on pasture for a certain period of time during the summer. In the southern part of the country, cattle must be on pasture at least 4 mo during the period from May 1 to October 15, whereas the required time in the central region is 2 mo during the same period. The animals must be on pasture every day for a minimum of 6 h, but deviations from this are accepted in case of very bad weather or other circumstances.

The milk samples were taken from the bulk tank after 2 milkings at each participating farm, which represented 24 h of production. Samples were cooled and frozen on the day of sampling and stored at −20°C until analyses for fatty acid composition, α-tocopherols, β-carotene, lutein, and zeaxanthin. At sampling the following information was given by the farmer: diet composition, number of milking cows, total milk produced, and milk quality parameters (fat and protein). Data on allocated feeds were given as amounts of DM per cow per day for all feeds.

Analysis of Fatty Acid Composition

Analysis of milk fatty acid composition was performed as described by Havemose et al. (2004) with some modifications. Milk fat was extracted from milk (2.00 mL) by adding methanol (2 mL) and chloroform (4 mL). The mixture was shaken vigorously for 1 min and then centrifuged for 10 min at 3,000 × *g* at 4°C. The lower phase containing the lipid fraction was isolated. Two subsequent extractions were carried out, each by adding 4 mL of chloroform and continuing as above. The 3 chloroform extracts were combined and evaporated to dryness under nitrogen. For methylation of fatty acids, approximately 10 mg of the extracted fat was dissolved in sodium methylate (1 mL) in sealed glass tubes filled with argon, incubated at 60°C for 30 min, and then cooled on ice. A saturated sodium chloride solution (4 mL) and pentane (1 mL) were added. The samples were mixed on a Vortex mixer (IKA Werke GmbH and Co. KG, Staufen, Germany) for 1 min and centrifuged at 1,700 × *g* for 10 min. The upper pentane phase was collected and used for analysis by gas chromatography.

Gas chromatographic conditions were a HP6890 GC-system (Hewlett Packard Co., Palo Alto, CA) with a flame ionization detector and a Supelco SI 2560 column (100 m × 0.25 mm × 0.20 μm; Supelco, Bellefonte, PA). The inlet temperature was 275°C with a split ratio 40:1, and the carrier gas was helium with a constant flow of 1.5 mL/min. The starting temperature of 140°C was held for 5 min and increased by 4°C/min to an end temperature of 240°C. The detector temperature was 300°C.

Fatty acids were identified and content as grams per kilogram of fatty acids were calculated based on the use of external standards. Only fatty acids present at a minimum of 5 g/kg of fatty acids (average) were included.

Analysis of Fat-Soluble Antioxidant Composition

Fat-soluble antioxidants (α-tocopherol, β-carotene, lutein, and zeaxanthin) were analyzed using the HPLC methods described by Havemose et al. (2004) with modifications as described by Slots et al. (2009). For analysis of α-tocopherol, milk samples (2 mL) were mixed with ethanolic ascorbic acid (2 mL). Saturated potassium hydroxide (0.3 mL) was added and saponification was carried out at 70°C for 30 min. Water (1 mL) and heptane (3 mL) were added, samples were centrifuged (1,700 × *g*, 3 min), and the supernatant was used for HPLC analysis. The HPLC analysis was carried out on an HP 1100 system (Agilent Technologies, Palo Alto, CA) equipped with a fluorescence detector (excitation 295 nm, emission 330 nm). For analysis of β-carotene, lutein, and zeaxanthin, milk samples (2 mL) were mixed with ethanolic butylhydroxytoluene (2 mL). Saturated potassium hydroxide (0.5 mL) was added and saponification was carried out at 70°C for 60 min. Water (1 mL) was added and samples were extracted 3 times with mixtures (3 mL) of heptane and dichloromethane (100:10, 100:20, and 100:20). Extracts were combined, evaporated until dryness, and redissolved in a mixture of acetonitrile:methanol:dichloromethane (100:10:5 vol/vol/vol) with further addition of triethylamine (0.5 mL/L) for HPLC analysis. The HPLC analysis was carried out on an HP 1100 system (Agilent Technologies) equipped with a diode array detector [detection at 448 nm (lutein) and 455 nm (β-carotene and zeaxanthin)]. The milk contents of α-tocopherol, β-carotene, lutein, and zeaxanthin were quantified by use of external standards and recalculated as content in milk fat.

Statistical Analysis

For 4 samples, fat-soluble antioxidant data were regarded as outliers and these data were omitted. Data were analyzed by principal component analysis (**PCA**) by use of SimcaP+ 12.0 (Umetrics AB, Umeå, Sweden) to obtain an overview of the different types of samples. One-way ANOVA were performed by the General Linear Models procedure of SAS (9.1 for Windows, SAS Institute Inc., Cary, NC) to determine how diet composition and milk composition were affected by geographical origin and summer or winter season and, for each geographical origin, by farm type and summer or winter season.

RESULTS

To obtain an overview of differences in milk composition, PCA were created based on the content of the following compounds: fat, protein, α-tocopherol, carotenoids, and fatty acid composition. Because of high correlations, in these multivariate analyses we used the sum of β-carotene, lutein, and zeaxanthin as carotenoids and for fatty acids we used the sums of C6, C8, and C10 and of C12 and C14. Figure 1 shows a PCA plot of all samples marked according to geographical origin. Samples could be separated into one group from central Sweden and another group from the south of Sweden, the former characterized by a higher content of carotenoids, C18:3 n-3, and C6 to C14 and the latter by a higher content of C16 and C16:1. Figure 2 shows the same PCA where samples are marked according to season, but the variation between summer and winter is not as clear as the geographical variation. The major differences between seasons were a higher content of C18:1 *cis*-9 and CLA *cis*-9,*trans*-11 in summer milk and a higher content of short- and medium-chain fatty acids (C6–C14) in winter milk. When Figures 1 and 2 are compared, seasonal differences were more pronounced for central Swedish samples than for samples from the south of Sweden.

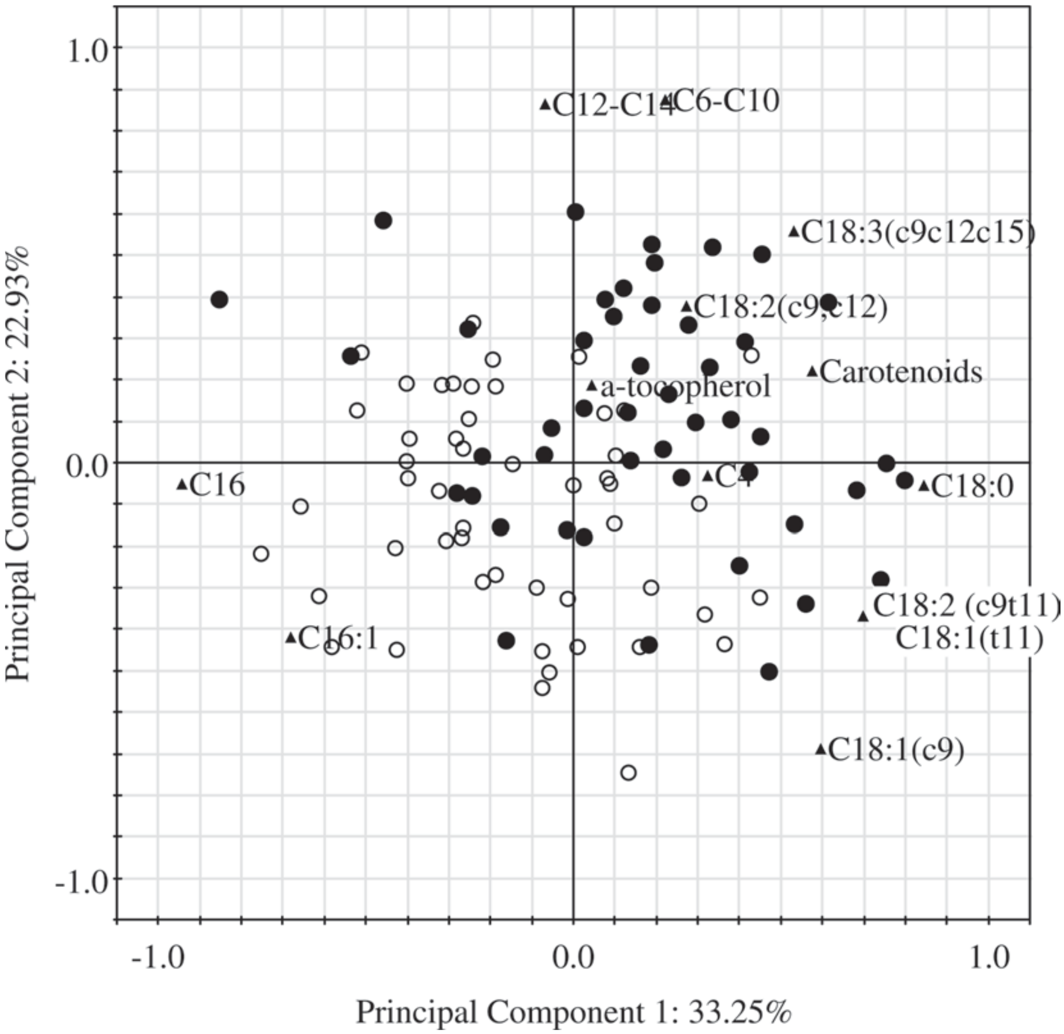

Figure 1. Principal component analysis scores and loadings biplot of all samples based on milk composition (●: samples from central Sweden; ○: samples from southern Sweden; ▲: loading vectors). c = *cis*; t = *trans*.

Central Swedish milk samples came from organic as well as conventional farms; however, the PCA plot of these given in Figure 3 shows no clear pattern of difference in milk composition between 2 farm types. Likewise, the PCA plot of milk samples from southern Sweden (Figure 4) showed no clear differences between the traditional conventional farm type and the farm type growing maize for silage.

Based on these results, samples were grouped according to geographical origin and season for further studies. Table 1 shows farm information, feed composition, and milk composition for southern and central Swedish farms in winter and in summer. The herds were larger in south Sweden and the milk yield did not differ significantly, neither between geographical origins nor between seasons.

The feeds used at the farms in southern Sweden were characterized by a higher content of maize silage, byproducts, and mineral-vitamin supplements and a lower content of grass silage and pasture. Byproducts cover a range of products and in the present study a range of farmers used a waste product from the processing of sugar beets mainly consisting of sugar beet fibers. For southern Swedish as well as central Swedish farms, differences between summer and winter feed were mainly the use of pasture in summer and the use of grass silage in winter, although the amount of pasture used in summer at southern Swedish farms was not significantly different from zero. Even for the central Swedish farms pasture was just one-fourth of the total feed intake or one-half of the total forage intake during summer.

Milk composition was affected by season as well as geographical origin. Southern Swedish milk samples had a higher content of C16 and C16:1 and a lower content of fat, protein, C18:3 n-3, C18, C6 to C10, and carotenoids. The main seasonal differences in milk

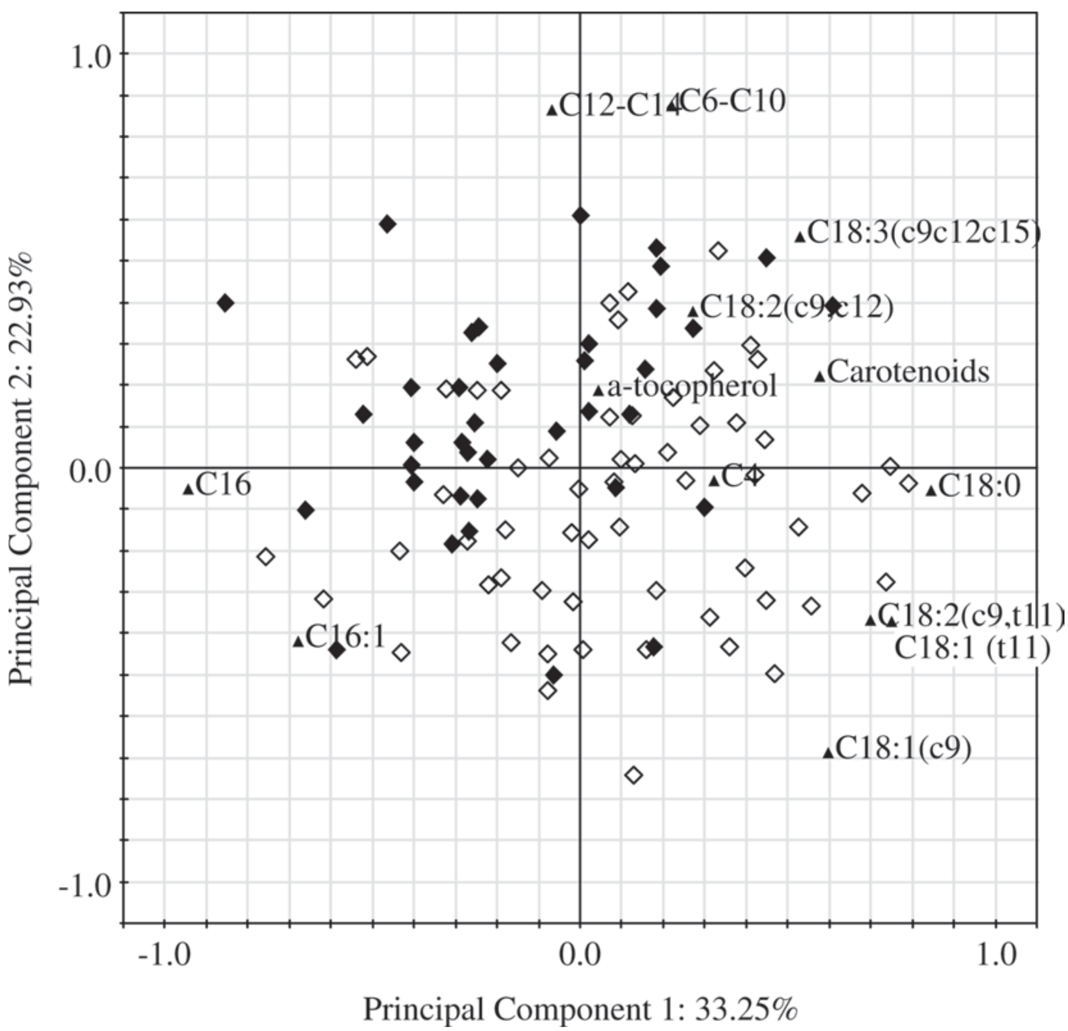

Figure 2. Principal component analysis scores and loadings biplot of all samples based on milk composition (♦: winter samples; ◊: summer samples; ▲: loading vectors). c = *cis*; t = *trans*.

composition were a higher content of fat and C6 to C16 in winter and a higher content of C18 fatty acids, especially C18:1 *cis*-9, in summer. For southern Swedish milk the tocopherol content was lower in summer, and for central Swedish farms the content of lutein and CLA *cis*-9,*trans*-11 was higher in summer.

Differences in diet and milk composition between farm types within each geographical origin were analyzed by univariate statistics, and parameters that showed significant differences ($P < 0.05$) between farm types are listed in Tables 2 and 3. For central Swedish farms, organic milk had a higher content of C18:3 n-3 and a lower content of CLA *cis*-9,*trans*-11 and the only significant difference in diet was a higher amount of concentrate used at conventional farms (Table 2). Milk from southern Swedish farms growing maize for silage had a lower content of carotenoids and C18:3 n-3 compared with milk from traditional farms, and traditional farms used higher amounts of grass silage and concentrates whereas maize silage was a significant feed source at farms growing maize for silage (Table 3).

DISCUSSION

In several other studies significant differences between composition of organic and conventional milks have been found, and these differences have been related to differences in feeding regimens (Jahreis et al., 1997; Ellis et al., 2006; Butler et al., 2008; Slots et al., 2008, 2009; Butler et al., 2009). However, in the present study the differences in milk composition between organic and conventional milks were minor, and much larger differences were found in milk composition between milk samples from central Sweden and southern Sweden. Such findings indicate that traditional conventional dairy farming in central Sweden is very

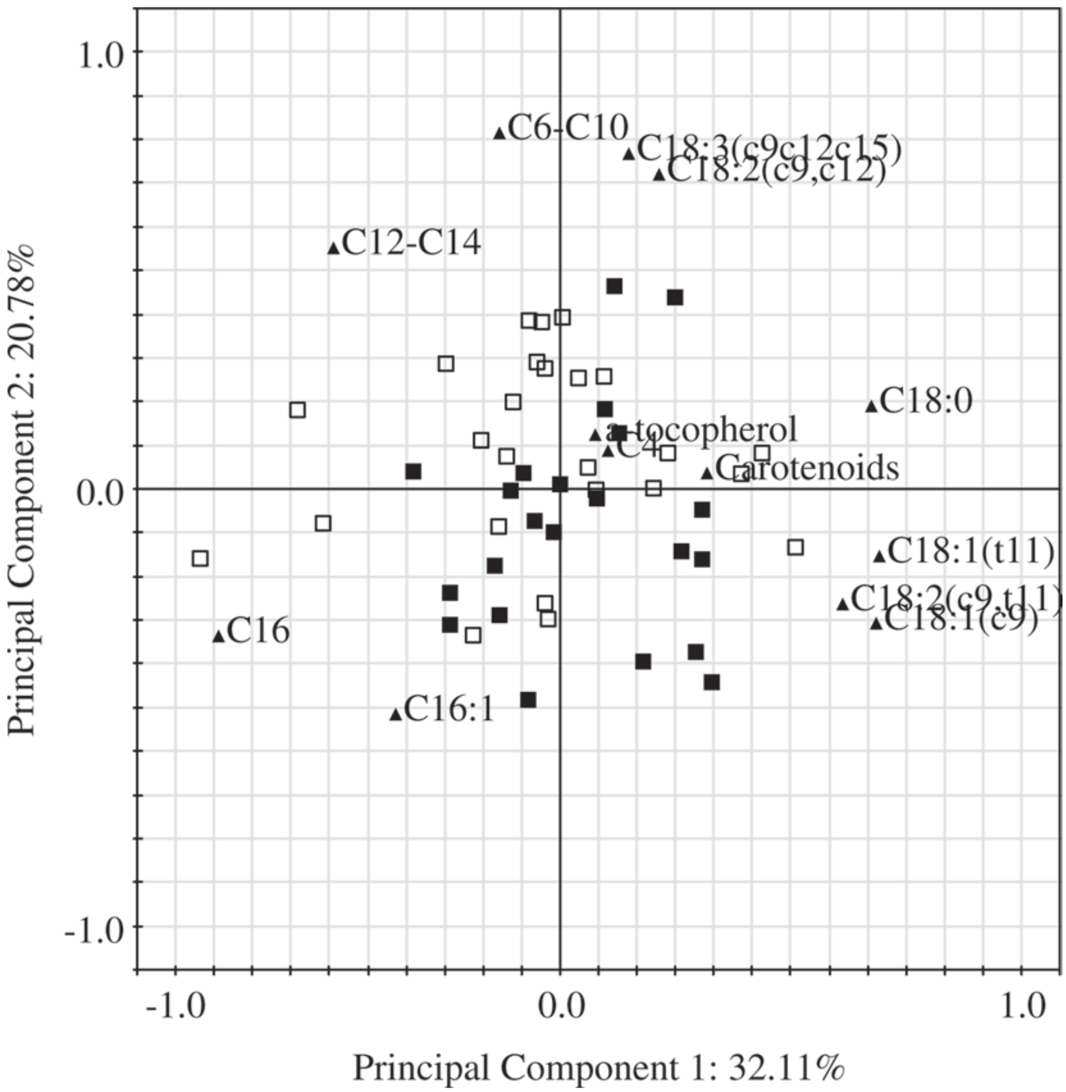

Figure 3. Principal component analysis scores and loadings biplot of central Swedish samples based on milk composition. Samples marked according to farm type (■: conventional farms; □: organic farms; ▲: loading vectors). c = *cis*; t = *trans*.

similar to organic farming, whereas differences between geographic origins deserve more attention. When farms were selected for participation in the present study, organic farming in south Sweden was very limited and it was not possible to find enough southern Swedish organic farms with suitable feeding patterns and herd sizes to be included in the survey.

Differences in milk composition between geographic origins or seasons are expected to be explained mainly by different feeding regimens, but other conditions may also affect milk composition. In the present study the higher fat content in milk from central Sweden compared with milk from southern Sweden was most likely attributable to the higher share of SRB in central Sweden because SRB cows produce milk with a higher fat content than SH cows. In contrast, the difference in fat content between summer and winter was most likely feed-related and is well recognized as normal for Swedish milk (Toledo et al., 2002). In contrast, Lindmark-Månsson et al. (2003) have not reported seasonal differences but, similar to our findings, they have found a higher fat content in milk from northern Sweden compared with milk from southern Sweden.

The differences in carotenoids between southern Swedish and central Swedish milk samples were larger than expected from the small differences in intake of grass products and maize silage and suggest possible variation in the composition of forages between the geographic regions. These could to some extent be attributable to differences in plant species such as

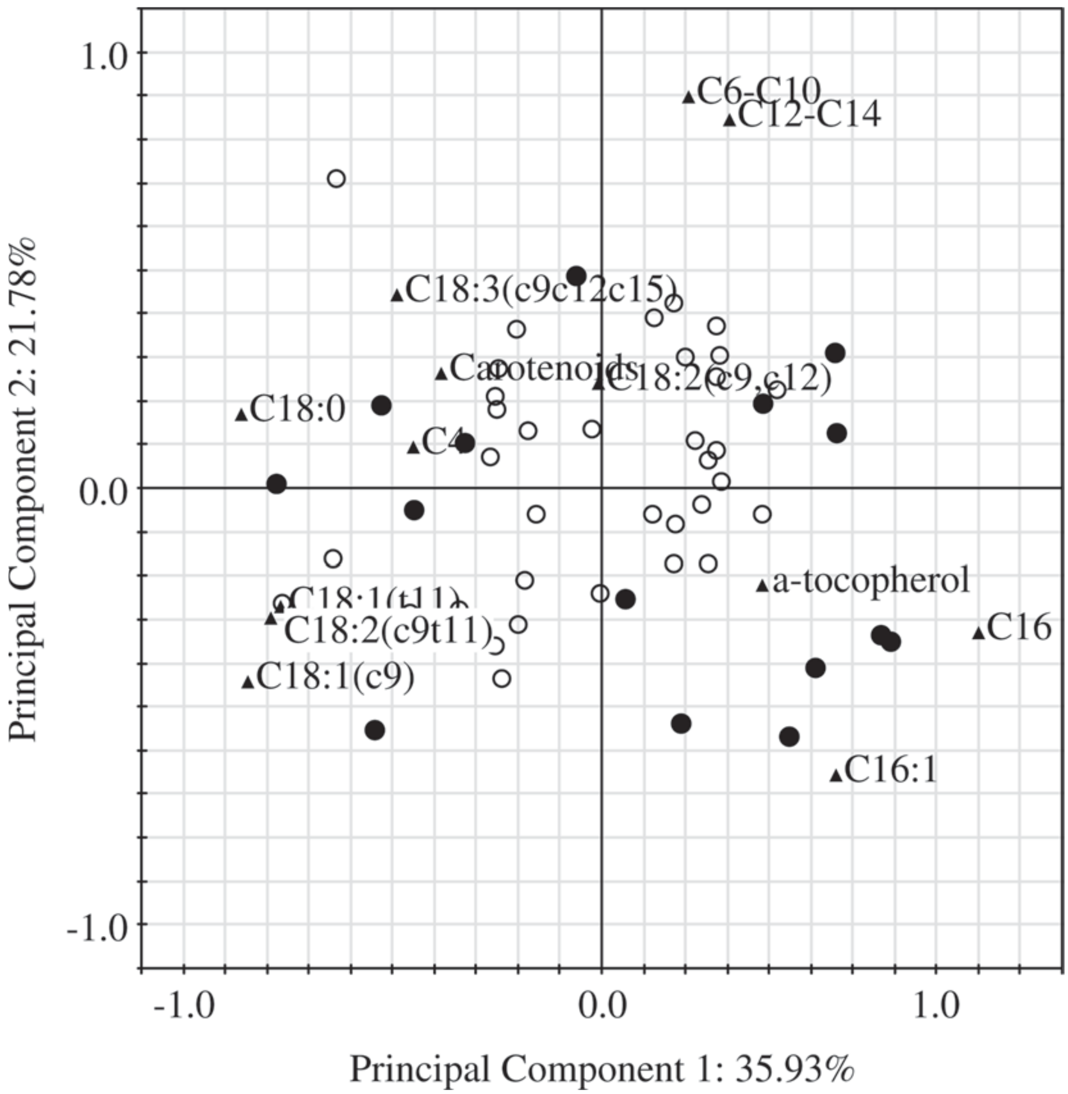

Figure 4. Principal component analysis scores and loadings biplot of southern Swedish samples based on milk composition. Samples marked according to farm type (●: farms growing maize for silage; ○: traditional farms; ▲: loading vectors). c = *cis*; t = *trans*.

higher shares of legumes in central Sweden, and different harvesting conditions could also create significant variation (Noziere et al., 2006). Also, the higher share of SH cows in south Sweden may influence the milk carotenoid content because milk from Holstein cows is reported to contain lower amounts of carotenoids compared with milk from other breeds (Noziere et al., 2006). The effect of maize silage on the milk carotenoid content was smaller than previously reported (Havemose et al., 2004) because the forage in the present study was a mixture of maize silage and grass products, whereas the previous study compared forages consisting entirely of either maize silage or grass silage (Havemose et al., 2004). In the Danish QLIF survey (Slots et al., 2009) the milk β-carotene content is 3.7 to 4.3 μg/g of milk fat. This is higher than the β-carotene content of milk from farms growing maize for silage in the present study. The Danish herds are also entirely Holstein and the feed share of maize silage is higher than that used at the farms growing maize for silage in the present study. Thus, differences could not be explained directly by breed or by the use of maize silage. Other factors that may influence the carotenoid content are forage manufacture and concentrate composition.

The higher C16 content of milk from southern Sweden may derive from feed or from de novo synthesis, but because the content of short-chain fatty acids in milk from southern Sweden was lower, the higher C16 content in this milk was most likely attributable to a higher dietary supply of C16. A possible feed source of C16 is the use of C16-enriched concentrate because this is commonly used and is known to result in higher milk

Table 1. Means ± SD of milk composition and allocation of feeds of central and southern Swedish farms in winter and in summer

	Central Swedish		Southern Swedish	
Item	Winter	Summer	Winter	Summer
Samples, no.	20	30	20	30
Herd size, no. of cows	39 ± 19[b]	38 ± 19[b]	69 ± 41[a]	70 ± 41[a]
Milk yield, kg/cow per day	28.1 ± 4.4	26.5 ± 4.5	29.8 ± 6.9	28.6 ± 7.3
Feed allocation, kg of DM/d unless noted				
Pasture	0.0 ± 0.0[b]	6.0 ± 4.6[a]	0.0 ± 0.0[b]	1.7 ± 2.4[b]
Grass silage	8.4 ± 3.4[a]	4.0 ± 3.7[c]	6.9 ± 2.5[ab]	5.5 ± 2.1[bc]
Maize silage	0.0 ± 0.0[b]	0.0 ± 0.0[b]	1.0 ± 1.8[a]	0.9 ± 1.8[a]
Other silage	1.1 ± 3.2	0.3 ± 1.6	0.3 ± 0.6	0.1 ± 0.3
Hay or straw	0.9 ± 1.1[ab]	1.3 ± 1.1[a]	0.7 ± 0.9[ab]	0.6 ± 0.7[b]
Cereals	4.1 ± 3.0	3.8 ± 2.7	4.3 ± 2.5	5.1 ± 1.5
Concentrate	5.0 ± 4.5	4.3 ± 3.9	5.6 ± 2.5	3.8 ± 1.7
By-products	0.1 ± 0.4[b]	0.0 ± 0.0[b]	2.6 ± 3.0[a]	1.9 ± 2.1[a]
Minerals, g/d	43 ± 47[b]	37 ± 41[b]	90 ± 52[a]	74 ± 65[a]
Milk composition				
Fat, g/kg of milk	45.1 ± 2.8[a]	43.3 ± 2.1[b]	42.8 ± 1.6[b]	41.5 ± 1.5[c]
Protein, g/kg of milk	34.6 ± 1.2[a]	34.5 ± 1.5[a]	33.8 ± 1.3[ab]	33.5 ± 1.1[b]
Total α-tocopherol, μg/g of milk fat	18.9 ± 4.6[a]	17.8 ± 4.7[a]	18.1 ± 4.9[a]	14.6 ± 2.9[b]
β-Carotene, μg/g of milk fat	5.0 ± 1.5[a]	5.7 ± 2.3[a]	3.4 ± 1.5[b]	3.4 ± 1.9[b]
Lutein, μg/g of milk fat	0.33 ± 0.09[b]	0.45 ± 0.19[a]	0.25 ± 0.08[c]	0.27 ± 0.09[bc]
Zeaxanthin, μg/g of milk fat	0.12 ± 0.05[a]	0.11 ± 0.05[a]	0.06 ± 0.04[b]	0.08 ± 0.02[b]
Fatty acids, g/kg of fatty acids				
C4	46 ± 6[a]	47 ± 5[a]	43 ± 6[b]	47 ± 4[a]
C6	27 ± 2[a]	26 ± 3[ab]	24 ± 2[bc]	24 ± 3[c]
C8	17 ± 2[a]	16 ± 2[ab]	15 ± 2[b]	14 ± 2[c]
C10	36 ± 4[a]	35 ± 5[ab]	33 ± 5[b]	30 ± 5[c]
C12	38 ± 4[a]	36 ± 5[ab]	37 ± 6[a]	33 ± 4[b]
C14	120 ± 8[a]	115 ± 7[b]	116 ± 9[ab]	108 ± 8[c]
C16	337 ± 34[b]	311 ± 29[c]	358 ± 31[a]	346 ± 34[ab]
C16:1	17 ± 3[b]	18 ± 2[b]	20 ± 2[a]	20 ± 2[a]
C18:0	111 ± 14[ab]	118 ± 13[a]	100 ± 14[c]	105 ± 15[bc]
C18:1 *trans*-9	3.3 ± 0.9[b]	3.5 ± 0.8[ab]	3.5 ± 7[b]	4.1 ± 1.3[a]
C18:1 *trans*-11	14 ± 4[b]	20 ± 6[a]	15 ± 2[b]	17 ± 3[b]
C18:1 *cis*-9	201 ± 21[b]	223 ± 18[a]	206 ± 16[b]	222 ± 23[a]
C18:2 *cis*-9,*cis*-12	20 ± 4	19 ± 3	18 ± 2	19 ± 2
CLA *cis*-9,*trans*-11	4.8 ± 1.2[b]	6.9 ± 2.2[a]	4.9 ± 0.6[b]	5.6 ± 1.0[b]
C18:3 n-3	6.5 ± 2.7[a]	6.5 ± 1.9[a]	4.5 ± 0.8[b]	4.3 ± 1.0[b]

[a–c]Means within a row with different superscripts differ ($P < 0.05$).

content of C16, whereas contents of other fatty acids decrease or are unchanged (Hedegaard et al., 2006). However, this level of detail on dietary ingredients was not recorded.

The contents of C18:0 and C18:3 n-3 were higher in milk from central Swedish farms compared with milk from southern Swedish farms. The main source of C18:0 is rumen biohydrogenation of polyunsaturated fatty acids (Lock and Garnsworthy, 2003); thus, increased milk content of C18:0 may to be attributable to higher hydrogenation rates as well as higher feed supply of unsaturated C18 fatty acids. However, because the

Table 2. Means ± SD of milk composition and allocation of feeds of central Swedish organic and conventional farms in winter and in summer

	Conventional		Organic	
Item	Winter	Summer	Winter	Summer
Samples, no.	10	15	10	15
Feed allocation				
Concentrate, kg of DM/d	7.9 ± 4.8[a]	6.8 ± 4.1[a]	2.1 ± 0.5[b]	1.7 ± 0.8[b]
Milk composition				
CLA *cis*-9,*trans*-11,[1] g/kg of fatty acids	5.7 ± 0.8[b]	7.6 ± 2.5[a]	3.9 ± 0.8[c]	6.2 ± 1.8[ab]
C18:3 n-3, g/kg of fatty acids	5.3 ± 2.4[b]	5.3 ± 1.5[b]	7.7 ± 2.6[a]	7.6 ± 1.6[a]

[a–c]Means within a row with different superscripts differ ($P < 0.05$).

[1]CLA = conjugated linoleic acid.

Table 3. Means ± SD of milk composition and allocation of feeds of southern Swedish traditional farms and farms growing maize for silage in winter and in summer

	Traditional		Maize growing	
Item	Winter	Summer	Winter	Summer
Samples, no.	14	21	6	9
Feed allocation, kg of DM/d				
Concentrate	6.4 ± 2.5^{a}	4.2 ± 1.7^{b}	3.8 ± 1.5^{b}	3.0 ± 1.4^{b}
Grass silage	7.6 ± 2.5^{a}	6.1 ± 2.1^{b}	5.3 ± 1.7^{bc}	4.0 ± 0.9^{c}
Maize silage	0.0 ± 0.0^{b}	0.0 ± 0.0^{b}	3.3 ± 1.9^{a}	3.0 ± 2.3^{a}
Milk composition				
β-Carotene, μg/g of milk fat	3.8 ± 1.6^{ab}	4.0 ± 2.0^{a}	2.4 ± 1.0^{bc}	2.1 ± 1.0^{c}
Lutein, μg/g of milk fat	0.28 ± 0.07^{a}	0.31 ± 0.08^{a}	0.18 ± 0.05^{b}	0.19 ± 0.04^{b}
Zeaxanthin, μg/g of milk fat	0.07 ± 0.03^{ab}	0.09 ± 0.02^{a}	0.05 ± 0.04^{b}	0.07 ± 0.02^{ab}
C18:3 n-3, g/kg of fatty acids	4.5 ± 0.8^{ab}	4.8 ± 1.0^{a}	3.7 ± 0.8^{c}	3.8 ± 0.5^{bc}

[a–c]Means within a row with different superscripts differ ($P < 0.05$).

higher content of C18:0 in milk was accompanied by a higher content of C18:3 n-3, these differences were attributable to higher feed supply of unsaturated C18 fatty acids, including C18:3 n-3.

An important feed source of C18:3 n-3 is grass products, and the difference in milk content of C18:3 n-3 between the 2 southern Swedish farm types could be related to the higher consumption of grass silage at southern Swedish traditional farms and the consumption of maize silage at farms growing maize for silage; this is in accordance with previous reports (Havemose et al., 2004). In contrast, the differences in milk content of C18:3 n-3 between southern and central Swedish farms and between organic and conventional central Swedish farms could not be directly related to the consumed amounts of grass products.

A higher share of legumes in the central Swedish leys as well as a higher share of legumes used at organic farms would create grass products with a higher content of C18:3 n-3 (Dewhurst et al., 2006). Besides, less oxidation during processing of grass products such as shorter wilting periods would give a better preservation of C18:3 n-3 in the final product (Dewhurst et al., 2006).

These feed factors increasing the milk content of C18:3 n-3 are similar to the factors increasing the milk content of carotenoids. These are important factors to ensure a characteristic composition of milk from central Sweden.

The main seasonal differences in milk fatty acid composition were a higher content of C18:1 *cis*-9 and a lower content of short-chain fatty acids in summer. These differences are claimed to be results of summer feeding (Toledo et al., 2002; Lindmark-Månsson et al., 2003; Zegarska et al., 2006).

The content of CLA *cis*-9,*trans*-11 was higher in conventional milk than in organic milk from central Sweden. The major difference in feed composition between these farm types was higher amounts of concentrate used at conventional farms. This effect of high concentrate feeding has been reported (Jiang et al., 1996) where the higher concentrate amounts cause a slower final rumen microbial hydrogenation of fatty acids, which leads to a higher blood content of unsaturated fatty acids, including C18:1 *trans*-11, the precursor of CLA *cis*-9,*trans*-11.

The content of CLA *cis*-9,*trans*-11 increased in milk from central Sweden during summer, whereas it was not affected by season in milk from southern Sweden. This was likely related to amount of fresh grass consumption, although the pasture consumption was too low to increase milk content of C18:3 n-3. Similar effects of moderate fresh grass consumption have been reported previously (Toledo et al., 2002; Lock and Garnsworthy, 2003). The effect of fresh grass consumption could be attributable to fresh plant components reducing the final rumen microbial hydrogenation of fatty acids, creating a higher blood content of unsaturated fatty acids, including C18:1 *trans*-11 (Lee et al., 2007).

The concentration of C18:1 *trans*-11 is closely related to the concentration of CLA *cis*-9,*trans*-11, and high correlations ($r = 0.85$ and $r = 0.994$, respectively) are reported (Jahreis et al., 1997; Zegarska et al., 2006). Our present results also showed a strong correlation between CLA *cis*-9,*trans*-11 and C18:1 *trans*-11 ($r = 0.94$) and the calculated desaturation indices [CLA *cis*-9,*trans*-11/(C18:1 *trans*-11 + CLA *cis*-9,*trans*-11); Kelsey et al., 2003] showed only minor seasonal differences that were not significant. Others have reported major seasonal differences (Butler et al., 2009) or minor seasonal differences (Lock and Garnsworthy, 2003). The large seasonal differences are reported for farms that use spring calving and desaturase indices are lowest during the first months after calving (Butler et al., 2009). Rather than a seasonal effect, this could be an effect of stage of lactation as desaturase indices increase during lactation, especially during the first month (Larsen and Nielsen, 2009).

The differences in milk composition between farm types were small compared with the results of the British QLIF survey (Butler et al., 2008) and similar to the differences between farm types in the Danish QLIF survey (Slots et al., 2009). The large differences between farm types in the British survey (Butler et al., 2008) are attributable to a comparison of conventional high input intensive production systems and low input extensive production systems, organic as well as nonorganic. The low input extensive production systems are characterized by very high shares of grazing, low milk yield, and high milk content of polyunsaturated fatty acids and fat-soluble antioxidants. The yield and composition of milk from British conventional high input production systems (Butler et al., 2008) and milk from Danish high input conventional or organic production systems (Slots et al., 2009) are similar to the present results from Swedish high input production systems. Thus, the milk composition is affected mainly by the intensity (high input vs. low input) of the production system and this effect is linked to the milk yield.

CONCLUSIONS

Results in the present study show that the concentrations of polyunsaturated fatty acids and carotenoids are higher in milk from dairy farms in central Sweden than in milk from farms in southern Sweden, and these differences may be used in marketing of milk from the central region. In contrast, differences between organic and conventional dairy farms in central Sweden are minor, so other benefits of organic milk may have to be emphasized in marketing. The climate in southern and central Sweden dictates which crops can be grown in these regions and the inclusion of these plants in the feed ration will influence the milk composition from dairy cows. In particular, the use of maize silage in southern Sweden opposed to the high proportion of legumes in central Sweden affects milk composition toward a lower content of polyunsaturated fatty acids and carotenoids. If farmers in the southern part of Sweden switch to have greater reliance on maize silage, this geographical difference will increase.

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