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Fat composition of organic and conventional retail milk in northeast England

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ABSTRACT

This study of UK retail milk identified highly significant variations in fat composition. The survey, conducted over 2 yr replicating summer and winter, sampled 22 brands, 10 of which indicated organic production systems. Results corroborate earlier farm-based findings considering fat composition of milk produced under conventional and organic management. Organic milk had higher concentrations of beneficial fatty acids (FA) than conventional milk, including total polyunsaturated fatty acids (PUFA; 39.4 vs. 31.8 g/kg of total FA), conjugated linoleic acid *cis*-9,*trans*-11 (CLA9; 7.4 vs. 5.6 g/kg of FA), and α -linolenic acid (α -LN; 6.9 vs. 4.4 g/kg of FA). As expected, purchase season had a strong effect on fat composition: compared with milk purchased in winter, summer milk had a lower concentration of saturated fatty acids (682 vs. 725 g/kg of FA) and higher concentrations of PUFA (37.6 vs. 32.8 g/kg of FA), CLA9 (8.1 vs. 4.7 g/kg of FA), and α -LN (6.5 vs. 4.6 g/kg of FA). Differences identified between sampling years were more surprising: compared with that in yr 2, milk purchased in year 1 had higher concentrations of PUFA (37.5 vs. 32.9 g/kg of FA), α -LN (6.0 vs. 5.1 g/kg of FA), and linoleic acid (19.9 vs. 17.5 g/kg of FA) and lower concentrations of C16:0 and C14:0 (332 vs. 357 and 110 vs. 118 g/kg of FA, respectively). Strong interactions were identified between management and season as well as between season and year of the study. As in the earlier farm studies, differences in fat composition between systems were greater for summer compared with winter milk. Large between-year differences may be due to changes in weather influencing milk composition through forage availability, quality, and intake. If climate change predictions materialize, both forage and dairy management may have to adapt to maintain current milk quality. Considerable variation existed in milk fat composition between brands.

Key words: milk quality in United Kingdom, organic milk production, fat composition

INTRODUCTION

Previous research has suggested that fatty acid (FA) and antioxidant profiles of milk and dairy products by cows under organic management differ from those produced by cows under conventional management in the UK (Ellis et al., 2006; Butler et al., 2008, 2009) and elsewhere in Europe (Bergamo et al., 2003; Kraft et al., 2003; Collomb et al., 2008; Prandini et al., 2009). However, published findings are inconsistent, and composition differences relative to conventional milk tend to be seasonal in nature with minimal differences reported for milk collected in winter (Butler et al. 2008). In addition, in the UK, results have been derived solely from farm-based studies and it is questionable if these can be extrapolated to judge milk quality available to consumers because (1) individual farms chosen for sampling may not be representative of the production systems within the country and (2) processing within the supply chain might subsequently influence milk composition. Such questions are addressed in this study, which examined fat quality in milk purchased in retail outlets as consumed by the milk-buying public.

The nutritional contribution of bovine milk and the potential health effects of its main components (fat, protein, antioxidants, vitamins, and minerals) have been reviewed extensively, most recently by Haug et al. (2007) and Steijns (2008). Although the protein, antioxidants/vitamins, minerals, and some mono- (MUFA) and polyunsaturated (PUFA) fatty acids in milk are considered beneficial, saturated fatty acids (SFA) in milk fat are generally considered to have negative effects on human health (Hu et al., 2001), although this is has been questioned (Parodi, 2009). The effect of SFA on the relative proportions of high and low density lipoprotein cholesterol and resulting coronary heart disease (CHD) have been documented (Hu et al., 2001), although these effects are thought to be caused specifically by lauric (C12:0), myristic (C14:0), and palmitic (C16:0) acids (Temme et al., 1996), with other SFA

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having neutral or possibly positive effects on health. A recent review vindicates SFA further by citing a lack of evidence to link SFA with CHD and suggesting that randomized controlled trials mostly fail to show a reduction in CHD risk by substituting SFA intake with vegetable oil (Parodi, 2009). Although the damaging effects of SFA might be questioned by some scientists, the general advice to the public is to moderate SFA intake (FSA, 2010).

Although the detrimental effects of SFA might be disputed, health benefits from unsaturated fatty acids appear less contentious. Some of the MUFA, such as oleic acid [**OA**, C18:1 *cis(c)*9], and PUFA such as linoleic acid (**LA**, C18:2 c9,12) and α -linolenic acid (**α -LN**, C18:3 c9,12,15) have been linked to positive health effects (Haug et al., 2007). In addition, the ratio of α -LN (the main n-3 PUFA in milk fat) to n-6 PUFA is thought to be an important parameter determining the nutritional value of milk. Generally western diets are considered to have a low intake of n-3 relative to n-6, which is thought to promote the pathogenesis of a range of chronic diseases such as cardiovascular disease, cancer, and inflammatory autoimmune diseases (Simopoulos, 2002). Benefits attributed to longer chain n-3 such as eicosapentaenoic acid (**EPA**, C20:5) and docosahexaenoic acid (**DHA**, C22:6) are greater than those for α -LN, especially relating to CHD (Kris-Etherton et al., 2003). However, α -LN can undergo elongation to EPA in the human body, especially at low intakes of EPA and DHA or if limited competition from LA in the diet exists (DeFilippis and Sperling, 2006). Oily fish and certain vegetable oils, particularly flaxseed or linseed, are major dietary sources of long-chain and medium-chain n-3, respectively. Although milk fat is not considered a major source of n-3 PUFA (EFSA, 2009), an elevation in α -LN and EPA relative to LA and other n-6 PUFA in milk fat might be desirable to address this dietary imbalance (Connor, 2000).

Conjugated linoleic acid (**CLA**), particularly the C18:2, c9,*trans* (**t**)11 isomer (**CLA9**), has also been linked to beneficial health effects, in particular plasma lipid profile, lower CHD risk, and reduced cancer risks as reviewed by Wahle et al. (2004) and Bhattacharya et al. (2006), although many of the benefits tend to be limited to animal models and are yet to be proven in humans. Because vaccenic acid (**VA**, C18:1 t11) is the major precursor for CLA9 and its supply influences CLA9 synthesis in human tissue (Turpeinen et al., 2002), dietary VA concentration ought to be considered in evaluating CLA9 supply in foodstuffs. Ruminant milk and meat are almost our exclusive source of dietary CLA (Parodi, 2003), and the consumption of organic dairy products has been linked to higher CLA concentrations in human breast milk and reduced eczema incidence in

infants in recent studies in the Netherlands (Rist et al., 2007; Kummeling et al., 2008).

The effect of dairy nutrition on milk fat composition is well documented (Jensen, 2002; Walker et al., 2004) and is thought to be stronger than the effects of other agronomic factors such as breed, stage of lactation, or age and health status of dairy cows. Although details of the metabolic processes determining milk fatty acid profiles are not totally predictable, it is increasingly recognized that dairy diet manipulation can increase the proportion of unsaturated fatty acids secreted in milk (Givens and Shingfield, 2004; Lock and Bauman, 2004; Givens, 2006). For example, increasing fresh forage intake (Dewhurst et al., 2006; Elgersma et al., 2006) or the use of vegetable oil and oilseeds supplements (Dhiman et al., 1999; Collomb et al., 2006; Glasser et al., 2008) have been shown to increase PUFA supply in ruminant diets and α -LN, CLA, and total PUFA concentrations in milk fat. In contrast, feeding conserved forage reduces the concentrations of nutritionally desirable PUFA (including CLA and α -LN) in milk fat and increases SFA concentrations (Elgersma et al., 2003). This results in seasonal variation in the fatty acid profile in milk from UK dairy systems, which tend to use grazing-based diets during the summer and ensiled forage diets during the indoor winter period (Lock and Garnsworthy, 2003). Farm surveys report that milk collected during the grazing period has higher concentrations of PUFA, including CLA9 and α -LN, compared with milk produced during the housed period when cows were fed silage-based diets (Lock and Garnsworthy, 2003; Ellis et al., 2006; Butler et al., 2008). In addition to dietary manipulation, genetic variation in desaturation activity is recognized in dairy cattle and selective breeding might offer longer term scope to improve milk fat milk composition (Schennink et al., 2007).

Organic dairying standards in the UK (Soil Association, 2005) prescribe a reliance on forage, especially grazing, and tend to encourage swards with red and white clover in the absence of nitrogen fertilizer, which have been shown to alter the FA composition of forage (Laidlaw and Withers, 1998) and dietary FA intake (Dewhurst et al., 2001). Such dietary differences are thought to explain, in large part, the higher concentrations of PUFA, CLA, and α -LN found in organic milk compared with milk from more intensive production systems, although results are not unanimous (Bergamo et al., 2003; Kraft et al., 2003; Ellis et al., 2006; Butler et al., 2008; Collomb et al., 2008; Prandini et al., 2009). In these comparisons of organic and conventionally produced milk, Prandini et al. (2009) found no evidence of elevated PUFA, Ellis et al. (2006) found no difference in concentrations of CLA9 and VA, Kraft et al. (2003)

reported nonsignificant differences in α -LN, although they were substantial (3.3 vs. 8.6 mg/g of fat). Of the studies reporting MUFA concentrations, 2 found higher concentrations in organic milk (Ellis et al., 2006; Collob et al., 2008) and 2 reported no significant effect of management (Butler et al., 2008; Prandini et al., 2009).

This study had 3 objectives: (1) to relate previous results from farm-based surveys to milk quality available to consumers by comparing fatty acid profiles of organic and conventional milk at the retail level, (2) to identify variation in milk fat composition between different brands of retail milk, and (3) to rule out if processing in the supply chain (pasteurization and homogenization) could be at least partially responsible for potential differences in milk fat composition between farm and retail milk (in the absence of published evidence to the contrary).

MATERIALS AND METHODS

Sample Collection and Milk Composition

The aim was to collect as many brands as possible of whole, fresh milk available in supermarkets and other retail outlets in northeast England, sampling on 4 occasions: August 2006 and January 2007 (period 1), August 2007 and January 2008 (period 2), representing milk produced in summer and winter seasons over 2 sampling years or periods. Out of 124 milk types purchased, 88 samples from 22 brands [12 from conventional production (numbered 1–12) and 10 organic (numbered 13–22)] were included in this study. Results from the remaining 36 samples were excluded because they were not available on all 4 dates (13 conventional and 1 organic brand), they were fortified with supplements (3 brands), or they were labeled as coming from Jersey or another minority breed of cow (5 brands). No UHT milk was purchased and all products were within their “use by” dates, although specific details were not recorded. As soon as milk was purchased, it was transferred from commercial packaging (high-density polyethylene bottles, between 0.6 and 1.1 L) into 30-mL sterile, screw-top plastic bottles and stored at -20°C until chemical analysis was carried out. Subsamples were submitted to the National Milk Record laboratory (Harrogate, UK) for standard analyses of fat, protein, and lactose using a Milkoscan FT 6000 (Foss Electric, Hillerød, Denmark) and for SCC using a Fossomatic instrument (Foss Electric).

Milk samples for the supplementary study aimed at assessing the effect of processing on fatty acid composition were collected from a single producer-retailer 5 times throughout 2004 and 2005; on each occasion, raw

milk from the farm bulk tank was compared with milk sampled from the same batch before doorstep delivery following pasteurization and homogenization. Milk was sampled into 500-mL plastic bottles (without preservative), frozen immediately, and stored at -20°C until analyzed.

Fatty Acid Composition

Sample preparation was based on a variation of the widely used method of Sukhija and Palmquist (1988) as reported by Pickard et al. (2008), using methanol:toluene for lipid extraction and acetyl chloride for methylation of fatty acids before GC separation and quantification. Milk was thawed overnight at 6°C and mixed thoroughly; a 0.5-mL aliquot was transferred to a glass tube. Then, 1.7 mL of methanol:toluene (4:1 vol/vol) solution and 0.25 mL of acetyl chloride were added before heating at 100°C for 1 h in tightly sealed tubes. Samples were left for 30 min to reach room temperature before adding 5 mL of potassium chloride. Samples were finally centrifuged at $150 \times g$ for 6 min and the upper layer was removed for fatty acid analysis by GC.

Analysis of fatty acid methyl esters (FAME) was carried out with a GC (GC-2014, Shimadzu, Kyoto, Japan) using a Varian CP-SIL 88 fused-silica capillary column (100 m \times 0.25 mm internal diameter \times 0.2 μm film thickness). Purified helium was used as a carrier gas with a head pressure of 109.9 kPa and a column flow of 0.43 mL/min. The injection system (Shimadzu AOC-20i) used a split ratio of 89.8 and an injector temperature of 250°C ; detection by flame-ionization detector was at 275°C . One microliter of each sample was injected at an initial temperature of 50°C , held constant for 1 min before being increased to 188°C at $2^{\circ}\text{C}/\text{min}$, held for 10 min, and then increased to 240°C at $2^{\circ}\text{C}/\text{min}$, where the temperature was held for 44 min, giving a total run time of 150 min. Peaks of individual fatty acids were identified by using a 39 FAME standard, composed of a 37 fatty acid standard (Supelco FAME mix C4-C24, 100 mg; Supelco, Bellefonte, PA) with individual C18:1 t11 and C22:5 c7,10,13,16,19 standards, purchased from Sigma-Aldrich (Gillingham, UK). A separate CLA isomer standard containing CLA c9t11 and CLA t10c12 was kindly provided by colleagues from the Danish Institute for Agricultural Science (Aarhus, Denmark). Identification of peaks was confirmed by GC-MS (GC-MS-QP2010, Shimadzu) using the same column run under identical conditions. Peak areas for individual fatty acids were integrated using Shimadzu GC Solution software with quantification of individual fatty acids based on peak areas for each fatty acid as a proportion of total peak areas for all quantified acids. It is accepted that this method of quantification does not

Table 1. Gross milk compositions (ranges, mean values, and standard errors) for SCC, protein content, and fat content

Item	n	SCC ($\times 1,000$ cells/mL)			Milk protein (g/kg of milk)			Total milk fat (g/kg of milk)		
		Range	Mean	SEM	Range	Mean	SEM	Range	Mean	SEM
Management										
Conventional	48	4–152	39	5	30–34	31.7	0.1	26–40	34.9	0.3
Organic	40	4–169	54	7	30–36	31.8	0.2	22–42	37.5	0.6
Season										
Summer	44	6–169	54	7	30–36	31.8	0.2	22–39	35.1	0.5
Winter	44	4–125	38	5	30–34	31.7	0.1	32–42	37.0	0.4
Year										
2006–2007	44	5–169	57	7	30–33	31.6	0.1	32–42	36.8	0.3
2007–2008	44	1–102	34	4	30–36	31.9	0.2	22–42	35.3	0.6
ANOVA										
<i>P</i> -values: main factors										
Management (M)			NS			NS			**	
Season (S)			*			NS			***	
Year (Y)			***			*			**	
<i>P</i> -values: interactions										
M \times S			NS			**			*	
M \times Y			NS			†			NS	
S \times Y			*			***			NS	

*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; † = $0.05 < P < 0.1$; NS = $P > 0.1$.

allow for slight variation in response factors relating peak areas to concentrations; however, this technique is widely used and does allow sound comparisons within individual studies.

Statistical Analysis

Linear mixed-effects models (Pinheiro and Bates, 2000) were used to investigate differences in fatty acid concentrations due to (a) management system (conventional or organic), (b) production season (winter or summer), and (c) sampling period or year (2006–2007 or 2007–2008), as in Butler et al. (2008). Management, season, and year were fixed factors and the origin of the sample (brand) the random factor. The effects of the 3 main factors and interactions were assessed. A one-factor analysis was carried out separately for conventional and organic brands to identify within-system variation in composition using the 4 date samples as replicates. Although fatty acid concentrations were arcsine transformed before ANOVA, all mean values presented were calculated from nontransformed data. Pairwise comparisons of means were carried out, where appropriate, by Tukey's honestly significant difference tests, using mixed-effects models. All statistical analyses were carried out using the R statistical environment (R Development Core Team, 2006).

RESULTS

Differences in milk fat composition can be attributed to management system, season, and sampling periods in which the milk was purchased. Results of milk and

milk fat composition (means and standard errors) along with *P*-values from ANOVA for these 3 main factors and their interactions are presented in Tables 1 and 2. Selected results, exhibiting significant interactions between the main factors, are depicted in Figure 1.

Effect of Production System on Milk Composition

Organic milk had a small but significantly higher fat content (7%) than conventional milk; no significant difference was observed for SCC or total protein content of milk from the 2 production systems (Table 1).

Significant differences were identified in fatty acid profiles between organic and conventional milk fat (Table 2, Figure 1). Although total SFA concentration was not influenced by the system of production, concentrations of individual SFA did differ. Concentrations of C12:0 and C16:0 were 5 to 6% lower, whereas those of C14:0 and C18:0 were 4 and 7% higher, respectively, in organic compared with conventional milk fat. No significant differences were found in total MUFA or OA concentrations between production systems, whereas organic milk fat had significantly (41%) higher concentrations of VA.

When the main nutritionally relevant individual PUFA and groups were compared, significantly higher concentrations of LA (15%), CLA9 (32%), α -LN (57%), EPA (62%), n-3 (60%), n-6 (12%), and total PUFA (24%) were found in organic compared with conventional milk fat, whereas production system had no significant effect on the minor CLA isomer C18:2, t10c12 (CLA10) concentrations.

Table 2. Milk fatty acid composition, mean values for each of the main factors (g/kg of total fatty acids) and ANOVA *P*-values for main factors and their interactions

Fatty acid ¹	Management ²		Season ³		Year ⁴		SEM	<i>P</i> -value						
	Con	Org	Sum	Win	06/07	07/08		Main factor ⁵			Interaction			
	n = 48	n = 40	n = 44	n = 44	n = 44	n = 44		M	S	Y	M × S	M × Y	S × Y	M × S × Y
Short-chain SFA														
C4	19.4	18.7	19.1	19.1	27.5	10.6	1.1	NS	NS	***	NS	NS	NS	NS
C6	13.6	15.2	15.0	13.7	19.0	9.6	0.6	*	*	***	NS	NS	NS	NS
C8	9.3	10.2	9.4	10.1	11.9	7.5	0.3	†	NS	***	NS	NS	NS	NS
C10	25.9	27.9	26.4	27.2	28.7	24.9	0.4	***	†	***	†	NS	***	NS
Medium-chain SFA														
C12	36.6	34.6	33.6	37.8	35.3	36.1	0.4	***	***	†	**	†	***	NS
C14	112	116	109	118	110	118	1	**	***	***	*	NS	***	NS
C15	11.0	11.9	11.1	11.7	11.2	11.6	0.1	***	***	**	†	NS	NS	NS
C16	354	332	325	363	332	357	4	*	***	***	*	NS	NS	NS
Long-chain SFA														
C18:0	119	127	127	118	120	125	1	*	***	**	NS	NS	*	NS
C20:0	1.3	1.4	1.4	1.3	1.5	1.2	0.0	NS	NS	**	NS	NS	NS	NS
C22:0	1.6	1.9	1.8	1.7	1.6	1.9	0.0	**	NS	**	NS	NS	***	NS
C23:0	1.4	1.6	1.6	1.3	1.5	1.5	0.0	*	***	NS	NS	NS	**	†
C24:0	1.2	1.4	1.4	1.2	1.3	1.3	0.0	*	NS	NS	NS	NS	NS	NS
MUFA														
C14:1	10.0	9.4	9.7	9.7	9.8	9.6	0.1	*	NS	NS	*	NS	†	NS
C16:1	19.8	18.3	19.8	18.4	19.1	19.1	0.4	†	*	NS	NS	*	NS	NS
Oleic acid (C18:1 c9)	219	217	232	204	217	219	2	NS	***	NS	NS	*	NS	†
Vaccenic acid (C18:1 t11)	11.5	16.2	18.3	9.1	14.5	12.8	0.6	***	***	**	*	†	*	NS
C20:1	1.0	1.0	1.0	1.0	1.1	0.9	0.0	NS	NS	*	NS	NS	NS	NS
PUFA														
Linoleic acid (C18:2 c9,12)	17.5	20.1	18.2	19.2	19.9	17.5	0.3	***	*	***	**	NS	NS	NS
CLA9	5.6	7.4	8.1	4.7	6.7	6.1	0.2	***	***	**	**	NS	NS	NS
CLA10	0.5	0.5	0.4	0.6	0.5	0.6	0.0	NS	**	†	NS	NS	**	NS
α-Linolenic acid (C18:3 c9,12,15)	4.4	6.9	6.5	4.6	6.0	5.1	0.2	***	***	***	***	NS	NS	NS
C20:3	0.9	0.9	0.9	0.9	1.0	0.8	0.0	NS	NS	**	NS	NS	*	NS
C20:4	1.2	1.2	1.4	1.1	1.4	1.0	0.0	NS	***	**	NS	NS	NS	†
C22:2	0.6	0.5	0.5	0.6	0.5	0.6	0.0	NS	NS	NS	NS	NS	NS	NS
EPA	0.5	0.8	0.8	0.5	0.8	0.5	0.0	***	**	**	NS	NS	*	NS
DPA	0.6	0.7	0.6	0.7	0.7	0.6	0.0	†	NS	NS	*	NS	NS	NS
DHA	0.1	0.3	0.2	0.1	0.2	0.1	0.1	NS	NS	NS	NS	NS	NS	NS
Calculated values														
SFA	707	699	682	725	701	706	3	NS	***	*	NS	†	NS	†
MUFA	262	261	280	243	262	261	2	NS	***	NS	NS	†	NS	NS
PUFA	31.8	39.4	37.6	32.8	37.5	32.9	0.6	***	***	***	NS	NS	*	NS
n-3	5.5	8.8	8.1	5.9	7.6	6.4	0.3	***	***	**	***	†	*	NS
n-6	20.7	23.2	21.4	22.2	23.2	20.4	0.3	**	†	***	**	NS	NS	NS
n-3:n-6	0.27	0.39	0.38	0.27	0.33	0.32	0.01	***	***	NS	***	NS	NS	NS

¹SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; c = *cis*; t = *trans*; CLA9 = conjugated linoleic acid (C18:2 c9t11); CLA10 = conjugated linoleic acid C18:2 t10c12; EPA = eicosapentaenoic acid (C20:5 c5,8,11,14,17); DPA = docosapentaenoic acid (C22:5 c7,10,13,16,19); DHA = docosahexaenoic acid (C22:6 c4,7,10,13,16,19); n-3 = total n-3 FA (α-linolenic acid, EPA, DPA, and DHA) and n-6 = total n-6 fatty acids (linoleic acid; CLA10; C20:3 c8,11,14; C20:4 c5,8,11,14; and C22:2 c13,16).

²Con = conventional; Org = organic.

³Sum = summer; Win = winter.

⁴06/07 = August 2006 and January 2007 and 07/08 = August 2007 and January 2008.

⁵M = management (conventional or organic); S = Season (summer or winter); and Y = year (August 2006 and January 2007 or August 2007 and January 2008).

*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; † = $0.05 < P < 0.1$; NS = $P > 0.1$.

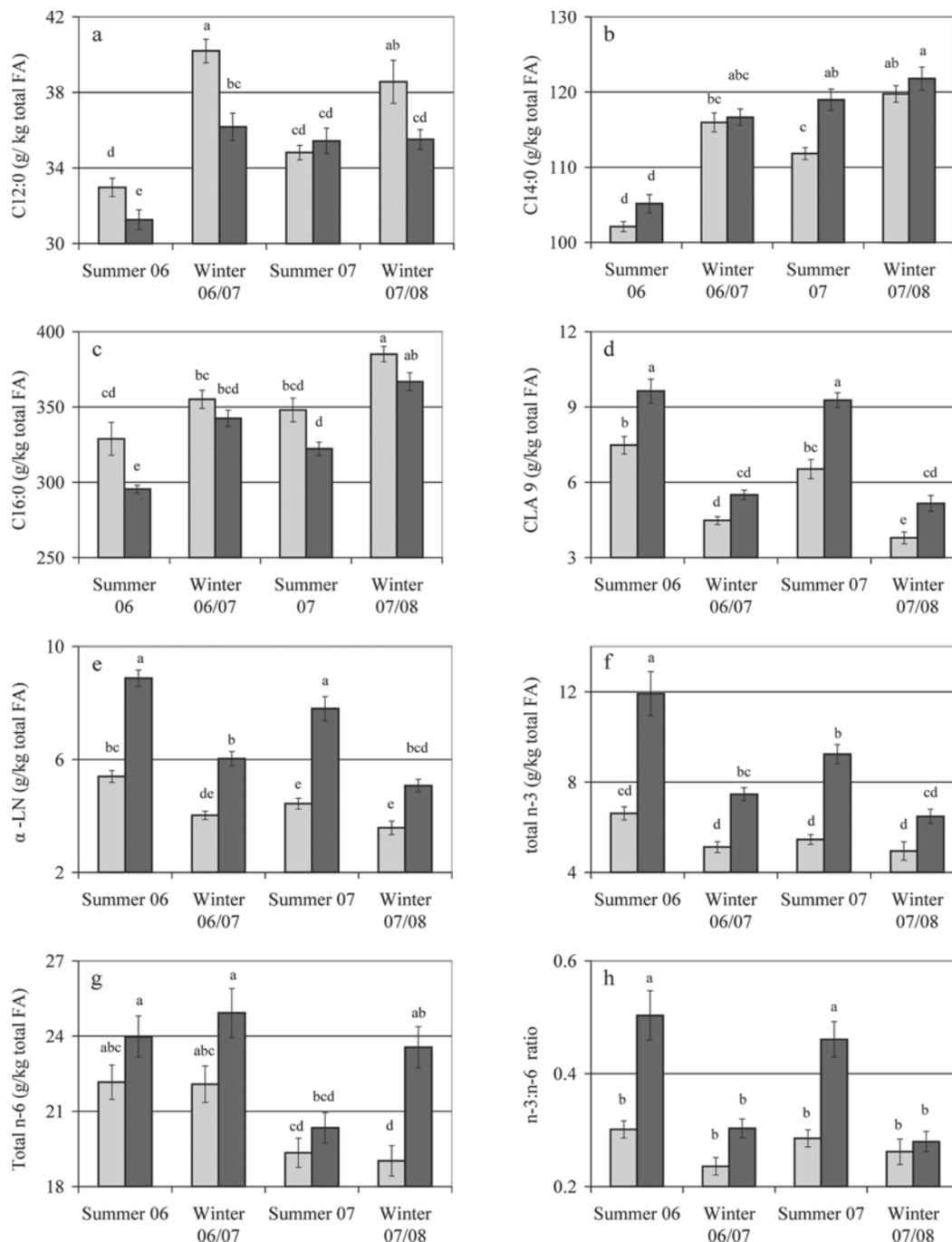


Figure 1. Concentrations of fatty acids (FA) and calculated values that demonstrate significant interactions between management system (M; conventional vs. organic), season (S; summer vs. winter), and year of purchase (Y; 2006–2007 vs. 2007–2008). ANOVA P -values are given for interactions between management and season (M×S) and season by year (S×Y): *** = $P < 0.001$, ** = $P < 0.01$, * = $P < 0.05$, NS = $P > 0.05$. Graphs show mean values (conventional milk as gray bars and organic milk as black bars) for a) C12:0 (**M×S; ***S×Y); b) C14:0 (*M×S; ***S×Y); c) C16:0 (*M×S; ^{NS}S×Y); d) CLA9, conjugated linoleic acid isomer C18:2 *cis*(c)9,*trans*(t)11 (**M×S; ^{NS}S×Y); e) α -LN, α -linolenic acid, C18:3 c9,12,15 (***M×S; ^{NS}S×Y); f) total n-3 FA (including α -LN C18:3 c9,12,15; eicosapentaenoic acid C20:5 c5,8,11,14,17; docosapentaenoic acid C22:5 c7,10,13,16,19; and docosahexaenoic acid C22:6 c4,7,10,13,16,19) (***M×S; *S×Y); g) total n-6 FA (including LA C18:2 c9,12; C20:3 c8,11,14; C20:4 c5,8,11,14; C22:2 c13,16 and CLA10 C18:2 t10, c12) (**M×S; ^{NS}S×Y); and h) n-3:n-6 ratio (***M×S; ^{NS}S×Y). Error bars represent standard errors of means. ^{a-d}Mean values with different letters are significantly different ($P < 0.05$) according to Tukey's honestly significant difference test.

Table 3. Differences in milk fat composition between brands of conventional milk: individual fatty acids (g/kg of total fatty acids, mean values over 4 dates)

Item	Fatty acid ¹					
	C16:0	C18:0	OA	VA	CLA9	α-LN
ANOVA <i>P</i> -value	***	***	***	**	***	***
Brand	n = 4	n = 4	n = 4	n = 4	n = 4	n = 4
1	343 ^b	127 ^a	228 ^{ab}	13.0 ^a	6.3 ^{ab}	4.5 ^{ab}
2	353 ^b	121 ^{ab}	220 ^{bc}	11.3 ^a	5.4 ^b	4.6 ^{ab}
3	333 ^b	123 ^{ab}	225 ^{abc}	12.6 ^a	6.2 ^{ab}	4.9 ^a
4	352 ^b	121 ^{ab}	224 ^{abc}	11.8 ^a	5.6 ^{ab}	4.5 ^{ab}
5	408 ^a	98 ^c	195 ^d	8.1 ^b	3.8 ^c	2.6 ^d
6	346 ^b	124 ^{ab}	224 ^{abc}	12.4 ^a	5.9 ^{ab}	4.4 ^{ab}
7	398 ^a	99 ^c	195 ^d	8.2 ^b	4.1 ^c	4.3 ^b
8	341 ^b	123 ^{ab}	223 ^{abc}	12.9 ^a	5.9 ^{ab}	4.7 ^{ab}
9	333 ^b	125 ^a	230 ^a	13.5 ^a	6.5 ^a	4.1 ^c
10	343 ^b	121 ^{ab}	225 ^{abc}	11.8 ^a	5.7 ^{ab}	4.5 ^{ab}
11	347 ^b	125 ^a	225 ^{abc}	11.8 ^a	5.5 ^b	4.7 ^{ab}
12	354 ^b	118 ^b	219 ^c	11.2 ^a	5.7 ^{ab}	4.4 ^{ab}

^{a-d}Values in the same column sharing the same letter do not differ significantly ($P < 0.05$).

¹OA = oleic acid C18:1 *cis*(c)9; VA = vaccenic acid C18:1 *trans*(t)11; CLA9 = conjugated linoleic acid C18:2 c9,t11; α-LN = α-linolenic acid C18:3 c9,12,15.

*** = $P < 0.001$, ** = $P < 0.01$.

Effect of Production Season (Winter vs. Summer)

Considerable variation in milk quality can be attributed to the season of production with many differences highly significant. Milk purchased in summer was found to have a higher SCC (38%), a slight but significantly higher fat content (5%), and a similar protein content compared with milk purchased in winter. Total SFA were significantly lower (6%) during the summer, whereas significantly lower concentrations of MUFA and PUFA (both by 15%) were found in winter milk fat (Table 2). However, when the nutritionally less desirable individual SFA were compared, concentrations of C12:0, C14:0, and C16:0 were all higher (13, 8, and 12% respectively) in winter milk fat, whereas concentration of C18:0 was higher in summer milk fat (8%; Table 2 and Figure 1, panels a–c).

The concentrations of the main nutritionally desirable MUFA and PUFA (OA, VA, CLA9, α-LN, and EPA) were all higher (14, 101, 72, 41, and 47%, respectively) in milk purchased during the summer (Table 2 and Figures 1, panels d and e). Whereas concentrations of total n-3 FA were higher (37%) in summer, concentrations of n-6 FA were significantly higher (4%) in winter, resulting in a significant increase (41%) in the ratio of n-3:n-6 FA in summer milk compared with winter milk (Table 2 and Figure 1, panels f–h).

Effect of Sampling Period (2006–2007 vs. 2007–2008)

Significant differences were found in milk composition between the 2 sampling periods. Milk bought in sampling period 1 (2006–2007) was significantly higher in

SCC (68%) and fat (4%) and slightly but significantly lower in milk protein content (1%; Table 1) compared with that from sampling period 2 (2007–2008). Milk collected in sample period 1 was slightly (1%) but significantly lower in SFA and higher in PUFA (14%) than milk sampled in period 2, although the MUFA content was not significantly affected by sampling period (Table 2). The concentrations of many individual medium- and long-chain SFA were higher in sampling period 2, and differences were significant for C14:0, C16:0, and C18:0 (7, 8, and 4% increases, respectively; Table 2 and Figure 1, panels a–c). In contrast, the concentrations of many of the unsaturated fatty acids were higher in sampling period 1 (Table 2 and Figure 1, panels d and e), with VA, LA, CLA9, α-LN, and EPA concentrations showing 13, 14, 10, 18, and 40% increases, respectively, compared with those in sampling period 2.

Interactions Between Management System, Production Season, and Sampling Period

No 3-way interactions involving management system, production season, and sampling period could be detected ($P > 0.05$), but several significant 2-way interactions were observed, especially between management system and season as well as between season and sampling period (Figure 1).

Strong interactions were found between the independent influences of management system and season (M×S), being highly significant ($P < 0.001$) for the concentrations of α-LN, which is carried forward to calculated values for n-3 FA and the ratio of n-3:n-6 FA (Figure 1, panels e, f, and h). Analyses of variance

Table 4. Differences in milk fat composition between brands of conventional milk: calculated values and SCC (mean values over 4 dates)

Item	Constituent ¹					
	SFA (g/kg FA)	MUFA (g/kg FA)	PUFA (g/kg FA)	Total n-3 (g/kg FA)	n-3:n-6	SCC (×1,000 cells/mL)
ANOVA <i>P</i> -value	***	***	**	***	**	**
Brand	n = 4	n = 4	n = 4	n = 4	n = 4	n = 4
1	695 ^d	272 ^a	34 ^{ab}	5.8 ^{abc}	0.27 ^{ab}	18 ^d
2	706 ^{bc}	262 ^{ab}	31 ^{bc}	6.1 ^{bc}	0.31 ^{ab}	40 ^{cd}
3	699 ^c	267 ^{ab}	34 ^{ab}	6.0 ^{abc}	0.28 ^{ab}	24 ^d
4	703 ^{bc}	266 ^{ab}	31 ^{bc}	5.6 ^{abc}	0.29 ^{ab}	51 ^{bcd}
5	736 ^a	237 ^c	28 ^d	3.2 ^d	0.15 ^c	90 ^a
6	707 ^{bc}	263 ^{ab}	30 ^{cd}	5.0 ^c	0.26 ^{ab}	24 ^d
7	732 ^a	237 ^c	31 ^{bc}	5.2 ^{bc}	0.24 ^b	80 ^{ab}
8	698 ^c	266 ^{ab}	36 ^a	6.2 ^a	0.26 ^{ab}	62 ^{abc}
9	693 ^d	273 ^a	33 ^{ab}	5.5 ^{abc}	0.27 ^{ab}	35 ^{cd}
10	701 ^{bc}	268 ^{ab}	31 ^{bc}	6.1 ^{ab}	0.32 ^a	24 ^d
11	701 ^{bc}	267 ^{ab}	32 ^{bc}	6.1 ^{ab}	0.30 ^{ab}	15 ^d
12	711 ^b	258 ^b	31 ^{bc}	5.8 ^{abc}	0.30 ^{ab}	15 ^d

^{a-d}Values in the same column sharing the same letter do not differ significantly ($P < 0.05$).

¹SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; n-3 = total n-3 fatty acids (α -linolenic acid, eicosapentaenoic acid, docosapentaenoic acid, docosahexaenoic acid); and n-6 = total n-6 fatty acids (linoleic acid, conjugated linoleic acid C18:2 *trans*(t)10,*cis*(c)12; C20:3 c8,11,14; C20:4 c5,8,11,14; and C22:2 c13,16).

*** = $P < 0.001$, ** = $P < 0.01$.

within results for milk protein content and concentrations of C12:0 (Figure 1, panel a), LA, CLA9, (Figure 1, panel d), and n-6 FA (Figure 1, panel g) showed significant interactions, with P -values < 0.01 ; those for C14:0, C16:0 (Figure 1, panels b and c), and VA were also significant ($P < 0.05$). The majority of these interactions were due to contrasting seasonal changes identified in milk from the 2 production systems. In the case of most of the beneficial FA (VA, CLA9, α -LN, and total PUFA) along with the ratio of n-3:n-6 FA, both summer and winter concentrations were significantly higher in organic compared with conventional milk, although the magnitude of the benefit was reduced in the winter samples. Differences in concentrations of C14:0 and C16:0 between the systems were significant for summer milk but not winter milk. In contrast, for C12:0, LA, and total n-6 FA, significant differences between the systems were identified in winter milk but not in summer milk.

Highly significant interactions ($P < 0.001$) also existed between the effects of season and sampling period or year (S×Y) for milk protein content, C12:0, C14:0 (Figure 1a and b), and CLA10, whereas for C18:0, VA, total PUFA, and n-3 FA (Figure 1f), interactions were slightly less obvious but still significant ($P < 0.05$). All these interactions can be explained by inconsistent year-to-year variation in composition between summer and winter milk. The SCC and protein, C12:0, and n-3 FA concentrations in summer milk did differ between

sampling periods, whereas milk tested in the winter was the same in both periods. On the other hand, summer milk was consistent in C18:0 and CLA10, but their concentrations in winter milk fat differed between the sampling periods. For C14:0 and total PUFA, year-to-year differences were significant in both summer and winter, although the magnitude of the difference was lower in yr 2 of the study.

In addition, significant interactions ($P < 0.05$) between management system and sampling period (M×Y) were detected for 2 MUFA (palmitoleic acid, C16:1, and OA); in both cases no significant difference between organic and conventional milk fat was detected in 2006–07, whereas higher concentrations were found in conventional milk fat in 2007–2008.

Effect of Product Brand on Milk Composition

Considerable variations in composition were identified between brands within the conventional and organic ranges. Mean values for the concentrations of individual fatty acids and calculated values showing significant differences between the conventional brands ($P < 0.05$) are presented in Tables 3 and 4. Highly significant differences ($P < 0.001$) were identified for C16:0, C18:0, OA, CLA9, α -LN, n-3 PUFA, SFA, and MUFA content. Significant differences ($P < 0.01$) were also found in VA and PUFA content and the n-3:n-6 ratio. In addition to these differences in fat composition,

Table 5. Differences in milk and fat composition between brands of organic milk (g/kg of total fatty acids, mean values over 4 dates)

Item	Constituent ¹				
	Milk fat (g/kg of milk)	OA	LA	PUFA	n-6
ANOVA <i>P</i> -value	*	*	***	*	***
Brand	n = 4	n = 4	n = 4	n = 4	n = 4
13	39.4 ^a	226 ^a	17.9 ^c	36.7 ^{bc}	20.5 ^d
14	38.7 ^a	214 ^{cd}	20.7 ^{ab}	39.8 ^{ab}	23.8 ^{abc}
15	38.8 ^a	205 ^d	17.0 ^c	35.7 ^c	19.6 ^d
16	37.3 ^a	226 ^{ab}	22.3 ^a	41.7 ^a	25.2 ^a
17	32.0 ^b	219 ^{abc}	22.0 ^a	41.3 ^a	25.5 ^a
18	38.9 ^a	218 ^{abc}	20.3 ^{ab}	40.6 ^a	23.6 ^{abc}
19	36.5 ^a	218 ^{abc}	21.7 ^a	41.6 ^a	25.2 ^a
20	36.0 ^a	214 ^{cd}	18.7 ^{bc}	36.9 ^{bc}	22.0 ^{cd}
21	39.0 ^a	216 ^{bcd}	18.7 ^{bc}	39.4 ^{ab}	22.2 ^{bcd}
22	38.7 ^a	210 ^{cd}	21.5 ^a	40.0 ^{ab}	24.6 ^{ab}

^{a-d}Values in the same column sharing the same letter do not differ significantly ($P < 0.05$).

¹OA = oleic acid C18:1 *cis*(c)9; LA = linoleic acid C18:2 c9,12; PUFA = polyunsaturated fatty acids; and n-6 = total n-6 fatty acids (LA, conjugated linoleic acid C18:2 *trans*10,c12, C20:3 c8,11,14; C20:4 c5,8,11,14; and C22:2 c13,16).

*** = $P < 0.001$; * = $P < 0.05$.

a significant ($P < 0.01$) variation in SCC was identified between the brands (Table 4).

Differences identified within organic brands are presented in Table 5. Highly significant differences ($P < 0.001$) were found for the LA, and hence n-6 FA, content of milk fat, and significant differences ($P < 0.05$) were found for milk fat and its concentrations of OA and PUFA.

Effect of Processing on Milk Composition

Virtually no significant differences ($P < 0.05$) were found in fatty acid composition in milk sampled before and after processing in the supplementary study (data not shown). The only significant difference detected was for arachidonic acid (C20:4), which was found at lower concentrations (0.4 g/kg of total FA) in raw milk fat compared with processed milk (0.9 g/kg of total FA; $P < 0.05$).

DISCUSSION

Effect of Production System

One aim of this study was to corroborate if composition differences between organic and conventional milk and dairy products (particularly higher concentrations of unsaturated fatty acids from organic management) recorded on farms in the UK (Ellis et al., 2006; Butler et al., 2008) and at the farm, dairy, and retail levels of the supply chain elsewhere in Europe (Bergamo et al., 2003; Kraft et al., 2003; Collomb et al., 2008; Prandini

et al., 2009) are also found in processed milk in major retail outlets of the UK. Overall, this study confirms the consensus of previous findings: total PUFA and a range of nutritionally desirable unsaturated fatty acids including VA, CLA9, α -LN, and EPA, as well as n-3:n-6 ratio, were significantly higher in organic compared with conventional milk fat (Table 2 and Figure 1, panels d–h). As in a UK farm survey reported by this group (Butler et al., 2008), the differential between organic and conventional milk was smaller in winter compared with summer. However, unlike the farm results, in this study, differences in retail milk were significant in winter as well as in summer. This inconsistency can probably be explained by the wide range of farms supplying dairy plants processing retail milk, thereby reducing variability between samples and increasing the sensitivity (i.e., smaller changes in milk quality being detected as significant) in the statistical tests used. Elevated concentrations of unsaturated fatty acids in organic milk fat potentially offer greater beneficial fatty acid supply at any given fat intake. Dairy products are our major dietary source of CLA9 and VA (Parodi, 2003), and a switch to those of organic origin in UK could increase total CLA9 consumption by 30 to 40%. On the other hand, although the extra 60% α -LN and EPA in organic milk may make a useful contribution in a balanced diet, under European Union standards (EFSA, 2009) or the American Heart Association guidelines (Kris-Etherton et al., 2003), it will make a more moderate contribution to achieving recommended n-3 PUFA intakes compared with regular consumption of oily fish.

When levels of less desirable fatty acids were compared, total SFA concentrations did not differ between management systems; however, concentrations of myristic acid (C14:0), a FA thought to carry the highest CHD risk (Hu et al., 2001), were significantly higher in organic compared with conventional milk. It is interesting to note that much of this difference between the systems can be attributed to the summer samples collected in sampling period 2 (see Figure 1, panel b), which is the only occasion on which this differential was significant. However, because SFA accounts for approximately 70% of the milk fat, future studies (focusing on breeding or oil seed and other feed supplementation strategies to improve milk fat composition) ought to focus on strategies to decrease concentrations of undesirable SFA, in particular myristic acid, as well as increasing concentrations of specific nutritionally desirable PUFA.

Recent studies (G. Butler, unpublished data) show significant differences in milk fat composition between European countries, with both organic and conventional milk from the UK having higher concentrations of nutritionally desirable fatty acids (CLA9 and n-3 FA) and antioxidants than milk produced in Denmark, Sweden, or Italy. Any increase in the level of organic or conventional milk imports from such countries is therefore likely to affect the composition of milk or the differential in composition between organic and conventional milk at the retail level in the UK.

Effect of Season and Production Sampling Periods

As expected, the fatty acid composition of milk fat was significantly affected by season (winter vs. summer milk) but also by the sampling period (2006–2007 and 2007–2008) in which the milk was bought, which was perhaps more surprising. Seasonal variation has been reported at the farm level (Lock and Garnsworthy, 2003; Ellis et al., 2006; Rego et al., 2008) and in milk collected at processing plants or commercial dairies (Collomb et al., 2008), and is well recognized as a factor influencing milk fat composition (Jensen, 2002; Walker et al., 2004; Elgersma et al., 2006), especially in production systems with substantial changes in dairy management and diets between summer and winter.

The greatest effect of season was detected for VA closely followed by CLA9 (see Table 2 and Figure 1, panel d). With over 75% of milk CLA9 being derived from desaturation of VA in the mammary gland (Griinari et al., 2000), the close link in the concentration of these 2 fatty acids is expected. Because VA can also be desaturated in humans (Turpeinen et al., 2002), it will contribute to net CLA9 supply to consumers. Concentrations of CLA in this study (individual samples rang-

ing between 4 and 11 g/kg of total FA in summer milk, and between 2 and 7 g/kg of total FA in winter) were comparable to the 6 to 9 g/kg of milk fat in summer months and 3 to 6 g/kg of milk fat in winter months reported by Ellis et al. (2006) in a survey involving 36 UK farms. However, they are lower than an earlier UK farm study (Lock and Garnsworthy, 2003), which reported CLA concentrations ranging between 9 and 17 g/kg of total FA in summer and between 6 and 9 g/kg of total FA in winter, and comparable values from a more recent UK farm survey (Butler et al., 2008), which report CLA concentrations of between 9 and 18 g/kg of total FA in summer and between 6 and 8 g/kg of total FA in milk from housed cattle in the winter. Milk VA and CLA9 concentrations tend to be heavily influenced by fresh forage in dairy diets (Collomb et al., 2006; Elgersma et al., 2006; Butler et al., 2009). Variation in their concentrations reported in the different studies described above suggest that the limited number of cows on the farm or farms in studies reported by Lock and Garnsworthy (2003) and Butler et al. (2008) had a higher dietary contribution from grazing than the larger populations of cows sampled through the supermarkets or reported by Ellis et al. (2006).

Concentrations of α -LN, EPA, and total n-3 were 41, 47, and 37% higher in summer compared with winter milk in results reported here covering both organic and conventional milk. These are similar to differences reported for α -LN and total n-3 (46 and 36%, respectively) in a recent UK farm-level survey (Butler et al., 2008), but considerably greater than the 4 to 6% difference between summer and winter milk reported in studies based solely on conventionally produced milk (Lock and Garnsworthy, 2003; Rego et al., 2008). Results from this study (Figure 1e) suggest that the magnitude of seasonal variation in α -LN concentration in milk is greater under organic rather than conventional management.

Relatively high levels of MUFA and PUFA in summer milk are thought to be due to a combination of (1) increased dietary supply of PUFA, (2) reduced rumen biohydrogenation, and (3) possibly enhanced desaturase activity in the mammary gland, which have been shown to occur with increasing intakes of fresh forage in dairy diets (Couvreur et al., 2006; Dewhurst et al., 2006; Elgersma et al., 2006). Previous farm surveys in northeast England showed that, in this region, most dairy production systems (under both conventional and organic management) allow cows to graze during the summer, with fresh forage making a significant contribution to their diets, although lower levels of supplementation and hence higher estimated intakes of fresh forage were recorded on farms under organic management (Butler

et al., 2006; Stergiadis et al., 2009). In contrast, during winter, cows are housed and receive diets based on conserved forage especially silages made from grass, maize, or other cereals, and such diets were shown to increase concentrations of C14:0 and other SFA and decrease concentrations of PUFA (Elgersma et al., 2004; Couvreur et al., 2006), thus offering an explanation for the differences in milk fat composition between summer and winter recorded in this study.

The finding of significant differences between sampling periods 2006–2007 and 2007–2008 was unexpected, but is likely due to differences in fresh and conserved forage availability, intake, and quality resulting from contrasting weather during these 2 periods. The UK weather conditions in 2006–2007 and 2007–2008 were quite different. In the northeast of England, the summer of 2007 was particularly wet with recorded rainfall approximately 30% higher and soil and air temperatures 12% lower during July and August compared with data from 2006 (Nafferton Ecological Farming Group weather station). Such conditions may affect the cows' behavior, reducing grazing intakes (Roche et al., 2009) and milk output; under these conditions farmers often increase supplementation with concentrate feeds or conserved forage to maintain milk yields (Bargo et al., 2003). In addition, during the main time for silage making in this location (late May to end of July), rainfall in 2007 (197 mm) was 3 times that recorded in 2006 (62 mm), which makes it likely that silage quality was poorer and thus requiring a higher level of concentrate in winter diets fed in 2007–2008 compared with those used in 2006–2007. Farmers are known to use higher levels of concentrate supplementation to compensate for poor silage quality (Wright et al., 2000). Based on previous studies, such dietary differences would explain the lower concentrations of PUFA, n-3, and n-6 and higher concentrations of C14:0 and C16:0 recorded in both summer and winter of the 2007–2008 sampling period compared with the previous year. Differences in forage availability and quality between years caused by variable weather conditions may help explain inconsistency in seasonal variation in milk quality reported in different UK farm-level studies (Lock and Garnsworthy, 2003; Ellis et al., 2006; Butler et al., 2008) and the strong interactions between sampling period and season detected in this study.

This study deliberately collected samples when the greatest contrast between summer and winter feeding, and hence milk quality, could be expected. However, in light of the changes in fatty acid profiles identified, it might be interesting to follow up with a detailed study over time with more frequent sampling to identify changes throughout the year, especially through seasonal transitions in feeding practice.

Effect of Brand

Considerable variation existed between different products, although most variation within the conventional range can be explained by 2 particular brands (5 and, to a lesser extent, 7) showing more extreme values than the majority of products, although other differences did exist. Compared with most other samples of conventional milk, sample 5 was significantly lower in many of the beneficial fatty acids (OA, total MUFA, total PUFA, CLA9, α -LN, n-3) and it had higher concentrations of C16:0 and total SFA, poorer ratio of n-3:n-6. Over the 4 samples collected, it also recorded a higher average SCC. For many of these parameters, sample 7 was comparable to sample 5 with the exception of slightly less extreme values for α -LN, n-3 PUFA, and ratio of n-3:n-6, which did fall within the range of some of the other brands. No management information was collected from contributing farms but depressed milk concentrations of PUFA, particularly CLA9, α -LN, and other n-3, are indicative of dairy diets with relatively low reliance on forages, especially fresh herbage (Elgersma et al., 2003; Couvreur et al., 2006; Dewhurst et al., 2006), and this suggestion of more intensive management on farms supplying brand 5, and possibly 7, maybe supported by the high SCC. Highly productive dairy cows are more prone to udder infection (Odensten et al., 2007). In addition, extreme concentrations of milk C16:0, in this case with average values of approximately 400 g/kg of total FA, implies considerable dietary supplementation with a widely used commercial product supplying calcium salts of palm oil, a practice shown to increase milk C16:0 concentrations (Jensen, 2002; Givens et al., 2009).

Results suggest greater uniformity of feeding practice on farms supplying organic milk because no organic brands differed consistently in fat composition. Organic standards might be thought to tightly prescribe feeding policy and be responsible for greater uniformity in fatty acid profiles. However, considerable flexibility is permitted within the standards and daily intakes of fresh forage can vary between farms as reported by Butler et al. (2008). Results in this study imply a uniform approach to feeding as practiced across farms supplying these brands, although consistency could be explained by the pooling of milk from several suppliers into each product. For organic brands no persistent outliers were observed, although compared with other organic brands, the fat composition of sample 15 had lower concentrations of OA and LA along with total n-6 PUFA, which is not easily explained. The reduced fat content of sample 17 (in breach of nutritional declarations of 40 g/kg milk on the label) could be the result of excessive skimming during processing, rather than management on farms.

This could also explain differences in milk fat reported in Table 1 apparently due to management, season, and year, although it is unlikely to influence the composition of the remaining milk fat, as reported in Table 2.

Effect of Processing

At the time of this trial no published work has indicated if pasteurization or homogenization might influence milk fatty acid profiles between farm and retail levels of the supply chain. The finding of very similar fatty acid concentrations in milk before and after processing confirms results of a subsequently published study, which reported no effect of pasteurization or homogenization on fatty acid profiles of milk (Rodríguez-Alcalá et al., 2009). This suggests that milk quality surveys at both the farm and retail levels will provide accurate information for consumers on differences in fatty acid composition between organic and conventional milk, assuming the sites sampled are representative of the milk being consumed.

CONCLUSIONS

This survey of processed milk from different UK retail outlets confirms the results of raw milk surveys at the farm level, showing higher concentrations of nutritionally desirable fatty acids and n-3:n-6 ratios in milk from organic production systems. Although these differences at the retail level were significant for both summer and winter milk, the differential between production systems for all nutritionally desirable parameters does decrease in winter. To provide organic milk with similar fatty acid profiles throughout the year it is therefore important to develop strategies (e.g., oil seed supplementation of winter diets) that allow the seasonal differences in milk quality to be reduced. The finding of relatively large differences in milk composition between the sampling periods in this study suggests that differences in climatic conditions may influence milk quality through an effect on forage availability, quality, and intake. Because climate change predicts alternations in rainfall patterns and the frequency of “extreme weather events” (IPCC, 2007), both forage crop and dairy management practices may have to be adapted in the future to maintain current levels of product quality.

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