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Review

The effects of dairy management and processing on quality characteristics of milk and dairy products

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ABSTRACT

Studies within the QLIF project reviewed in this article suggest that organic or low-input management is more likely to result in milk with fatty acid profiles that are higher in α-linolenic acid and/or beneficial isomers of conjugated linoleic acid and antioxidants with up to a 2.5-fold increase in some cases, relative to milk from conventional production. These advantages are preserved during processing, resulting in elevated contents or concentrations of these constituents in processed dairy products of organic or low input origin. Much of the literature suggests that these benefits are very likely to be a result of a greater reliance on forages in the dairy diets (especially grazed grass). Since the adoption of alternative breeds or crosses is often an integral part sustaining these low-input systems, it is not possible to rule out an interaction with genotype in these monitored herds. The results suggest that milk fat composition with respect to human health can be optimized by exploiting grazing in the diet of dairy cows. However, in many European regions this may not be possible due to extremes in temperature, soil moisture levels or both. In such cases milk quality can be maintained by the inclusion of oil seeds in the dairy diets.

Contents

1. Introduction

For a number of years there has been debate in the literature about the impact of milk fat on human health [1,2]. The high contents of saturated fats, especially C12, C14 and C16 (the number denotes the length of the carbon chains), are known to increase the concentration of low-density lipoprotein or 'bad' cholesterol, which increases the risk of heart diseases [3]. However, milk fat also contains beneficial unsaturated fatty acid groups known to have a

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Abbreviations: αLA, alpha linolenic acid; CLA, conjugated linoleic acid; CLA9, C18:2 c9t11; DM, dry matter; DMI, dry matter intake; FA, fatty acid; GC, gas chromatography; HPLC, high-performance liquid chromatography; MUFA, monounsaturated fatty acid; n-3, omega 3 fatty acid; n-6, omega 6 fatty acid; PUFA, polyunsaturated fatty acid; QLIF, QualityLowInputFoods; SFA, saturated fatty acid; USF, unsaturated fatty acid.

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positive impact on health, especially conjugated linoleic acid (CLA) and omega 3 fatty acids (n-3). Both groups of fatty acids (dominated by C18:2 c9 t11 (CLA9) and C18:3 c9,12,15 α-linolenic acid or αLN in milk), have been reported to benefit human health by showing protection against some or all of the following chronic conditions: coronary heart disease, cancer, hypertension, obesity and diabetics while enhancing the immune system and positively affecting bone formation [1,4,5].

The dominant factor controlling milk fatty acid (FA) profiles is known to be the dairy diet, as this influences both the dietary supply of polyunsaturated fatty acids (PUFAs) and subsequent rates of biohydrogenation in the rumen, hence PUFAs' availability for secretion into milk [5,6]. The inclusion of fresh forage in the diet is known to maximize PUFA content of milk fat, especially CLA and n-3 FAs [6], and milk fatty acid profiles change as cows move from summer to winter diets and vice versa at turnout [7,8]. Since organic standards dictate that dairy cows should be offered a minimum of 60% forage of total dry matter intake as well as being allowed access to pasture for grazing when conditions allow [9], it is a fair assumption that organic milk is higher in PUFAs compared with milk produced under conventional management. The picture across Europe is not clear. Ellis et al. [10] reported higher concentrations of αLA (the main n-3 FA) in organic milk in the UK but CLA levels were not higher in milk from certified organic than in milk from conventional farms. In Italy, Bergamo et al. [11] reported elevated concentrations of both CLA and αLA in organic dairy products compared with those produced under conventional management, and Jahreis et al. [12] found milk from organic farms in Germany to be higher in CLA although there was no mention of αLA in their paper. In addition, previous studies considering milk fat profiles throughout the year have shown that the fluctuation in milk fat profiles over the seasons was larger where there was a clear contrast between summer grazing and silage-based winter dairy diets [13,14].

However, approximately 50% of the milk produced in the EU is not consumed as liquid milk but processed into a wide range of dairy products [15], and questions are posed relating to the stability of milk fatty acid profiles during these processing procedures. Do these beneficial fatty acids survive in yoghurts, cheese, cream and butter?

Increasing the concentration of unsaturated fatty acids in the fat profile may improve the health reputation of dairy products, but may not necessarily be considered positive with respect to quality since double bonds in these unsaturated fats are prone to oxidation and can lead to the development of off-flavours during storage [16,17]. It is important that any increase in the concentration of unsaturated FAs is accompanied by an increase in antioxidants, especially if this 'healthy' milk is to be perceived as a quality product. As with the fatty acids, there is evidence that high forage intakes by dairy cows (especially from grazing) results in milk with higher antioxidant levels, but again, there is no clear picture relating to the situation with milk from organic or low-input production systems [11,18,19]. These natural preservatives are also good for consumers' health since they continue to prevent oxidation and cell damage after consumption, giving protection against chronic diseases [20].

CLA is a general term used to describe any C18:2 molecules with adjacent or *conjugated* double bonds, potentially 28 in total with differing combinations of position and geometric configurations of the double bonds, 14 of which have been identified in milk [21,22]. Not all isomers share the beneficial properties of the major form C18:2 c9t11 (CLA9), which often comprises more than 75% of total C18:2 [23]. In 2002 when this EU project, considering the quality and safety of organic and low input food in Europe (QualityLowInputFood or QLIF), was planned there was no reported knowledge of the impact of production system or dairy diet on the relative concentrations of these individual CLA isomers in milk.

A number of studies in the QLIF project set out to address these questions relating to the quality of milk and dairy products from organic or low-input production systems, which are reviewed in this paper, covering both published and unpublished findings. Generally these studies focus on the fatty acids and fat-soluble antioxidant profiles in milk fat and can be described as falling into three distinct studies: (1) a survey carried out in four European countries (Denmark, Sweden, Italy and UK) to consider the impact of management system on milk quality, (2) processing and stability of 'enriched' milk (Switzerland) and (3) the influence of management, processing and storage on detailed CLA profiles (UK and Switzerland).

2. Individual studies

Much of the work within the QLIF project has already been published. In that case only a brief outline of the methodology will be given with reference to the original publication if relevant. But more information will be given in the absence of greater detail available elsewhere.

2.1. Study 1: Farm survey about the impact of the dairy management system on milk quality

Three papers have been published from this work about the impact of dairy management on milk quality, and a more detailed explanation of the structure and procedures can be found in Butler et al. [24], Slots et al. [25] and Larsen et al. [26]. A survey collecting bulk-tank milk samples and management information was carried out across a wide range of dairy farming systems in four European countries. Sampling took place on five occasions over the seasons of 2004 and 2005. Each farming system was represented by groups of five similar farms and because system classification somewhat varied among countries, comparison of records and milk quality parameters was assessed between systems within countries, rather than between countries.

In Italy, the farms (conventional or with organic certification) were located in distinct geographic areas: three system groups of conventional farms located around Bologna, Potenza and Cosenza and two under organic management near Milan and Modena.

In Sweden, the farms were classified according to a combination of geographic location, herd genotype (Swedish Red or Holstein/Friesian) and organic or conventional certification, with three conventional groups and one organic system group.

In Denmark, the farms were classified according to intensity of management and organic or conventional certification (three conventional and two organic system groups).

In the United Kingdom, the farms were classified according to geographic location (north-east England (NE) or south-west Wales) and organic or conventional certification (two groups of each) with an additional group of low-input farms in Wales, which were not certified as organic.

Despite the geographic diversity among Italian farms, these farms were remarkably similar in management and milk quality with no statistically significant differences identified among any of the five system groups for herd size (176 milking cows), milk yield (241 per cow per day), milk fat content (39 g kg^{-1}) milk protein content (34 g kg^{-1}) or the relative proportions of saturated (SFA), monounsaturated (MUFA) and PUFA in the milk fat (694, 265 and 41 g kg^{-1} total fat, respectively). On the other hand, production systems monitored in the northern countries showed greater variation in milk composition, with the greatest differences identified within the UK. Compared with conventionally managed cows, organic and low-input herds in the UK produced less milk per day (18 vs. 26 l, $p < 0.001$) with a higher fat (43 vs. 40 g kg^{-1}, $p < 0.001$), protein

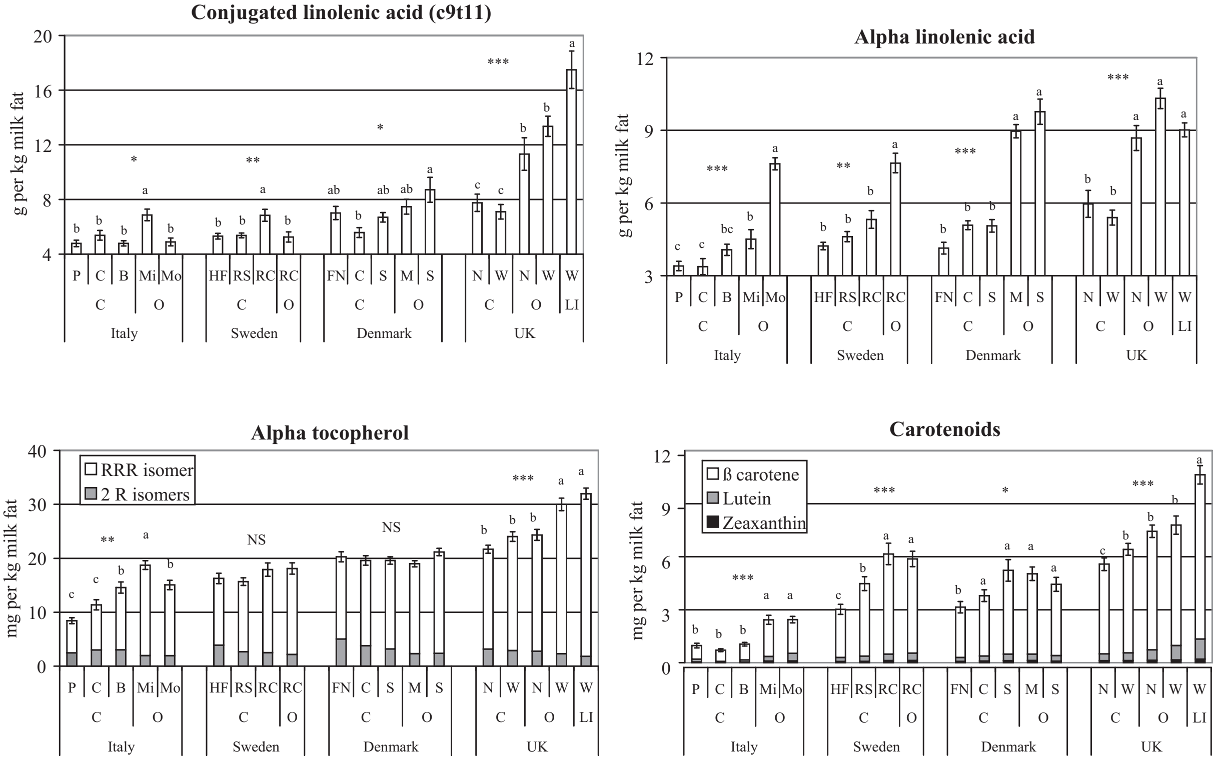

Fig. 1. Milk fat composition data from European Farm survey. Concentrations of conjugated linolenic acid C18:1 c9t11, α-linoleic acid, α-tocopherol and carotenoids in milk from different production systems.

Mean values within countries were compared by Tukey's Honest significant difference test. Values with the same letter do not differ significantly ($p < 0.05$). Statistical significance. NS = not significant; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Key to farm identity: Management: C = conventional, O = organic, LI = low input not organic. Italy: P = Potenza, C = Cosenza, B = Bologna, Mi = Milan and Mo = Modena. Sweden: HF = Holstein Friesian cows South, RS = Swedish Red cows South, RC = Swedish Red cows Central. Denmark: FN = frequent milking (>2 times per day), C = conserved forage feeding, S = standard, M = maize silage. UK: N = NE England, W = SW Wales.

(35 vs. 33 g kg^{-1}, $p < 0.01$) and urea (2.9 vs. 2.6 mg kg^{-1}, $p < 0.05$) content. Lower milk yields in organic herds were also recorded in Denmark (25 vs. 29 l for conventional herds, $p < 0.001$), although here there was no difference in gross milk composition among the management systems, 33 g protein and 4.2 mg urea per kg milk, or among FA groups. In Sweden there was no significant difference in milk yield per day among the management systems (28 l) although milk from organic herds was slightly but significantly higher in fat than that from Holstein/Friesian herds in southern Sweden under conventional management (44 vs. 42 g kg^{-1} milk, $p < 0.01$). Other aspects of quality were consistent among the four systems in Sweden: protein content 35 g kg^{-1}, SFA 712 g kg^{-1} fat, MUFA 257 g kg^{-1} fat and PUFA 31 g kg^{-1} fat.

Although production system did not always influence the fat content of the milk, in all cases it did have a significant impact on the composition of that milk fat, as shown in Fig. 1. Generally these differences were not consistent between the countries surveyed, with the exception of concentrations of αLA, which were higher in organic than in conventional milk in all countries—although this was only statistically significant for one of the two organic systems in Italy (interestingly, the other was significantly higher in CLA9). Generally, variability in milk fat quality across systems in each country tended to mirror the diversity in diet composition (presented in Fig. 2) with the concentrations of CLA9, αLA and/or antioxidants appearing to be elevated by the inclusion of fresh grazing and/or grass silage.

2.1.1. Diet and milk fat composition in Italy

Italian dairy farms tended to feed a relatively high level of concentrate feeds (32% of total dry matter intake (DMI) on organic farms and 46% on conventional farms) and, with the exception of the two organic system groups, made little or no use of fresh grass or grass silage—hardly surprising given the climatic constraint on grass growth, especially during the summer. Maize silage and hay formed the bulk of the forage contribution, with the latter averaging over 50% of total intake on one of the organic system groups. These feeding practices resulted in milk with relatively low levels of CLA and carotenoids (although the latter was significantly higher in milk from organic farms) with little variation between systems. Both system groups certified as organic produced milk with significantly higher levels of at least some of the beneficial

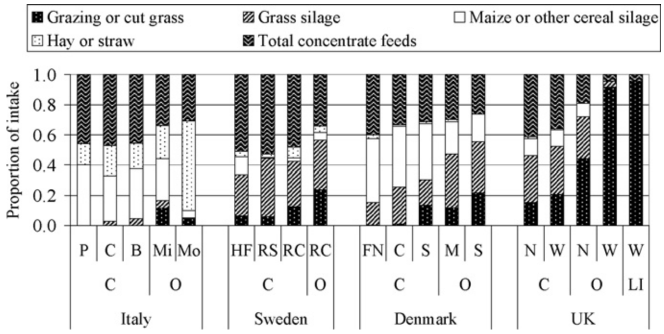

Fig. 2. Breakdown of dry matter intake recorded on farms with different production systems in different European countries (averages over all samples).

Key to farm identity: Management: C = conventional, O = Organic, LI = low input not organic. Italy: P = Potenza, C = Cosenza, B = Bologna, Mi = Milan and Mo = Modena. Sweden: HF = Holstein Friesian South, RS = Swedish Red cows South, RC = Swedish Red cows Central. Denmark: FM = frequent milking (>2 times per day), C = conserved forage feeding, S = standard, M = maize silage. UK: N = NE England, W = SW Wales.

components: milk from herds receiving a high proportion of hay in the diet (centred near Modena) had elevated concentrations of αLA, whereas milk from organic herds fed maize or grass silage based diets (from Milan) had significantly higher CLA and α-tocopherol concentrations in comparison with the conventional systems. Milk from cows in the conventional group near Bologna was also found to be significantly higher in α-tocopherol than from other conventionally managed cows, despite appearing to receive a similar diet to those at Cosenza.

2.1.2. Diet and milk fat composition in Sweden

The diet of the Swedish cows had similarities with those in Italy despite, or perhaps because of, contrasting climates—here limitation to grazing are likely to be due to cold, wet conditions. Again there were high intakes of concentrate feeds (32% on organic farms and 51% of the diet of cows under conventional management) and little reliance on grazing, although in Sweden conserved forage was dominated by grass silage with only a small proportion of maize or cereal silage. Organic cows in Sweden consumed more grass and were offered less concentrates than those in other systems. There were few differences in milk fat quality between the systems except for the fact that the organic milk was significantly higher in αLA, although one of the conventional systems in central Sweden produced milk with higher concentrations of CLA than those in other production system groups.

2.1.3. Diet and milk fat composition in Denmark

Concentrate supplementation was lower in Denmark than in Italy or Sweden, with concentrates comprising 28% of total DMI in the case of organic herds and 35% on conventional farms. Two of the three conventional systems groups made little use of grazing or fresh forage and all groups, including some of the organic farms, relied on a combination of grass and maize or cereal silage for a high proportion of their forage. In Denmark there was little difference between the systems with respect to antioxidant and CLA concentrations of milk with the exception of lower levels of carotenoids in milk from one of the more intensive conventional farming groups, and lower concentrations of CLA levels in milk from the other intensive system. On the other hand, milk from both of the organic system groups had significantly higher concentrations of αLA compared with the three conventional system groups.

2.1.4. Diet and milk fat composition in UK

The farming systems in UK showed a wide variation in the dietary components and this is reflected in milk quality. Generally there was a greater reliance on grazing by all systems compared with other countries especially in the organic and low-input groups, and a wide range in the proportion of concentrate feeds from 45% down to 4% of total DMI. All beneficial constituents considered showed highly significant differences among the systems, with a graduation in levels recorded. CLA and αLA levels were both significantly higher in organic and low-input milk compared with milk from cows under conventional management, and milk from the low-input system relying almost exclusively on grazed grass had concentrations of CLA that were even higher than the elevated levels found in the organic milk. It is interesting to note that the highest levels of α-tocopherol were found in milk from the organic and low-input farming system with the lowest reliance on synthetic vitamins and mineral supplements (rates of supplementation not shown).

Table 1

CLA content (g kg^{-1} total fat) of cream and butter from organic and conventional production in study 2.

Management	*n*	Cream	Butter	Difference
Conventional	7	13.5 a[a]	13.1 a	0.4
Organic	5	15.4 b	14.8 b	0.6

[a] Means in the same column, followed by a different letter are statistically different ($p < 0.05$).

This survey confirmed the link between dairy diets and milk fat composition reported in the literature [6,27–30], and milk produced under organic management within each country was generally higher in αLA and n-3 FA and to a lesser extent in CLA and antioxidants although there were exceptions. These can be largely explained by the diet of the cows under both organic management and their comparable conventional systems, and/or by variation throughout the year with many differences identified between the countries studied (results over seasons not shown).

2.2. Study 2: Enhancing CLA concentrations in processed dairy products

As with study 1, output from this study has already been published and more details have been reported by Bisig et al. [31], Mallia et al. [32], Rehberger et al. [33] and Mallia et al. [34].

Study 1 and other published work shows that milk produced under organic or low-input management with a high reliance on dietary fresh forage can have elevated concentrations of CLA. This processing study considered the fatty acid profile of butter samples made from milk from cows under organic and conventional management, assessing CLA concentrations before and after processing. Results presented in Table 1 show that organic cream did have higher contents of CLA, which were preserved during processing, resulting in organic butter with similarly elevated levels of CLA.

This processing study also used milk with contrasting FA profiles, largely as a result of oil seed supplementation, to look at the storage properties of the two butters produced at the pilot plant

Table 2

Fatty acid (g kg^{-1} total fat) and antioxidant (μg kg^{-1} total fat) concentrations in conventional and enriched butter; fresh and after 8 weeks (FAs only) study 2.

	Fresh		8 Weeks stored		Statistical difference[a]
	Control	Enriched	Control	Enriched	
Beneficial fatty acids or groups					
MUFA	251	358	251	355	*
PUFA	38	57	37	55	*
Total CLA	8.8	20.5	8.8	20.6	**
αLA	5.0	4.5	5.0	4.6	NS[b]
Original antioxidant concentrations					
α-tocopherol	28.7	34.3			
Retinol	12.0	14.7			

[a] Statistically significant differences between butter types (*$p < 0.05$; **$p < 0.01$) (the differences between the fresh and stored samples were not statistically significant).

[b] NS = not statistically different ($p > 0.05$).

Table 3

CLA isomer concentration (g kg^{-1} fat) from (a) UK farm survey: effect of (and interactions between) production system (conventional high input [HI], organically certified [O-LI], non-organic [NO-LI] low input) and sampling date, and (b) Swiss supplementation trial: effect of sunflower supplementation.

CLA isomers	(a) UK farm systems survey						(b) Swiss supplementation trial[d]		
	Production system in Wales (PS)			ANOVA results (*p*-value)			Diet		ANOVA
	HI*n* = 16	O-LI*n* = 20	NO-LI*n* = 10	PS[a]	SD[a]	PS × SD[b]	Control	Enriched	*p*-value
Trans/trans isomers[e]									
1. t12 t14	0.12 b	0.3 a	0.35 a	***	0.06	*	0.13	0.14	NS
2. t11 t13	0.22 b	0.68 a	0.83 a	***	**	0.06	0.24	0.25	NS
3. t10 t12	0.05	0.04	0.03	NS	NS	NS	0.03	0.13	NS
4. t9 t11	0.17	0.22	0.26	0.09	***	NS	0.10	0.15	NS
5. t8 t10	0.03	0.03	0.01	NS	NS	NS	0.04	0.04	NS
6. t7 t9	0.07	0.07	0.06	NS	***	**	0.04	0.06	NS
7. t6 t8	0.01	0.02	0.01	NS	*	NS	0.01	0.01	NS
Cis/trans isomers[e]									
8. c/t12,14	0.03 b	0.07 a	0.07 a	***	*	0.05	0.04	0.04	NS
9. t11 c13	0.22 b	0.61 a	0.8 a	**	**	*	0.20	0.40	NS
10. c11 t13	0.02 b	0.04 a	0.05 a	**	NS	NS	0.02	0.03	NS
11. t10 c12	0.02	0.02	0.01	NS	NS	NS	0.05	0.10	NS
12. c9 t11	6.04 c	10.72 b	15.06 a	***	***	**	7.32	18.04	**
13. t8 c10	0.12 c	0.18 b	0.22 a	**	***	*	0.17	0.37	NS
14. t7 c9	0.35	0.35	0.39	NS	*	NS	0.40	0.81	**
Total CLA[c]	7.46 c	13.33 b	18.15 a	***	***	**	8.78	20.55	**

[a] Main effects.

[b] Interaction.

[c] Calculated value. PS, production system; SD, sampling date.

[d] The impact of storage was not statistically significant; values shown are means of 35 samples before and 35 after 8 weeks.

[e] cis (c) and trans (t) refer to the geometric configuration of the double bonds in the carbon chains. Statistical significance: means in the same row, followed by a different letter are statistically different ($p < 0.05$). NS: not statistically different.

[*] $p < 0.05$.

[**] $p < 0.01$.

[***] $p < 0.001$.

of Agroscope Liebefeld-Posieux, ALP. Both butters were made from milk produced by Holstein/Friesian cows at the same stage of lactation. Control cows ($n = 10$) were fed a conventional diet of pasture supplemented with maize silage (estimated 5.7 kg DMI per cow per day). The enriched butter was produced using milk from grazing cows ($n = 10$) supplemented with sunflower seed at 1.8 kg DMI per cow per day for 2 weeks, creating a butter higher in unsaturated fatty acids (UFA) and CLA, relative to the control (Table 2). The sweet cream butter was foil wrapped in 100-g packets before being stored in the dark at 6 °C for 8 weeks. Contents of some of the beneficial fatty acids and antioxidants in these contrasting butters before and after storage are presented in Table 2. The sensory acceptability of the two butters was assessed by a taste panel and gas chromatography, mass spectrophotometry and olfactory methods using two trained sniffers to detect their oxidative stability throughout the storage period.

After 6 weeks of storage, the UFA/CLA enriched butter showed more intense cheesy, rancid, chemical, mushroom-like, green and metallic notes than conventional butter, mainly due to the presence of fatty acids, alcohols, aldehydes and ketones. However, the sensory evaluation panel could not detect differences between the two butter types before or after storage, except for the spreadability and the creamy aroma (always higher in enriched butter) and described the two kinds of butter as ageing in the same way. No significant differences were detected with regard to the attributes related to oxidative processes, i.e., rancid and oxidized odour/aroma. These undesirable traits increased simultaneously in both butter types during storage and were perceived, in particular, from 6 weeks onwards. On the basis of chemical and sensory findings, the shelf life of enriched butter stored at 6 °C was comparable with that of the control sweet cream butter.

Other studies on the effect of heating milk showed no changes in CLA content or isomer profile: in commercial fermented dairy products no effects of fermentation on CLA content were observed [31], and studies on cheese showed no changes in the CLA content during manufacturing or ripening. The conclusion is that processing and storage of dairy products generally do not alter CLA contents of milk fat. During processing, CLA passes from raw material into final product proportionally to content and CLA isomer profile in fat.

2.3. *Study 3: The impact of management, processing and storage on CLA profiles in milk and dairy products*

Milk samples from the three farming systems in Wales, UK under study 1 and the contrasting butters in study 2 from Switzerland, before and after 8 weeks storage, were investigated for detail CLA isomer profiles, determined by silver ion (Ag^+) high-performance liquid chromatography (HPLC), with further details on the trial design and analytical methods reported by Butler et al. [35] and Mallia et al. [34], respectively. Fourteen isomers of CLA were identified in both sets of samples (presented in Table 3) with concentrations ranging from 0.01 g kg^{-1} to 18 g kg^{-1} fat. In all cases these were dominated by CLA9, accounting for 80–88% of total CLA content. The Swiss study found elevated concentrations of only two isomers as a result of supplementing dairy diets with sunflower oil; the contents of CLA9 and C18:2 t7c9 (the next most common and the only other isomers to be synthesized by desaturation in the udder) were significantly higher in the *enriched* butter. No significant changes in isomer profiles were identified throughout 8 weeks storage in both butter, and results presented (Table 2) are mean values from before and after storage. In contrast, the farm survey in Wales identified seven isomers (including CLA9 and t7c9) whose concentration was significantly influenced by the production system, and the relative contents of four of these, along with four other isomers, were also altered significantly throughout the seasons. Mean concentrations of the individual isomers at each sampling date are not shown although Table 3 indicates which isomers changed significantly over the season. In both studies, the concentrations of these variable isomers were lowest in milk produced under conventional/control management with as much as a threefold increase in the concentration of some isomers under oil supplementation or high grazing intakes. These responses are in line with findings of other work [21,36–38], although some of these studies report greater proportional increases in some of the minor isomers (which appear in conventional/control samples at concentrations of less than 0.05% total fat) as a result of increased linolenic acid intake in supplement.

Sunflower supplementation and high grazing intakes recorded on low-input farms raised CLA9 concentrations (and hence total CLA) 2.3–2.5-fold relative to milk fat from the control diet/conventional farms. In contrast, CLA9 concentrations in milk from organic cows, which also recorded high grazing intakes, were only 1.8 times that of the conventional herds, indicating differences in the nature of herbage under these two production systems.

3. Conclusions

These studies carried out under the QLIF project reviewed in this article suggest that organic or low-input dairy management is more likely to result in milk with fatty acid profiles that are less damaging to our health, This milk was higher in αLA and/or beneficial isomers of CLA and in antioxidants with up to a 2.5-fold increase in some cases compared with milk from conventional production. These advantages were preserved through processing, resulting in elevated concentration of these constituents in processed dairy products of organic or low-input origin. While much of the literature suggests that these benefits are highly likely to be due to greater reliance on forages within the dairy diets (especially grazed grass), in the monitored herds an interaction with genotype cannot be ruled out since the adaptation of alternative breeds or crosses are often an integral part of sustaining these low-input systems. Results suggest that milk fat composition with respect to human health can be optimized by exploiting grazing in the diet of dairy cows. However, in many European regions this is not possible due to extremes in temperature or soil moisture levels, and under such circumstances milk quality may be maintained by the inclusion of oil seed in the dairy diets.

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