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ORIGINAL RESEARCH

Case study: Comparison of milk composition from adjacent organic and conventional farms in the USA

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A study of two adjacent dairy farms, one using conventional confined herd management and the other organic management, revealed significant differences in the fatty acid composition of the milk. Compared with conventional milk, organic milk had higher levels of conjugated linoleic acid (CLA) and α-linolenic acid (the major omega-3 fatty acid in milk), and less stearic and linoleic acid (the major omega-6 fatty acid in milk) during the spring–summer grazing season. When discarding geography and weather as variables, organic milk appears to yield more CLA and α-linolenic acid, which should be beneficial to health.

Keywords CLA, Linolenic acid, Omega-3 fatty acids, Organic milk.

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INTRODUCTION

Omega-3 (n-3) fatty acids and conjugated linoleic acid (CLA) appear to be advantageous to human health. The n-3 fatty acids exhibit anti-arrhythmic effects, decrease blood triglyceride levels and incidence of heart attack, and may improve other aspects of well-being (US National Institutes of Health, 2005). Omega-6 (n-6) fatty acids, primarily linoleic acid (18:2) and arachidonic acid (20:4), are also essential for the prevention and management of coronary heart disease and other conditions, although the Western world consumes them at a rate much higher than necessary (Gómez Candela *et al.* 2011). CLA has been associated with the inhibition of atherosclerosis, protection from catabolic effects of immune stimulation and reduction of body fat gain while enhancing lean body mass gain (Dilzer and Park 2012).

The most common n-3 fatty acid in milk is α-linolenic acid (18:3), which is converted in the body to docosahexaenoic acid (22:6) through the intermediates eicosopentaeinoic acid (20:5) and docosapentaenoic acid (22:5) (Semplicini and Valle, 1994). This conversion is thought to be maximised when the n-6:n-3 ratio in the diet is 2.3 (Kris-Etherton *et al.* 2000); the ratio now seen in the diet of Americans is around 10 (Benbrook *et al.* 2013). Fish is cited as being a good source of n-3, and species commonly eaten in the US (catfish, halibut, salmon, tilapia, trout and tuna) contain significant amounts of 18:3, 20:5, 22:5 and 22:6. Milk contains no 22:6 but does have eight times the average amount of 18:3 in fish, more 20:5 than catfish, tilapia and tuna and more 22:5 than all but salmon (Benbrook *et al.* 2013). CLA is produced in the rumen of cattle during microbial hydrogenation of 18:2 and 18:3 and is found in all food products of ruminants, particularly those that are grass fed (Dhiman *et al.*, 2000). The *cis*-9, *trans*-11 isomer of 18:2 is the predominant form of CLA in the human diet. CLA levels may be increased in milk by adding supplements such as fish oil (Donovan *et al.* 2000), and soybean and linseed oil (Dhiman *et al.* 2000) to the diet of the cows. The types and amounts of pasture plants clearly affect the production of fatty acids in milk (Kälber *et al.* 2011), and 18:3 may be increased by adjusting the plants that the animals forage (Dewhurst *et al.* 2006).

There is tremendous growth of organic milk and dairy products in the US because consumers perceive that the products coming from organic farms are healthier than products from conventional operations (Dmitri and Greene, 2000). Key differences between these management systems centre on the federal requirements that certified organic farms must provide access to pasture for all milking animals and cannot administer hormones or antibiotics to the animals to increase milk yield. To be certified as organic, all aspects of milk production and dairy food processing must conform to federal standards defined by the US Department of Agriculture, Agricultural Marketing Service, National Organic Program as stated in the Code of Federal Regulations (2015). To be labelled as grass fed, animals must have continuous access to pasture and receive no grain or grain-based products (US Department of Agriculture, 2007).

Organic milk was first sold in mainstream supermarkets in the US in 1993 (Glaser and Thompson 2000) and can now be found in almost all of them. While the sales of total fluid milk in the US have declined from 25.1×10^9 kg in 2006 to 23.4×10^9 kg in 2013, sales of organic milk in the same period have grown from 0.48×10^9 kg to 1.02×10^9 kg, representing more than a twofold increase in market share (Economic Research Service, USDA 2014). Organic feed costs more than conventional feed and the cows produce about 30% less milk than their conventional counterparts, which raises the cost of production (McBride and Greene 2009). However, organic milk is sold at a premium that approaches twice the price of conventional milk (Glaser and Thompson 2000), making it a profitable alternative for many small dairy farmers. More than 254 700 dairy cows were certified as organic in 2011, up from <40 000 in 2000 and <2300 in 1992 (McBride and Greene 2009; Schultz 2013).

In previous research, Jahreis *et al.* (1997) observed seasonal differences in organic and conventional milk from large herds over 1 year, but the farms were not in the same geographical area. CLA and 18:3 were significantly higher in cows that had transitioned to grazing in a study by Kelly *et al.* (1998), but only 16 animals were used in a period of 2 months. In a 2003–2004 study, Ellis *et al.* (2006) observed no significant differences in CLA content in the milk from 17 organic and 19 conventional dairies in the UK, although the n-6:n-3 ratio in the organic milk was consistently and significantly lower in the organic milk. The only individual fatty acids reported in that paper were CLA and *trans*-18:1 (vaccenic acid, which is not a *trans* fatty acid thought to be harmful). Benbrook *et al.* (2013) analysed organic and conventional milk from 14 commercial processors from across the US and determined that over a 12-month-period organic milk averaged 62% more n-3 fatty acids and 25% fewer n-6 fatty acids than conventional milk. They reported individual fatty acids, finding that the CLA concentration was 18% higher in organic milk. These analyses were performed on retail samples and not on farm milk. Schwendel *et al.* (2015) recently concluded that researchers generally have not controlled sufficient variables to allow for valid comparisons between organic and conventionally produced milk.

Our laboratory has examined the milk from two adjacent dairy farms: one uses conventional herd management (confined herd with no access to pasture) and the other was transitioned from conventional to pasture/organic feeding in the year before this study. The results during the transition period showed that once cows in the transitioning herd had acclimated to an organic diet, the amount of 18:3 in their milk exceeded that of the conventional herd (Tunick *et al.* 2015). As the geography and weather conditions of the two farms were the same, and the compositions of the herds and the soils were similar, the only differences observed following the transition would be due to diet. This paper will describe the differences in 18:3 and other compositional aspects between the two sources of milk over an 80-wk period covering two grazing seasons.

MATERIALS AND METHODS

Milk

The milk for the study was supplied by two farms located <1 km apart in Berks County, Pennsylvania, USA, designated CONV (conventional milk) and ORG (organic milk). The CONV farm had 64–74 cows, with a 9:1 ratio of Holsteins to Jerseys and a rolling herd average ranging from 9840 to 10640 kg milk over the course of the study. As described previously (Tunick *et al.* 2015), cows received total mixed rations consisting of alfalfa haylage, high-moisture maize silage, ryelage (all produced on farm) and a supplement of high-moisture maize, wet brewer's grain, soybeans and minerals. CONV cows had no pasture access.

The ORG farm had 51–63 cows, with a 3:1 ratio of Holsteins to Jerseys and Jersey crosses, and a rolling herd average of 6125–7575 kg milk. ORG cows received dairy mineral supplements and averaged a minimum of 53% of their dry matter intake (DMI) from fresh pasture during the grazing season, which ran from mid-April to mid-October and was designated spring-summer (S-S). The DMI from pasture exceeded the minimum of 30% required for organic milk during grazing periods. The pastures consisted of well-established organic fields containing alfalfa, orchard grass, perennial rye, red clover, timothy and white clover. Weeds present (and observed to be eaten) included dandelion, lamb's quarters, narrow leaf plantain and smooth pigweed. During the rest of the year, designated fall–winter (F-W), the cows were fed alfalfa haylage, high-moisture maize silage, hay (all produced on farm) and a supplement of dry maize, spelt, soybeans, kelp meal and minerals (Tunick *et al.* 2015). This feed also comprised 47% of the DMI during the grazing season. Throughout the study, the somatic cell counts in the milk for both herds were <400 000.

Samples of fresh raw milk (1.2 L) were taken from the bulk tanks at the farms and poured into 3.7-L resealable plastic storage bags (Ziploc; S.C. Johnson & Son, Racine, WI, USA) prior to immediate freezing at −20 °C. Milk was

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collected during most weeks from 12 April 2012 to 24 October 2013. Samples were transported to the US Department of Agriculture laboratories, placed in secondary vacuum bags, thawed to 20 °C, redistributed in smaller aliquots for immediate analysis and refrozen at −20 °C for individual assays. Portions of the thawed milk were centrifuged to obtain lipid fractions for fatty acid assays. The analyses were unaffected by freezing and thawing.

Composition

The fat, total protein, lactose and solids-not-fat analyses were performed in accordance with AOAC Method 972.16 (AOAC International, 2012) using a MilkoScan Minor (FOSS, Hillerød, Denmark). Ash was determined by AOAC Method 945.46 (AOAC International, 2012), and the ash samples were then dissolved in nitric acid (2 g/100 mL) to analyse Ca, Fe, K, Mg, Mn, Na, P and Zn contents using an ICP-OES spectrometer (iCAP 6300 Duo; Thermo Fischer Scientific, Madison, WI, USA). A PHM82 pH meter (Radiometer, Copenhagen, Denmark) was used to determine pH levels. All analyses were performed in triplicate.

Fatty acid profiles

The fat in each sample was obtained by centrifugation at 5000 *g* for 30 min at 10 °C as previously described (Tunick *et al.* 2015). The procedure of Tunick *et al.* (2015), based on a procedure by Christie (2003), was used to convert the fatty acids to methyl esters and analyse them by gas chromatography. Lipid samples were melted, 100–125 mg was dissolved in 2.5 mL hexane (Fisher Scientific, Fair Lawn, NJ, USA), and 100 μL sodium methoxide (25 g/100 g methanol) was added (Sigma-Aldrich, St. Louis, MO, USA). The samples were shaken by inversion for 5 min, and 5 μL glacial acetic acid (J.T. Baker, Phillipsburg, NJ, USA) and 1.0 g anhydrous $CaCl_2$ (Mallinckrodt Specialty Chemicals, Paris, KY, USA) were added. One hour later, the liquid was centrifuged at 5000 *g* for 2–3 min and the supernate was pipetted into a 2-mL vial with a screw cap containing a Teflon-faced silicone septum (Supelco, Bellefonte, PA, USA). The hexane was then evaporated under nitrogen, and 1.0 mL ethyl acetate (Burdick & Jackson, Muskegon, MI, USA) was added. An autosampler injected 1.0 μL into a HP 6980 gas chromatograph containing an SP-2380-fused silica capillary column (60 m × 0.25 mm; Supelco) and a flame ionization detector (Hewlett-Packard, Santa Clara, CA, USA). The percentages of fatty acids in the fat were calculated with the instrument's software by integration of the chromatographic peaks. Concentrations of fatty acids in the entire sample were obtained by multiplying the concentration of fat in the milk. C4:0-C24:0 methyl esters and conjugated methyl linoleate (GLC448 and UC-59M, respectively; Nu-Chek-Prep, Elysian, MN, USA) were the chromatographic reference standards. Samples were analysed in duplicate.

Statistics

Analysis of variance with mean separation using the Bonferroni LSD technique was performed on the sample averages for each type–season combination and on each response variable using the general linear models procedure of SAS (SAS Institute Inc. 2013). Differences are described as significant only when $P < 0.05$.

RESULTS AND DISCUSSION

Composition

The results of the compositional analyses are shown in Table 1. Seasonal variations were observed in fat content (Fig. 1). The Jersey cows in the herds produce more fat in their milk than Holsteins, which probably accounted for the difference. During F-W, when no cows grazed, the ORG contained 4.04 g fat/100 g milk and CONV contained 3.73 g fat/100 g milk. These values were significantly different. The amount of fat in the ORG during S-S, 3.56 g/100 g milk, was significantly lower than the F-W value. The amount of protein in the ORG also decreased significantly in S-S. Cows on pasture typically produce less fat and protein in their milk during the grazing season (Palmquist *et al.* 1993). In F-W, the level of lactose in the ORG was significantly less than that of the CONV. The only significant seasonal change in the CONV was solids-not-fat, which was higher in F-W than in S-S. Ash did not vary significantly between types of milk or seasons.

Table 1 Composition of conventional and organic milk from neighbouring farms during fall-winter (F-W) and spring-summer (S-S) periods

	Conventional		*Organic*	
Component	*F-W*	*S-S*	*F-W*	*S-S*
Major components (g/100 g)				
Fat	3.73^{b}	3.60^{bc}	4.04^{a}	3.56^{c}
Protein	3.30^{ab}	3.21^{b}	3.38^{a}	3.26^{b}
Lactose	4.90^{a}	4.85^{ab}	4.74^{c}	4.80^{bc}
SNF[1]	8.92^{a}	8.78^{b}	8.83^{ab}	8.78^{b}
Ash	0.69^{a}	0.67^{a}	0.67^{a}	0.68^{a}
Minerals (mg/L)				
Ca	1340^{a}	1420^{a}	1350^{a}	1470^{a}
Fe	0.39^{a}	0.49^{a}	0.38^{a}	0.47^{a}
K	1550^{ab}	1520^{ab}	1570^{ab}	1720^{a}
Mg	120^{b}	140^{a}	120^{b}	150^{a}
Mn	0.03^{a}	0.03^{a}	0.03^{a}	0.03^{a}
Na	660^{a}	620^{a}	610^{a}	640^{a}
P	1110^{b}	1610^{a}	1050^{b}	1650^{a}
Zn	3.87^{b}	5.06^{a}	4.25^{ab}	4.84^{a}

[1]Solids-not-fat.

Values within a row with different letters are significantly different ($P < 0.05$).

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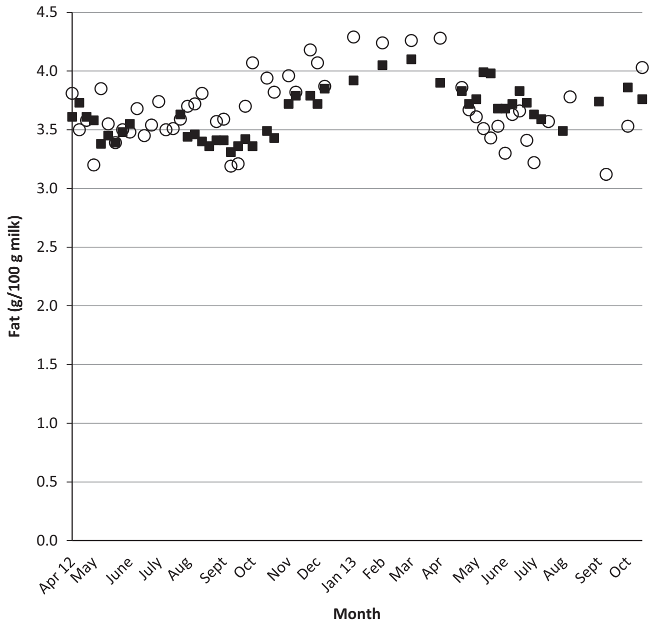

Figure 1 Variation in fat content of milk from neighbouring farms from April 2012 to October 2013. ■ = conventional milk; ○ = organic milk.

The minerals in the samples are shown in Table 1. In most cases, the mineral content did not significantly differ between seasons or types of milk. Mg and P were higher in S-S in ORG and CONV milk, and Zn was higher in S-S in CONV only. Both herds were fed mineral supplements, and the averages for each mineral were within or slightly above published ranges (Gaucheron 2005; Sola-Larrañaga and Navarro-Blasco 2009). The differences in Mg, P and Zn presumably resulted from differences in these supplements.

Fatty acids

The fatty acid profiles are shown in Table 2. The results are reported as g/100 g fat instead of g/100 g milk as ORG cows produced significantly more fat in their milk than CONV cows during F-W. Of the fatty acids measured, only the levels of 10:0 (caprylic), 12:0 (lauric), 14:1 (palmitoleic), and *trans*-18:1 changed significantly between seasons in the CONV. This relative lack of variation was not surprising as the feed did not change. With the ORG, however, the levels of 6:0 (caproic), 8:0 (caprylic), *trans*-18:1, 18:1 (oleic) and 18:2 were significantly higher in S-S, while levels of 14:1 and 16:0 (palmitic) were lower. The decrease in 16:0, the most prevalent fatty acid in milk, was observed by Khanal *et al.* (2008) during a transition from conventional to pasture feeding and was attributed to the increase in the supply of longer chain fatty acids (especially 18:0 and 18:1) in the diet. Ellis *et al.* (2006) also found *trans*-18:1 to be higher in organic milk. Both types of milk in the present study tended to have more total monounsaturated and total polyunsaturated fatty acids in S-S, although the differences between seasons and between ORG and CONV were not significant.

Table 2 Major fatty acids in conventional and organic milk from neighbouring farms during fall-winter (F-W) and spring-summer (S-S) periods

	Conventional		*Organic*	
Fatty acid	*F-W*	*S-S*	*F-W*	*S-S*
g/100 g fat				
6:0	1.31^{ab}	1.55^{ab}	1.10^{b}	1.65^{a}
8:0	1.23^{a}	1.21^{a}	1.06^{b}	1.19^{a}
10:0	3.15^{a}	2.83^{b}	2.70^{b}	2.75^{b}
12:0	3.68^{a}	3.24^{b}	3.27^{ab}	3.30^{b}
14:0	11.26^{ab}	10.71^{b}	11.39^{a}	11.05^{ab}
14:1	1.11^{b}	0.77^{c}	1.43^{a}	0.97^{b}
15:0	1.08^{bc}	1.01^{c}	1.25^{a}	1.18^{ab}
16:0	29.03^{b}	28.95^{b}	34.53^{a}	29.77^{b}
16:1	1.19^{b}	1.47^{b}	1.56^{ab}	1.75^{a}
17:0	0.53^{a}	0.74^{a}	0.68^{a}	0.63^{a}
18:0	12.74^{ab}	13.72^{a}	10.55^{c}	11.67^{bc}
trans-18:1	1.68^{c}	2.49^{b}	1.59^{c}	3.12^{a}
18:1	21.54^{a}	22.78^{a}	19.21^{b}	21.78^{a}
18:2	3.53^{a}	3.66^{a}	2.14^{c}	2.71^{b}
CLA[1]	0.77^{b}	0.71^{b}	0.84^{ab}	0.94^{a}
18:3	0.53^{b}	0.63^{b}	0.77^{a}	0.79^{a}

[1]Conjugated linoleic acid.

Values within a row with different letters are significantly different ($P < 0.05$).

The levels of CLA and 18:3 did not vary seasonally, but the S-S ORG contained significantly more CLA than the CONV, and the 18:3 in both S-S and F-W was significantly higher in the ORG. The CLA of the ORG, calculated as g/100 g fat, was on average 25–30% higher than the CONV throughout the study; Benbrook *et al.* (2013), who calculated values based on g/100 g whole milk, observed a 42% difference during the summer months but none during the winter months. When converted to mg/100 g milk, the results of the present study show a 29–36% difference (Table 3). The 18:3 concentration of the ORG was on average 36% higher than that of the CONV on a fat basis

Table 3 Conjugated linoleic acid (CLA) and α-linolenic acid (18:3) in conventional and organic milk from neighbouring farms during fall-winter (F-W) and spring-summer (S-S) periods

	Conventional		*Organic*	
Fatty acid	*F-W*	*S-S*	*F-W*	*S-S*
mg/100 g milk				
CLA	28.3^{c}	25.2^{c}	38.4^{a}	32.4^{b}
18:3	20.5^{b}	22.0^{b}	31.9^{a}	28.1^{a}

Values within a row with different letters are significantly different ($P < 0.05$).

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and 28–56% higher on a milk basis; Benbrook *et al.* (2013) calculated a 60% difference on a milk basis.

Implications

The results indicate that CLA and 18:3 are elevated in organic milk from pasture-fed cows. This disparity may be more pronounced in the US than in other places. In 2009, 63% of organic dairies reported to the US Department of Agriculture that half of their dairy forage fed to their cows came from pasture during the grazing months, and a third indicated that at least three-quarters came from pasture; in contrast, only 18% of conventional dairies used fresh forage (McBride and Greene 2009). In contrast, cows on conventional dairy farms in Europe usually have access to pasture. For example, a recent survey from the north-east of England revealed that 20% of the average DMI on conventional outdoor farms came from pasture grazing, compared with 37% from organic farms (Stergiadis *et al.* 2012). The differences in milk composition between organic and conventional dairy farms in the US would therefore be greater than in Europe (Benbrook *et al.* 2013).

CLA and 18:3 can be increased naturally through the cow by supplementing feed with ingredients such as marine oils or oilseeds (Chilliard *et al.* 2001), but this study shows that consuming normal pasture plants will also be successful.

No research on consumer acceptance of dairy products enriched with 18:3 has been reported, but studies have shown that dairy products can receive satisfactory evaluations when fortified with CLA from fish oil (Kolanowski and Weiβrodt 2007) or flaxseed oil and microencapsulated fish oil (Bermúdez-Aguirre and Barbosa-Cánovas 2011). In a comparison of milk samples without fortification of feed, organic milk from pasture-fed animals (>1.0 g CLA/100 g milk) could not be differentiated from conventional milk (<0.8 g CLA/100 g milk) in a test of trained panellists (Croissant *et al.* 2007).

A study of consumer attitudes towards organic milk reveals that it is perceived as a premium product that is healthier, tastier and better for the environment than conventional milk (Hill and Lynchehaun 2002). Some consumers purchase organic milk because they feel it is safer than conventional milk (with no pesticides, antibiotics, hormones, rBST or GMOs) is unadulterated and helps the family farmer (Bernard and Bernard 2009; Klöckner and Ohms 2009). The increase in organic milk purchases in the US is expected to continue for the foreseeable future, and the presence of higher levels of healthy components ought to enhance this trend. Organic milk from pasture-fed cows should be acceptable to consumers while providing them with beneficial fatty acids.

CONCLUSIONS

The amounts of CLA and 18:3 were higher in organic milk (from pasture-fed cows) than in conventional milk (no access to pasture) from neighbouring farms where geography and weather were identical. Expected seasonal variations in fat and protein contents were observed. Grazing cows on pasture will elevate CLA and 18:3 in their milk without having to supplement their diet. The sales of organic milk are growing in the US, and the presence of elevated levels of beneficial fatty acids ought to maintain this trend.

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