Feeding Strategies to Improve Nutritional Quality of Dairy and Beef

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If milk and meat are nearly the perfect foods, then the question follows as to why we would want to change their compositions. Over the years, there have been changes in the human diet, lifestyle, and environment that have resulted in consumers being more health- and environmentally conscious. Our knowledge about foods, food composition, and their influence on human health and environment has increased. Scientists are interested in improving the quality of foods and providing accurate information about foods to consumers. Interestingly, animals' diets have also changed over the years. Recent research gives ample evidence showing that an animal's diet can influence the composition of the food it produces. Therefore, composition and nutritional properties of milk and meat are of considerable importance to dairy and beef producers, processors, and consumers.

Animal nutritionists have developed feeding strategies that will improve the nutritional and therapeutic values of milk and meat with minimal impact on the environment. Milk producers are paid for their milk based on quantity of fat, protein, and overall quality of milk. The key to success is that-on farm manipulation of milk and meat composition will only occur if it is perceived to be economically viable and does not negatively affect consumer acceptability. Presumably, producers will receive a premium prices in the future for enhanced nutritional quality of milk and meat.

The objective of this article is to review some of the feeding practices that have potential to improve the nutritional qualities of milk and meat. The discussion will be limited to manipulation of fat and vitamin E in milk and meat from ruminants.

Milk fatty acid profile

Bovine whole milk contains 3.4 to 4.1% fat and this fat consists of about 95.8% triacylglycerol, 2.25% 1,2-diacylglycerol, 0.08% monoacylglycerol, 0.28% free fatty acids, 0.74% phospholipids, 0.37% sphingomyelin, and 0.48% cholesterol and cholesterol esters. Milk fatty acids (**FA**) are divided into short-chain (C_4-C_{12} chain length), medium-chain (C_{14}-C_{16}), and long-chain FA ($> C_{16}$). Fatty acids in milk are also classified as saturated, monounsaturated, n-6, or n-3 FA. The comparative FA compositions of milk and different meats are presented in Table 1.

Bovine milk fat is perceived as a risk factor for coronary heart diseases (**CHD**) because it is a source of cholesterol and saturated FA. The general perception is that food containing saturated fat is unlikely to be beneficial to health. Over the past 30 years, fluid whole milk consumption in the United States has been decreasing. The "ideal" milk fat for human health has been defined as <10% polyunsaturated FA, <8% saturated FA, and >82% monounsaturated FA. Producing milk on the farm with an "ideal" fat profile is unrealistic because milk with high levels of unsaturated FA will be prone to oxidation, negatively affecting manufacturing and consumer acceptability characteristics. However, it is possible to increase the proportions of mono- and polyunsaturated FA in milk through dietary manipulations and management practices on the farm.

Table 1. Comparative FA composition and total fat in milk and meats[1] (g/100 g of fat)

	Food					
Fatty Acid	Milk	Lamb	Beef	Pork	Chicken	Red Fish
SFA[2]	63.90	43.80	48.00	37.49	30.17	28.03
Trans fat[3]	5.23	5.22	7.17	0.65	2.18	0.79
MUFA[4]	26.10	46.30	39.26	49.20	46.56	36.76
CLA[5]	0.58	0.48	1.28	0.13	0.16	0.05
PUFA[6]	4.80	4.64	5.58	12.66	21.10	34.42
n-6[7]	3.56	3.55	2.86	11.49	19.57	11.17
n-3[8]	0.57	0.52	1.34	0.59	1.04	22.07
Ratio n-6:n-3	6.33	8.22	3.62	19.19	18.70	0.51
Total FA, g/100 g of product	3.33	15.83	15.46	20.20	9.37	8.83

[1] Average of n = milk (23), beef (40), lamb (14), pork (24), chicken (11), red fish (7).

[2] Saturated fatty acid = sum of $C_{4:0}$, $C_{6:0}$, $C_{8:0}$, $C_{10:0}$, $C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{22:0}$, and $C_{24:0}$.

[3] *Trans*-fat = sum of $C_{16:1,\ 9\text{-}trans}$ and all $C_{18:1\ trans}$ isomers.

[4] Monounsaturated fatty acids = sum of $C_{14:1\text{-}cis}$, $C_{16:1\text{-}cis}$, $C_{17:1\text{-}cis}$, and $C_{20:1}$.

[5] Conjugated linoleic acid = sum of $C_{18:2\ cis\text{-}9,\ trans\text{-}11}$, and $C_{18:2\ trans\text{-}10,\ cis\text{-}12}$ isomers.

[6] Polyunsaturated fatty acids = sum of $C_{18:2}$, $C_{18:3\gamma}$, $C_{18:3\alpha}$, $C_{18:2\ cis\text{-}9,\ trans\text{-}11}$, $C_{18:2\ trans\text{-}10,\ cis\text{-}12}$, $C_{20:2}$, $C_{20:3\ n\text{-}6}$, $C_{20:3\ n\text{-}3}$, $C_{20:4}$, $C_{20:5}$, $C_{22:4}$, $C_{22:5}$, and $C_{22:6}$.

[7] n-6 fatty acids = sum of $C_{18:2}$, $C_{18:3\gamma}$, $C_{20:2}$, $C_{20:3\ n\text{-}6}$, $C_{20:4}$, and $C_{22:4}$.

[8] n-3 fatty acids = sum of $C_{18:3\alpha}$, $C_{20:3\ n\text{-}3}$, $C_{20:5}$, $C_{22:5}$, and $C_{22:6}$.

The ability to modify milk and meat FA profiles is largely dependent on the efficiency by which FA are transferred from the diet to the milk. Biohydrogenation of unsaturated FA supplied through the diet is extensive and ranges from 60-90%. Digestibility of FA reaching the small intestine is also a factor affecting the efficiency of FA transfer from diet to milk. Supplemental fat supplied up to 2% of diet DM is efficiently digested by ruminants. Transfer of FA in triglyceride form to mammary or adipose tissue is another factor that will influence the transfer efficiency from the diet.

The proportions of different FA in milk will vary with the animal's diet, amount and composition of dietary fat, genetics, stage of lactation, and season. Providing feeds rich in unsaturated FA results in higher proportions of unsaturated FA in milk fat (Dhiman et al., 1995 and 1999). Feeding 4.0 kg/d of raw or roasted soybeans to dairy cows increased the proportions of unsaturated FA ($C_{18:1}$, $C_{18:2}$ and $C_{18:3}$) in milk compared to the control treatment without soybeans (Figure 1; Dhiman et al., 2000). The increase was higher in milk from cows fed roasted soybeans than raw soybeans. Feeding raw soybeans had no effect on $C_{18:2}$ *cis*-9, *trans*-11 (**CLA**) content in milk compared to control. However, feeding roasted soybeans doubled the CLA content in milk compared to control. Feeding raw seeds has little or no effect on the CLA content of milk fat because polyunsaturated FA in the intact seeds are relatively unavailable to the rumen microbes for biohydrogenation. If raw seeds, however, are processed by grinding, roasting, micronizing, flaking, or extruding, those processed seeds are effective at increasing the CLA content in milk.

Feeding soybean oil at 2 or 4% of the diet DM to dairy cows increased the proportions of CLA in milk compared to control (Figure 2; Dhiman et al., 2000). Increasing the soybean oil in the diet to 4% reduced the milk fat content and resulted in lower CLA yield/d. Under similar feeding conditions, oils rich in linoleic acid were more effective in enhancing CLA and $C_{18:2}$ *trans*-11 (**VA**) in milk fat than oils containing linolenic acid in dairy cows (Bu et al., 2007; Figure 3). The effects of mixing linoleic and linolenic acids (50:50) on enhancing VA and CLA were additive, but not greater than when fed separately.

Figure 1. Percent increase in unsaturated FA in milk from cows fed raw (RAWSB) or roasted soybeans (RSB) at a rate of 4.0 kg/d (Dhiman et al., 2000).

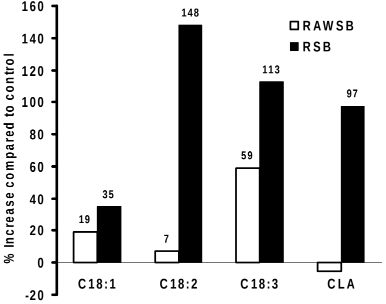


Figure 2. Percent increase in unsaturated FA in milk from cows fed soybean oil at 2 (SO2) or 4% (SO4) of diet DM compared to control without soybean oil (Dhiman et al., 2000).

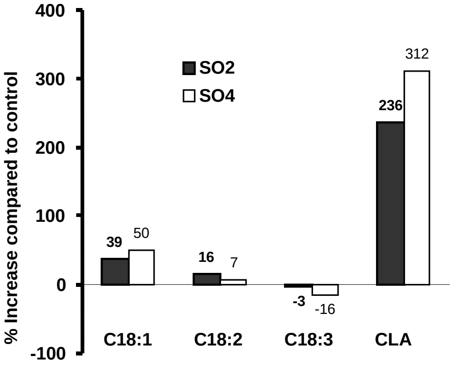
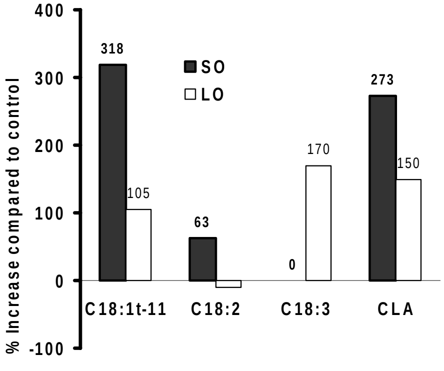


Figure 3. Percent increase in unsaturated FA in milk from cows fed 4% of the diet DM as soybean oil (SO) or linseed oil (LO) compared to control without oil (Bu et al., 2007).



Supplementing peanut oil, sunflower oil, or linseed oil at 5.3% of dietary DM resulted in 1.33, 2.44, and 1.67% CLA in milk fat, respectively, compared with 0.50% of milk fat in the control (Kelly et al., 1998). Feeding canola oil at 4% of diet DM to dairy goats increased CLA content to 3.2% of FA compared to 1.0% in milk fat from the control (Mir et al., 1999).

The feeding of fish oil has also been shown to enhance the CLA and VA contents of milk fat, but reduced total fat content of milk. Feeding fish oil at 1.6% of the diet DM increased the CLA and VA contents in milk fat from 0.16 and 1.03% in control to 1.55 and 7.50%, respectively (Offer et al., 1999). Feeding partially rumen-protected calcium salts of fish oil to dairy cows increases the proportions of VA, CLA, n-3 and total unsaturated FA in milk (Table 2; Allred et al., 2006).

Table 2. Selected FA in milk from cows fed calcium salts of palm and fish oil alone or in combination with soybean products (Allred et al., 2006).

	Treatment[1]					
Fatty acid[1]	CTL	FO	FOESM	FOSO	SEM	*P*
	--g/100-g of fatty acids reported--					
$C_{18:1}$ *t*-11, (VA)	3.29^{c}	4.66^{b}	6.34^{ab}	7.81^{a}	0.50	**
$C_{18:1}$ c-9	21.0^{b}	25.0^{a}	25.4^{a}	23.6^{a}	0.71	**
$C_{18:3}$ *c*-9,12,15	0.53	0.52	0.55	0.53	0.02	0.80
CLA *c*-9,*t*11 (CLA)	0.56^{c}	1.20^{b}	1.36^{ab}	1.74^{a}	0.13	***
CLA yield, (g/d)	7.5^{c}	14.7^{b}	16.0^{ab}	17.5^{a}	0.10	***
$C_{20:3}$ *c*-11,14,17	0.009	0.015	0.013	0.014	0.001	0.06
$C_{20:5}$ (EPA)	0.03	0.05	0.04	0.04	0.004	0.06
$C_{22:6}$ (DHA)	0.01^{b}	0.05^{a}	0.04^{a}	0.04^{a}	0.004	***
Total n-3 FA[2]	0.62^{b}	0.69^{a}	0.69^{a}	0.67^{ab}	0.02	*
Total n-6 FA[3]	5.15	5.41	5.56	5.31	0.14	0.30
n-3:n-6	0.118	0.129	0.121	0.125	0.003	0.10
Saturated FA	66.7^{a}	60.2^{b}	57.7^{b}	58.3^{b}	0.87	***
Unsaturated FA	33.3^{b}	39.8	42.3^{a}	41.7^{a}	0.87	***

[a, b, c] Means in the same row with different superscripts differ for treatment effect with *P* value as mentioned in column for significance.

* = Significant at $P < 0.05$, ** = Significant at $P < 0.01$, *** = Significant at $P < 0.001$.

[1] Cows were fed a control basal diet containing 44% forage and 56% concentrate mix (CTL), basal diet supplemented with either 2.7% (DM basis) calcium salts of palm and fish oil (Ca-PFO; FO), 2.7% Ca-PFO + 5% full-fat extruded soybeans (FOESM) or 2.7% Ca-PFO + 0.75% soybean oil (FOSO).

[2] Sum of $C_{18:3}$ *c*-9,12,15; $C_{20:3}$ *c*-11,14,17; $C_{20:5}$ (EPA); $C_{22:5}$, and $C_{22:6}$ (DHA).

[3] Sum of $C_{18:2}$, $C_{18:3}$ *c*-6,9,12; $C_{20:3}$ *c*-8,11,14; $C_{20:4}$, and $C_{22:4}$.

Forage maturity and method of preservation also seem to be important factors influencing the polyunsaturated FA content of milk. Cows fed immature forages have higher levels of CLA in milk than cows fed mature forages. Cows grazing on lush green pastures have significantly higher levels of unsaturated FA compared to cows fed a typical dairy cow diet containing 50% conserved forage and 50% grain (Figure 4; Khanal et al., 2005). Once cows are turned out to pasture, it takes approximately 3 weeks before CLA content in milk is maximized (Figure 5; Aguiar et al., 2004).

Our work suggests that consumer acceptability of milk from dairy cows grazing on pasture or fed a conventional mixed ration is similar (Khanal et al., 2005). Consumer panel scores of milk for mouth-feel, color, flavor, and overall quality did not differ between treatments. Specific flavor attributes were similar, except for barny flavor, which was scored higher in milk of cows grazing on pasture.

Figure 4. Percent increase in unsaturated FA in milk from grazing cows compared with cows fed a diet containing 50% conserved forage and 50% grain (Khanal et al., 2005).

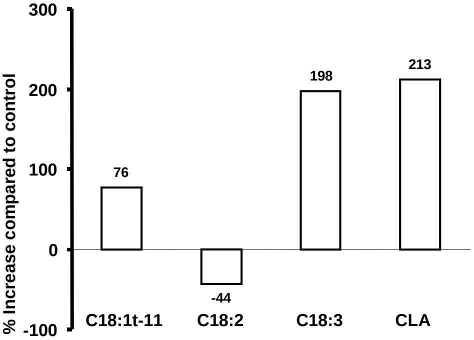
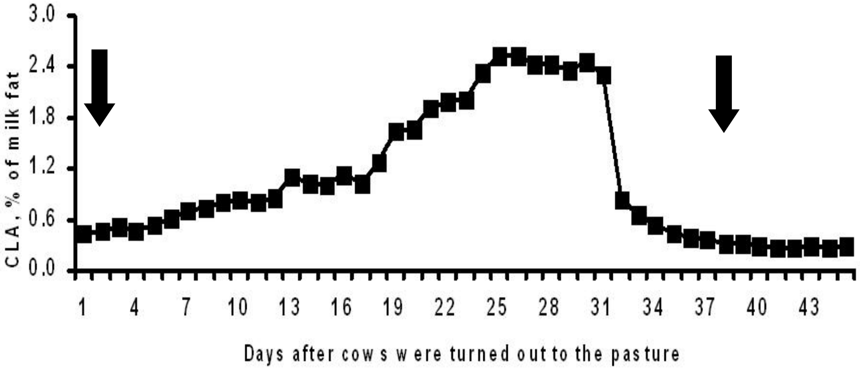


Figure 5. Effect of turning cows out to pasture on CLA content of milk. The arrows indicate the time cows started grazing (left arrow) and returned to the barn (right arrow). Cows were fed a total mixed ration before and after grazing (Aguiar et al., 2004)



Dairy cow management systems also influence the CLA content of milk. Jahreis et al. (1997) collected milk samples over a period of one year from three farms with different management systems: 1) conventional farming with indoor feeding using preserved forages; 2) conventional farming with grazing during the summer season; and 3) ecological farming with no use of chemical fertilizers to produce forages and grazing during the summer season. The CLA content was 0.34, 0.61, and 0.80% of fat in milk from cows fed indoors, grazed during summer, and cows grazed in ecological farming conditions, respectively. Reasons for these results could be due, in part, to differences in vegetation or forage quality among the three systems. Therefore, most of the time, differences in CLA content of milk from cows under different management systems are actually due to the differences in feedstuffs produced under different management styles. Depending on the season, CLA content in milk varied from 0.6 to 1.2% of milk fat, with content being higher in spring and summer than in winter.

Some studies suggest that dairy cow breed can also influence the CLA content of milk. Montbeliard cows displayed a tendency to have higher CLA in milk fat (1.85%) when compared to Holstein-Friesian (1.66%) or Normande cows (1.64%) grazing on pasture (Lawless et al., 1999). Holstein-Friesian cows had higher CLA content in milk as compared to Jerseys fed diets containing conserved forages and grains (Dhiman et al., 2002). Conjugated linoleic acid content was also higher in milk fat from Holstein-Friesians (0.57%) than for Jersey cows (0.46%) when grazed on pasture (White et al., 2002). The average difference in CLA content of milk fat among Brown Swiss, Holstein-Friesian, and Jersey breeds is 15 to 20% when fed similar diets. Brown Swiss cows have inherently higher CLA in milk fat, followed by the Holstein-Friesian and Jersey breeds. The data on other breeds are too limited to form any firm conclusions.

Existing literature suggests that CLA in milk fat is a stable compound under normal processing and storage conditions; however, processing dairy products at >80°C may slightly elevate the CLA content (Dhiman et al., 2005a).

Milk fat is not a rich source of eicosapentaenoic acid ($C_{20:5}$; **EPA**) and docosahexaenoic acid ($C_{22:6}$; **DHA**) for humans compared to some other foods such as fish (0.08 vs. 19-24% of total fat is n-3 FA). The importance of an optimum balance of n-6:n-3 FA in human health leads to greater interest in the potential health benefits of $C_{18:3}$ n-3. Although present in small amounts in milk fat, $C_{18:3}$ n-3 proportions can be increased 2-3 times by grazing cows on pasture or feeding green chopped forage compared to feeding conserved forages and grains. Dairy cows fed a typical diet containing 50% conserved dry forage and 50% grain had 0.41% of total milk FA as $C_{18:3}$ n-3 compared to 1.22% in milk FA from grazing cows (Figure 4; Khanal et al., 2005). Feeding oil seeds or oils (Figure 3) rich in linolenic acid (canola and rapeseeds) to dairy cows can also increase the levels of $C_{18:3}$-n-3 FA in milk (Kennelly et al., 1996). Manipulating the diet of dairy cows can produce milk fat that would be a good source of $C_{18:3}$ n-3 FA for humans. A summary of dietary factors influencing the proportions of unsaturated FA in milk is shown in Table 3.

Table 3. Summary of dietary factors influencing the proportions of unsaturated FA in milk from dairy cows

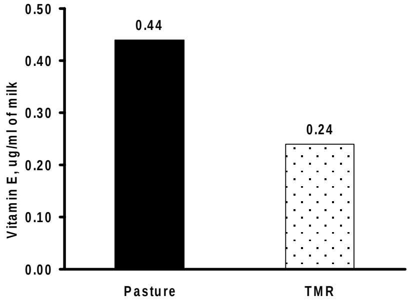
Factor	Changes
Feeding high forage diets	increase
Grazing early vegetative forage	increase
Feeding fresh cut forage	increase
High starch diets	decrease
Processed oil seeds	increase
Plant oils	increase
Marine oils	increase
Feeding algae	increase
Ionophores	increase
Partially rumen protected salts of unsaturated FA	increase
Heat stress	increase

Vitamin E in milk

Supplementation of vitamin E or feeding green forage to dairy cows will result in milk that is naturally enriched in vitamin E. The vitamin E level of milk was higher while cows were grazing compared to when fed conserved forage and grain (Figure 6;

Aguiar et al., 2004). Others have also seen increased vitamin E in milk when grazing cows on pasture compared to feeding mixed rations (Kay et al., 2005; Leiber et al., 2005).

Figure 6. Vitamin E (α-tocopherol and γ-tocopherol) levels in milk from cows grazing on pasture or fed a total mixed ration containing 50% conserved forage and 50% grain (Aguiar et al., 2004).



Fatty acid profile of beef

Beef contains 44 and 56% saturated and unsaturated FA, respectively (Table 1). The FA that are of most interest in beef are VA, CLA, $C_{18:3}$, and other n-3 FA. Increasing the proportions of these FA would increase the nutritional and therapeutic value of beef. Existing research suggests that feeding plant oils or oil seeds to beef steers during the finishing period has no effect on the proportions of total saturated and unsaturated FA in beef (Figure 7; Dhiman et al., 2005b). Raising cattle on forages and pasture results in significant increases in the proportions of unsaturated FA compared to feeding high-grain diets (Figure 8). The proportions of $C_{18:3}$ and n-3 FA can be increased in beef by feeding oils containing these FA or increasing the proportion of forage in the diet (Figures 7 and 8). As is the case with dairy cattle, grazing animals on pasture, feeding fresh forages, or increasing the amount of forage in the diet will elevate the percentages of VA and CLA as a proportion of total FA in meat from ruminants. Grazing beef steers on pasture or increasing the amount of silage in the diet increased the CLA content in fat by 29 to 45% as compared to control (Shantha et al., 1997; McGuire et al., 1998). The increase in beef CLA content varies with the quality and quantity of forage in the animal's diet. Beef from steers raised on green pasture had 200 to 500% more CLA as a proportion of fat as compared to steers fed an 87% corn grain-based feedlot diet (French et al., 2000; Poulson et al., 2004).

Figure 7. Proportions of unsaturated FA in beef muscle from steers fed high grain diets supplemented with either 0 (CTL), 2 (SO2), or 4% (SO4) soybean oil for 105 d before harvest (Dhiman et al., 2005b).

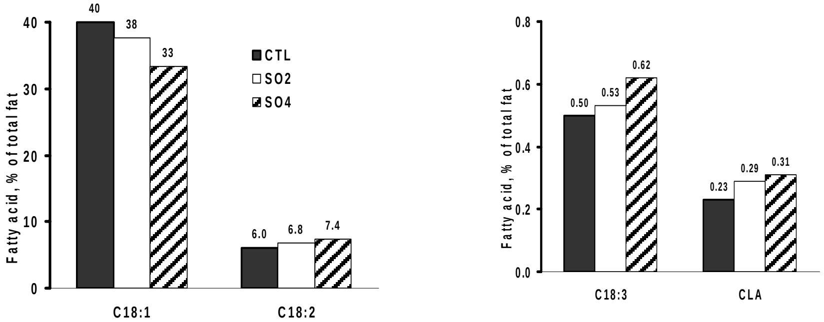
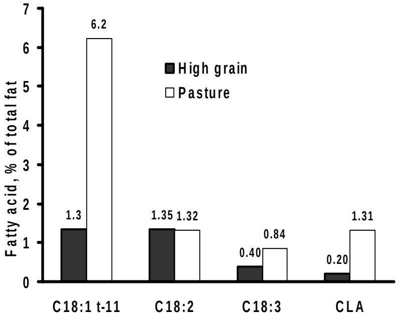


Figure 8. Proportions of unsaturated FA in beef muscle from steers raised on high grain diets or forages/pasture (Poulson et al., 2004).



Rule et al. (2002) observed that the percentage of CLA was higher in intramuscular fat of range-fed cattle compared with that of steers fed a high-grain diet under feedlot conditions. However, the increase in CLA content of beef is not as dramatic as the increase seen in milk from cows grazing on pasture. This difference is probably due to differences in CLA production in the rumen or endogenous synthesis of CLA in intramuscular fat of beef cattle compared to endogenous synthesis in the mammary gland of dairy cows.

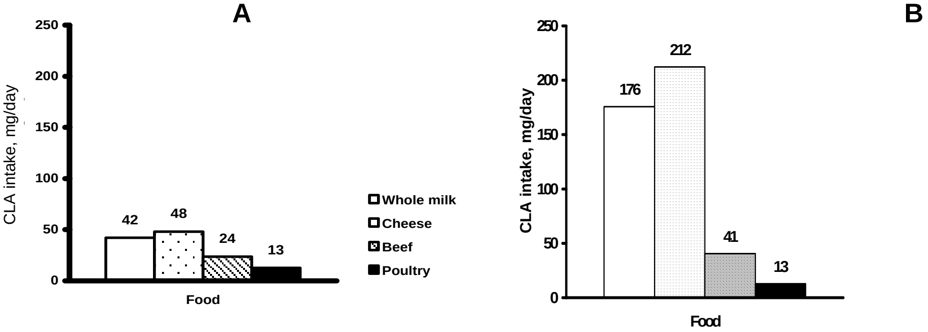
Studies from our laboratory suggest that there were no differences in tenderness or juiciness of steaks from animals raised on high grain or forage/pasture. However, steaks from animals raised on forages had a higher off-flavor score, which was described as a "grassy" flavor by two of the more experienced panelists (Poulson et al., 2004).

Besides dietary factors, researchers have also studied the influence of beef cattle breed on CLA content in meat. Limited studies suggest that there is little breed effect. The CLA content in beef muscle was similar among European x British crossbreeds and 75% Wagyu cattle fed high-grain, barley-based diets (Mir et al., 2000). Limousin cattle had only marginally higher CLA content in beef muscle as compared to Wagyu and Limousin x Wagyu cattle fed similar diets (Mir et al., 2002). More studies are needed in order to understand the breed influence on CLA content of beef.

Existing literature indicates that the total CLA content (sum of *cis*-9, *trans*-11 and *trans*-10, *cis*-12 isomers) of beef varies from 0.17 to 1.35% of fat. The broad range of CLA content of beef is related to the wide variety of feeds offered, breed differences, and management strategies used to raise cattle. Large portions of the studies do not report total fat content. Therefore, caution should be taken when interpreting these data with respect to total CLA yields. Our practical recommendations to enhance the VA, CLA, and omega fatty acids in beef would be to increase the proportions of forage or add feed sources rich in linolenic acid to beef cattle diets.

The question may now arise as to just how much CLA humans are currently consuming and how much should be consumed in order to reap the health benefits and anticancer effects that have been observed from adding proper levels of CLA to the diet. Figure 9, panel A, shows the amounts of CLA provided in one normal serving of milk, cheese, lean beef, and poultry. Figure 9, panel B, shows the amounts of CLA provided by one serving of milk, cheese, beef, and poultry from CLA-enriched foods.

Figure 9. Daily CLA intake by humans from one serving of low-CLA whole milk, cheese, beef, and poultry (A); and daily CLA intake from one serving of high-CLA whole milk, cheese, beef, and poultry (B; Dhiman et al., 2005a).



It has been reported that the minimum effective dose of CLA needed to help prevent the incidence of cancer in animal models is 0.05% of the diet (Ip et al., 1994). Assuming that the average adult consumes 600 g of food/day, a person eating one serving each of low-CLA whole milk, cheese, beef, and poultry per day would have a CLA intake of approximately 127 mg/day (Figure 9, panel A), which amounts to 0.021% of the total diet. However, a person consuming the high-CLA products would have a CLA intake of about 441 mg/day (Figure 9, panel B), amounting to 0.074% of the diet, which is well above the minimum intake that has been shown to be effective in reducing the incidence of cancer in animal models.

Vitamin E and color stability of beef

The mean vitamin E contents were 1.33 and 5.33 mg/kg of fresh meat for high grain and forage/pasture raised beef, respectively (Poulson et al., 2004). Meat from animals finished on pasture had 300% higher vitamin E content when compared with animals finished on high grain. Higher vitamin E contents have been shown to improve the color stability of beef. In our study, meat from animals raised on forages and pasture retained their redness better than meat from grain-finished cattle. The improved redness retention is most likely associated with the naturally increased levels of vitamin E in meat from pasture finished animals (Liu et al., 1996). Others have also observed increased vitamin E contents in meat when cattle were finished on pasture compared to high-grain diets (Yang et al., 2002; Descalzo et al., 2005).

Summary

The proportions of polyunsaturated FA, CLA, VA, and n-3 FA in milk can be increased by feeding processed oilseeds, plant oils, marine oils, algae, and ionophores alone or in combinations to dairy cows. Forages and fresh pasture increase both beneficial fatty acids and vitamin E contents of milk. Feeding plant oils to beef cattle results in minor changes in polyunsaturated FA in beef. The proportions of CLA, VA, and n-3 FA in beef can be increased by increasing the proportions of forage in the diet, grazing on pasture, or by feeding oils rich in linolenic acid to beef cattle. Beef cattle finished on pasture or forages produce meat with significantly higher vitamin E content.

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