NUTRITIONAL STRATEGY FOR DESIGNER MILK WITH FAT CONSTITUENTS BENEFICIAL FOR HUMAN HEALTH - A REVIEW

J.K. Movaliya, K.S. Dutta, H.H. Savsani and S.S. Patil
College of Veterinary Science and Animal Husbandry, Junagarh Agricultural University, Junagadh - 362 001, India

Received: 13-08-2012
Accepted: 14-03-2013

ABSTRACT

Health conscious consumers are demanding dairy products which should be richer in mono and polyunsaturated fatty acids. Opportunities exist to modify the composition of milk fat from dairy animals and to improve milk fat's nutritional and manufacturing properties. Different feeding experiments shows that suitable nutritional strategy can be chalked out for production of milk with increased content of beneficial fatty acids as healthy designer milk for consumers and will aid in increasing the profits of livestock farmers.

Key words: Consumers, Designer milk, Milk fat constituent, Nutritional management.

Health conscious consumers are demanding dairy products which should be richer in mono and polyunsaturated fatty acids. Dietary recommendations to reduce elevated serum cholesterol level emphasize a reduced intake of total fat, saturated fat and cholesterol. Because milk fat contains primarily saturated fat and a small amount of cholesterol, butter and full fat dairy products automatically gets elimination from cholesterol reducing diets. Opportunities exist to modify the composition of milk fat from dairy animals (Baer, 1991; Banks, 1987 and Banks et al., 1989) and to improve milk fat's nutritional (Baer, 1991 and Ney, 1991) and manufacturing properties (Baer, 1991; Banks et al., 1983 and Banks et al., 1989). Feed and animal factors influence the composition of milk fat (Christie, 1979; Grummer, 1991 and Palmquist et al., 1993). Typical milk fat from a dairy cow is contains approximately 5% polyunsaturated fatty acids (PUFA) including ω-3 fatty acids, 70% saturated fatty acids (SFA) and 25% monounsaturated fatty acids (MUFA). The difference in fatty acid composition between the “ideal” milk fat and typical milk fat is enormous. The ideal nutritional milk fat, based on current dietary recommendation, would contain less than 10% PUFA including ω-3 FA, up to 8% SFA and the rest (82%) being MUFA (O’Donnell, 1989). There is evidence to indicate that dietary SFA are not equal in their effect on plasma cholesterol in humans. Specifically, hypercholesterolemic effect of saturated fats in human diets is largely due to C12:0 C14:0 and C16:0. Fatty acid C18:0 is an effective as oleic (cis-C9 to C18:1) acid in reducing plasma cholesterol (Bonanome et al., 1988; Keys et al., 1965 and Wrthasarathy et al., 1990). Therefore, it may be desirable to increase the C18:0 ratio in total milk fat as well as increase the proportion of short chain fatty acids (C4 to C10).

Fatty acids in milk and their health benefits:
Fat and oil are major source of stored energy in both plants and animal. They are ester of fatty acids with glycerol. Fatty acids classified as saturated fatty acids having high molecular weight, conform chemical stability and provide physical hardness and unsaturated fatty acids having conform chemical reactivity and provide physical softness. While fatty acids are present as triglycerides in seeds and animal adipose tissue where as diglycerides are found in plants leaves, in which one fatty acid is replaced by galactolipid. The fatty acids like linolenic, eicosapentaenoic, docosahexaenoic are ω-3 fatty acids where as linoleic and arachidonic are ω-6 fatty acids. In ω-3 fatty acid double bond is present between carbon atom three and four from terminal methyl group and in ω-6, double bond is present.

*Corresponding authore’s e-mail: drsrpatt@gmail.com
between carbon atom six and seven. Fatty acids have two isomers i.e. cis isomer in which hydrogen atoms are present on the same side of the carbon atom attached with double bond where as in trans isomer hydrogen atoms are on the opposite side.

Conjugated linoleic acids (CLA) are a naturally occurring fatty acid in foods derived from ruminants. CLA is a term used for a mixture of positional and geometric isomer of linoleic acid (cis-9, cis-12 octadecadienoic acid) that contains conjugated unsaturated double bonds. More than 82% of the CLA in dairy products is the cis-9, trans-11 isomer (Chin et al., 1992). CLA has been shown to have anti-carcinogenic properties (Ha et al., 1987; Ha et al., 1990; Ip et al., 1991 and Parodi et al., 1984) and possibly other effects like antiatherogenic, antidiabetic and immune stimulatory that would be positive for human health. Monounsaturated fatty acids in the diet have been shown to have beneficial effect on the plasma lipoprotein indicators of coronary heart disease risk in human. They have been shown to alter nutrient partitioning and lipid metabolism, and reduce body fat in a number of different animal species.

Feeding, digestion and biosynthesis of milk fat in lactating animals:

a. Feeding and digestion of fats in animals: Livestock are generally fed with forages in which fat content is low from 1-4 % of dry matter (DM), have high proportion of linolenic acid (18:3) and in leaves, fat is in the form of diglycerides and grains in which fat content is variable from 4 to 20 % of DM, have high proportion of linoleic acids (18:2) and in oils of seeds fats is in the form of triglycerides. Forage contains di-galactose-diglycerides which is converted into mono-galactose-diglycerides under the influence of α-galactosidase with releasing one molecules of galactose and mono-galactose-diglycerides is converted into diglycerides by the enzyme β-galactosidase. It also contains diglycerides which gets converted into fatty acids and glycerol by the enzyme lipase produced by Anaerovibrio lipolytica.

Grain contains triglycerides which are converted into fatty acids and glycerol by the enzyme lipase. The galactose and glycerol is converted into volatile fatty acid propionate. The fatty acids using H+ with reductase and converted into saturated fatty acids which are not absorbed into the rumen and coated by the feed particles and calcium salts pass to the small intestine.

b. Postruminal fat digestion and absorption: Fatty acids from the rumen mostly saturated and not absorbed in the rumen, are attached to feed particles, microbes and Ca salt fatty acids, dissociate in the acid environment of the abomasums. pH of duodenum and jejunum remains acidic which affects solubility of fatty acids in aqueous environment. For efficient absorption in the Small intestine emulsification and micelle formation is essential.

c. Biosynthesis of milk fatty acids: There are three stages in milk fat biosynthesis, first is the accumulation of fatty acids in the mammary cell through de-novo synthesis or absorption from the blood stream, second is triacylglycerol formation and fat globule assembly and last is secretion in the milk acini. Fatty acids having 4 and 14 carbon atoms are synthesized de-novo in the mammary gland whereas those with 18 carbon atoms are of dietary origin and are absorbed from the blood stream. Palmitic acids (16 carbon atoms) are supplied approximately equally from the diet and de-novo synthesis. In ruminants the principle sources of carbon for fatty acids synthesis are acetic acid and α-hydroxy butyrate.

SYNTHESIS OF FATTY ACIDS IN RUMINANTS

<table>
<thead>
<tr>
<th>DIET</th>
<th>BLOOD</th>
<th>MILK FATTY ACIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAEBHYDRATE</td>
<td>ACETATE</td>
<td>14:0</td>
</tr>
<tr>
<td>Β-OH BUTYRATE</td>
<td>16:0</td>
<td></td>
</tr>
<tr>
<td>FAT</td>
<td>FATTY ACIDS</td>
<td>18:0</td>
</tr>
<tr>
<td>(PRIMARILY LCFA)</td>
<td>18:1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18:2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18:3</td>
<td></td>
</tr>
<tr>
<td>BODY STORES OF FAT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
fibrosolvans). Cis-9, trans-11 CLA comprises 75 to 90 % of total CLA in ruminant’s fat, and it is an intermediate in the biodegradation of linoleic acids in the rumen (Bauman et al., 2001). However, the substrate source of cis-9, trans-11 CLA is endogenous synthesis, with trans-11 18:1 derived in the rumen as the substrate and enzyme Δ9-desaturase catalyzing the addition of the cis-9 double bond (Griinari et al., 2000 and Corl et al., 2001). The second most abundant isomer, at 3 to 16 % of total CLA, is trans-7, cis-9, which originates almost exclusively from endogenous synthesis via Δ9-desaturase adding a cis-9 double bond to trans-7 18:1 derived from rumen biohydrogenation (Piperova et al., 2002). Other isomer found in ruminants fat make up a very small portion of total CLA and is derived from rumen output. In ruminants, the major tissue sites for Δ9-desaturase (Stearoyl CoA desaturase) and endogenous synthesis of CLA are adipose tissue during growth and the mammary gland during lactation; hepatic level of Δ9-desaturase is negligible. Under certain conditions an alteration in rumen environment occurs to cause a shift in rumen biohydrogenation resulting in a modification of profile of biohydrogenation intermediates produced in the rumen. One example is trans-10, cis-12 CLA, a potent inhibitor of fat synthesis in dairy cows, and rumen production of this CLA isomer coincides with dietary induced milk fat depression in dairy cows (Bauman et al., 2001).

**Nutritional strategy for manipulation of milk fat concentration and composition:** Changing milk fat concentration is achieved by altering either the level of de-novo synthesis in the mammary gland or the supply of long chain fatty acids in diet. To a large extent most effects on milk fat concentration are mediated through the rumen fermentation. Dietary factor that affect the supply of acetic acids from the rumen for de-novo synthesis include fiber quantity and quality. In general, feeding rumen protected fat increases milk fat concentration whereas moderate amount of unprotected unsaturated fat tends to decrease it. Typical milk fat fatty acids profiles vary different from that perceived by the public and research scientists to a beneficial for human consumption. The functional and nutritional properties of bovine milk fat are dependent on the fatty acid composition and structure of the triacylglycerols. Much nutritional manipulation has been directed at increasing the proportion of unsaturated fatty acids in order to enhance its appeal to the consumer and to produce a softer fat. A more spreadable butter could be produced from such fat thus overcoming a major criticism of conventional butter.

If unsaturated fatty acids are fed to ruminants in an unprotected form rumen microbial digestion can be impaired and the unsaturated fatty acids are extensively saturated in the rumen. One strategy has been to include unsaturated fatty acids in a form, protected from microbial digestion in the rumen (Harvatine et al., 2005 and Garg et al., 2012). This resulted in the production of milk fat with greatly increase concentrations of PUFA from which low melting point butter was produced. This product was predisposed to oxidative deterioration. More recently whole oilseeds have been fed to dairy cows. The unsaturated 18-carbon fatty acids in these seeds are hydrogenated in the rumen but activity of a Δ9 desaturase, mainly in the mammary gland; convert the stearic acid (18:0) to the MUFA, oleic acid (18:1). Milk fat rich in oleic acid is softer than conventional milk fat allowing the manufacture of a more spreadable butter (Jakobsen et al., 2009). MUFA in the diet have been shown to have beneficial effect on the plasma lipoprotein indicators of coronary heart disease risk. From a human nutrition point of view it could be considered beneficial to incorporate the long chain ω-3 fatty acids, eicosapentanoic acid (C20:5) and docosahexanoic acid (C22:6), in milk fat. The principal source of these fatty acids is fish oil but research to date indicates that their transfer into milk fat is inefficient (Murphy, et al., 2000). The nutritional manipulation of animal diets is the promising area for ideal milk fat production from the dairy cattle. There are different feeding management strategies as follows,

a) **Effect of feeding pasture:** Pasture feeding generally increases the concentration of beneficial fatty acids like CLA. Dhiman et al.(1999) conducted trial with dividing animal into 3 groups. One group fed 1/3 pasture, second fed 2/3 pasture and third fed only pasture. They found that milk yield, 3.5 % fat corrected milk yield and saturated fatty acid content were significantly higher in the group fed 1/3 pasture where as CLA, C18:3, others FA were significantly higher in the group fed only pasture.
The research study conducted on cows fed on pasture reveals the importance of endogenous synthesis of cis-9, trans-11 CLA in milk fat. In this study milk yield decreased after infusion of sterculic oil 1.1 kg/d whereas it increases after supplementation of sunflower oil at the rate of 1.7 kg/d. The CLA content was higher in the group fed pasture only and pasture and 450g/d sunflower oil supplementation (Kay et al., 2004). In another study effect of fed either fresh alfalfa or alfalfa silage diet on milk yield, composition and FA profiles (g/100 g milk fat) milk was studied. They concluded that mono unsaturated, polyunsaturated, total n-3 and n-6/n-3 were significantly higher and saturated fatty acid was significantly decreased in the group fed fresh alfalfa compared to the group fed ensiled alfalfa (Whiting et al., 2004).

b) Influence of forage: concentrate ratio: Increase forage to concentrate ration in feeding of animals also have positive effect on increasing the concentration of desirable fatty acids. Dhiman et al. (1999) reported that cows were fed four different roughage to concentrate ratios and examined the effect on milk yield and composition of milk in cows. They concluded that the unsaturated fatty acids were significantly higher in the treatment group fed 98.2 percent coarse chopped grass hay than other groups fed mixed ration of grains and grass hay. Fat percent and C18:3 fatty acids were significantly higher in this group.

Jiang et al. (1996) fed three groups of cattle to examine effect on the milk yield, composition and FA content of cow milk. Vaccenic acid (trans-11-18:2) and cis-9, trans-11-C18:2 were significantly higher in the treatment group fed restricted diet with 35:65 forage to concentrate ratio than other groups.  

c) Influence of dietary ingredients: Studies with different feed ingredients also showed that certain feed ingredients are responsible for increase in concentration of beneficial fatty acids in milk. Dayani et al. (2003) examined the effect of feeding soybean and sunflower seeds on milk yield & its composition. The fat and linoleic acid content were significantly higher in the group fed soybean seeds where as 16:1(trans-9), 16:1(cis-9), 17:0, 17:1 (cis-9) fatty acids significantly higher in the group fed sunflower seeds. The CLA yield increased by 55 percent in the group fed sunflower seeds.

Reklewska et al., (2002) used 21 g linseed (equivalent of 7.8 g fat) and 21 g mineral mixture and examined effect on decreased the cholesterol and increase the PUFA in the milk fat by dividing animals into two groups. They found decreased cholesterol content by 15 percent, decrease saturated fatty acid content by 8.8 percent and increased unsaturated fatty acid, CLA and linolenic acid content by 14, 83 and 30 percent respectively. It has also been found that substance like sapogenins, which occurs in Fenugreek decreases circulating blood cholesterol in species like rat and humans (Mir et al., 1997) and usually not get destroyed in the rumen (Shah et al., 2004).

Shah et al. (2004) fed fenugreek seeds to cattle and determined the organoleptic acceptability of milk and milk cholesterol content and production parameters. There was no change in milk constituents but functional fatty acid like 18:2 (C9,C12,19:0,18:3(C6,C9,C12),CLA yield (g/d), 18:3(C9,C12,C15) were higher whereas hypercholesterolemic, (C12:0,C14:0 & C16:0), medium chain(FA C14:0-C17:1), cholesterol mg/g fat decreased in group supplemented with 20 percent fenugreek seed than the control group.

Lawless et al. (1998) fed cows on pasture and full fat soybean or full fat rapeseed supplement or fed unmolasses sugar beet pulp (is a sugar beet pulp with no added molasses having high soluble fibre content and used for feeding of horses) examines effect on milk yield and composition and fatty acid profile of cow milk. They concluded that by feeding full fat soybean and full fat rapeseed the CLA content of milk was increased by 27 and 60 percent respectively. Mewara et al. (2008) examined the effect of soybean oil supplementation (at the rate of 2, 4 and 6 percent level) on milk yield and fatty acid concentration in the milk fat (g/100g). Fat, lactose and unsaturated fatty acid content was significantly increased while saturated fatty acid decreased in the group supplemented with 4 % soybean oil than other groups with 2 and 6 percent soybean oil. Depeters et al. (2001) conducted a trial where experimental cows were fed with canola oil in diet, infused canola oil ruminally, and infused canola oil abomasally and examined the effect on production performance and FA profile of milk. They found that fat percent and C18:2, C18:3 were
significantly higher in the group where canola oil infuse was infused abomasally than other groups. Zheng et al. (2005) examined the effect of different vegetables oils like cottonseed, soybean, corn oil on milk yield, milk composition and fatty acid of milk fat. The fat percentage was significantly \( p < 0.01 \) lower in the entire group supplemented with cottonseed, soybean and corn oil than control group. The C18:1 trans-11 and CLA cis-9, trans-11 percent was significantly \( p < 0.01 \) higher in the milk of group soybean oil supplemented group than other groups. Dhiman et al. (2000) conducted a research trial in which cows are fed with diets rich in linoleic and linolenic acids. They fed raw cracked soybean, roasted cracked soybean, soybean oil and linseed oil in different groups. They concluded that fat percent was significantly higher in the raw cracked soybean supplemented group than other groups. CLA yield was significantly higher in the group supplemented with soybean oil. C18:1 was significantly higher in the group supplemented with Linseed oil at 4.4 percent level. Kelly et al. (1998) used Peanut, sunflower and linseed oil at 5.3 percent level in the diet and examined the effect on milk yield and fatty acid composition in dairy cows. They concluded that protein, 18:1, CLA was significantly \( p < 0.001 \) higher in the group supplemented with sunflower oil. Bharathan et al. (2008) examined the effect of fish oil (0.5 percent) and corn distiller soluble (10 percent) by dividing the cattle into four groups on milk yield and composition as well as fatty acid of cows milk. They concluded that fat percent was significantly \( p < 0.001 \) higher in control group than that of the other group. The total CLA, total USFA and long chain FA were significantly \( p < 0.001 \) higher whereas total SFA, short chain FA and medium chain FA were significantly \( p < 0.001 \) lower in the milk of group supplemented with corn distiller soluble (10 percent) than other groups. Shingfield et al. (2006) fed fish oil and sunflower oil in the diet of dairy cows and examined the effect on milk yield, composition and FA of milk. They concluded that fat, protein, total C14 saturated fatty acids were lower but fatty acid like total MUFA and total PUFA, EPA, DHA, vaccenic acid and CLA were significantly \( p < 0.001 \) higher in fish oil supplemented group.

Whitlock et al. (2006) fed different diets supplemented with soybean and fish oil. They concluded that medium, long, saturated and unsaturated fatty acids was significantly \( p < 0.001 \) higher in the group supplemented with 0.33% fish oil and 1.67% fat from extruded soybean than other groups. Abu Ghazaleh et al. (2004) fed a CLA stimulating diet for an extended period of time and examined the effect on milk cis-9, trans-11 CLA and vaccenic acid (VA) concentrations by feeding animal into two groups one has control and other treatment group in which diet contained fish meal and extruded soybean (0.5% fish oil and 2.0% soybean oil from extruded soybeans). They concluded that milk fat, short and medium chain FA significantly \( p < 0.001 \) decreased but milk yield, C20:5(EPA), C22:6(DHA), long chain fatty acid significantly \( p < 0.001 \) increased in the treatment as compare to control group.

Petit et al. (2003) examined the effect of formaldehyde treated oil seeds on milk yield and composition of milk from cows. They concluded that 2.04% of formaldehyde increase milk production by an average of 2.65 kg/d but it was not effective in protecting PUFA against ruminal biohydrogenation. While feeding of flaxseed containing rations resulted in the lowest \( \omega-6 \) to \( \omega-3 \) fatty acid ratio.

**d) Influence of feeding protected fat:** Different studies revealed that bypass or protected fat can influence the fatty acid composition in positive way. Chouinard et al. (2001) examined the effect of Ca salts of FA from different plant oils. They concluded that CLA was significantly \( p < 0.001 \) higher in the group supplemented with calcium salt of soybean oil.

Schroeder et al. (2003) fed following different diets to dairy cattle to examine the effect on milk yield and composition and fatty acid profile in milk fat of dairy cows. Different diets were TMR (Total mixed ration), P corn (Pasture plus corn based concentrate) P Fat (Pasture plus corn based concentrate with Ca salts of fatty acids). They concluded that milk fat and protein percentage were significantly \( p < 0.001 \) higher in the group diet offered total mixed ration. CLA and total long chain FA were significantly \( p < 0.001 \) higher, whereas total short chain, medium chain and saturated: unsaturated ratios were significantly lower in the group offered diet fat as per mention above (Table 1).
TABLE 1: Effect of feeding TMR (Total mixed ration), P corn (Pasture plus corn based concentrate) P Fat (Pasture plus corn based concentrate with Ca salts of fatty acids) on milk yield and composition of dairy cows.

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment</th>
<th>TMR</th>
<th>PCorn</th>
<th>PFat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk yield, kg/d</td>
<td></td>
<td>20.2</td>
<td>19.2</td>
<td>20.2</td>
</tr>
<tr>
<td>Milk fat, %</td>
<td></td>
<td>3.91ª</td>
<td>3.45b</td>
<td>2.56c</td>
</tr>
<tr>
<td>4 % FCM , kg/d</td>
<td></td>
<td>19.5ª</td>
<td>17.8ªb</td>
<td>16.1ªb</td>
</tr>
<tr>
<td>Protein, %</td>
<td></td>
<td>3.70ª</td>
<td>3.49ªb</td>
<td>3.41ªb</td>
</tr>
<tr>
<td>Lactose, %</td>
<td></td>
<td>5.06</td>
<td>4.88</td>
<td>4.79</td>
</tr>
</tbody>
</table>

FA, g/100 FA

- Total short chain: 11.9ª, 10.4ªb, 8.85b
- Total medium chain: 56.5ª, 47.6ªb, 41.0c
- CLA: 0.41ªbc, 1.12ªb, 1.91ªb
- Total long chain: 40.1ªb, 39.5ªb, 51.4ªb
- Saturated: Unsaturated: 69.29ª, 64.32ªb, 53.42ªbc

**CONCLUSION**

Modified fats in the milk have certain health benefits to tackle ever increasing ailments like heart attack. Conjugated linoleic acids (CLA) are examples of healthy fatty acids in foods derived from ruminants shown to have anti-carcinogenic properties and possibly other effects like antiatherogenic, antidiabetic and immune stimulatory that would be positive for human health. Nutritional intervention of feeds and feeding of livestock can create opportunities to modify the composition of milk fat from dairy animals and to improve milk fat's nutritional and health benefiting properties. Different beneficial fatty acids like those of C18:1, C18:6 and C18:3 and PUFA can be augmented in animals fed on different feeds like fresh alfalfa, linseed meal, fenugreek seeds, soybean oil, fish oil, sunflower seed, flaxseed, heat treated full fat soybeans and with monensin supplementation. These different experiments can serve as building blocks on which suitable nutritional strategy can be chalked out for production of milk with increased content of beneficial fatty acids which will not only serve the purpose of healthy designer milk for consumers but also can be used as a value added tool for increasing the profits of livestock farmers.

**REFERENCES**


**e) Influence of feed processing**: Feed processing like extrusion of feed have positive effect on fatty acid concentration of milk. Chouinard et al. (2001) concluded that the CLA yield was significantly higher in cows fed with micronized soybean (MSB) and soybean extruded at 140°C.

**f) Influence of feed additives**: Feed additives like monensin antibiotic can also affect milk fat composition in desirable way. Da Silva et al. (2007) fed diet containing whole or ground flaxseed with or without monensin to dairy cows and examined the effect on milk yield, composition and fatty acid of milk. They observed that the functional fatty acid viz. trans-11-18:1, PUFA, MUFA were significantly higher in the group fed ground flaxseed with monensin than other groups and SFA were increased in the milk of cow fed whole flaxseed without monensin.

Bell et al. (2006) conducted two trials to examine the effect on milk yield, milk and FA (g/100 g of FA) composition of cow milk. They concluded that cis-9, trans-11 CLA were significantly (p<0.05) higher in the group fed safflower oil plus monensin than other groups. The CLA content was significantly (p<0.05) higher in the group fed safflower oil plus monensin plus vitamin (6 % + 24 ppm/kg + 150 IU/kg).


Harvatine, K. J. and Allen, M. S. (2005). The Effect of Production Level on Feed Intake, Milk Yield, and Endocrine Responses to Two Fatty Acid Supplements in Lactating Cows. J. Dairy Sci. 88:4018-4027


