

Functional Milk: Nutritional Engineering with CLA and Omega-3

P. Hemasundar, G.K. Choudhury, K. Sethy* and S.P. Satapathy

Department of Animal Nutrition, C.V.Sc and AH, Odisha University of Agriculture and Technology, Bhubaneswar, 751003, Odisha

*Corresponding author: ksethy@ouat.ac.in

doi.org/10.5281/TrendsInAgriculture.22862539

Introduction

Milk is the most promising food in human nutrition that supplies all the essential nutrients like carbohydrate, fat, protein, essential mineral and vitamins irrespective of age groups. For this reason, milk is also considered as a complete food. Functional milk, in a broad way, is defined as a form of milk that is designed to meet the precise nutrient requirement and physiological need of specific age group or persons as compared to conventional milk. Functional milk has much more nutrient benefits than traditional milk in terms of mineral and vitamin composition, energy contribution, protein and fat percentage etc. Among these nutrient modifications, milk fat modification has more significance because milk fat is not considered merely as a energy source for the consumers but also it affects the nutritional characteristics of processed dairy products prepared from milk. There are various ways to increase the nutrient quality of milk such as incorporation of bioactive agents, animal genetics, animal nutritional modification and processing of milk in a specific manner. Among these cited techniques, animal nutritional modification sounds more suitable as it allows the modification in a natural manner rather than addition of nutrients post lactation.

Modification of milk fat composition is the main target of nutritional engineering. Naturally, milk is rich in many saturated fatty acids but the proportion of PUFA (poly unsaturated fatty acids) is comparatively lower. From human nutrition point of view, PUFA are essential fatty acids. Hence major objective in nutritional engineering is to increase the PUFA content of milk especially Conjugated Linoleic Acid (CLA) and Omega-3 fatty acids. Recent reviews have established that changes in forage, vegetable oils, oilseeds, fish oil and other lipid sources can substantially modify milk-fat composition (Chilliard *et al.*, 2007; Shingfield *et al.*, 2010). CLA is a bioactive lipid that is generated via ruminal metabolism but omega-3 enrichment needs dietary supplementation to the lactating animals.

Conjugated linoleic acid

This is a broad term covering all the positional and geometric isomers of linoleic acid containing conjugated double bond. Approximately 28 CLA isomers have been described, although cis-9, trans-11 CLA and trans-10, cis-12 CLA receive the greatest scientific attention (Gebereyowhans, 2024). Naturally rumen products are rich in cis- 9 and trans- 11 CLA which is known as Rumenic Acid.

Nutritional strategy for CLA enriched milk

1. Feeding oil seeds and vegetable oils

Dietary lipid supplementation is one of the easiest approaches to modify milk CLA. Linseed, soybean, sunflower, canola and other oilseeds provide substantial quantities of C18 PUFA. Their incorporation into dairy rations modifies the process of ruminal biohydrogenation and increases the supply of intermediates that can contribute to milk CLA synthesis. It has been observed that linseed supplementation can increase total milk CLA by approximately 1.8–2.5 times (Gebereyowhans, 2024). The exact response to nutritional supplementation, depends on the form of the oilseed. Whole seeds, extruded seeds and free oils do not necessarily produce identical outcomes. Extrusion may increase lipid accessibility and digestibility, but greater ruminal exposure can also alter the biohydrogenation pathway.

2. Pasture based feed supplementation

The major volatile fatty acid responsible for the milk fat synthesis is Acetic acid, which is produced upon the fibre digestion. By giving more roughage to animal, the milk fat synthesis can be intensified. Hence pasture based feeding helps in the enrichment of milk with PUFA as pasture feed are poor in saturated fatty acid. It has been observed that pasture feeding generally decreases saturated fatty acids and increases favourable fatty acids such as 18:3n-3 and cis-9, trans-11 CLA (Chilliard *et al.*, 2007). Pasture acts as an efficient mechanism for production of functional milk but seasonal availability, geographical conditions, animal productivity and pasture quality can lead to substantial variability.

3. Fish oil and marine feed implementation

Fish oil acts in both ways for enrichment of milk. Firstly, it adds long chain omega-3 fatty acids like EPA and DHA. Secondly, it interferes with ruminal biohydrogenation and prevents the accumulation of ruminal biohydrogenation intermediaries which leads to addition of CLA in milk. Fish oil can inhibit the final biohydrogenation of trans-18:1 intermediate to stearic acid, thereby increasing the availability of vaccenic acid for mammary conversion to cis-9, trans-11 CLA.

Omega-3 enrichment in milk

These are the essential fatty acids required for body growth. The major omega-3 fatty acids are α -linolenic acid (ALA; 18:3n-3), eicosapentaenoic acid (EPA; 20:5n-3), docosapentaenoic acid (DPA; 22:5n-3), docosahexaenoic acid (DHA; 22:6n-3). Flax seeds act as a chief source for ALA whereas EPA and DHA sources are commonly associated with marine foods and micro algae. In conventional milk the proportion of these fatty acids are very low. The mean total n-3 PUFA values of approximately 0.52 g/100 g fatty acids in Holstein milk, 0.44 g/100 g in Jersey milk and 0.25 g/100 g in buffalo milk (Huang *et al.*, 2024).

Strategy for enrichment of omega-3 fatty acid

1. Flax seed feeding

It acts as a crucial source of α -linolenic acid (ALA; 18:3n-3). Therefore, feeding different forms of flax seeds increase the ALA content of milk (Huang *et al.*, 2024). But it does not help in increasing the EPA and DHA content for which reason feeding flax seed can't be the whole solution in enrichment of omega-3 fatty acids.

2. Feeding fish oil and micro algae

These are the sources of EPA and DHA. There are certain microalgae which are particularly rich in DHA and hence provides a more direct enrichment of DHA in milk bypassing the secondary enrichment by elongation and destruction of ALA. Fish oil and marine algae can increase long-chain PUFA in ruminant products, but the enrichment of 20- and 22-carbon PUFA in milk remains relatively modest because of ruminal metabolism and tissue handling (Shingfield *et al.* 2010).

Simultaneous enrichment CLA and omega-3 fatty acid

These are not the competing objects rather there are certain feeds that increase the concentration of both simultaneously. A combination of fish oil with plant oils (linseed, sunflower, soyabean) helps in increasing CLA along with ALA, EPA, DHA. Plant oils supply substrate for CLA producing ruminal microbiome whereas fish oil prevents the biohydrogenation of trans-11 intermediates. In bovine and ovine, fishmeal has been reported for increasing EPA and DHA and reduces the saturated fatty acid percentage (Gebereyowhans 2024).

Challenges

One of the major challenges is depression in milk fat. Milk fat determines the market quality of milk and the revenue generation from selling milk. Supplementation of PUFA in both higher side and lower side alters the ruminal biohydrogenation process and leads to depression of milk fat. The oxidative threshold of milk gets declined i.e. it becomes more prone

to oxidative damage during processing, storage and transport. These post collection losses affect the profit and revenue from milk to a great extent. The main reason of oxidative instability is the increased concentration of PUFA which is the most available substrate for lipid oxidation. Huang *et al.* (2024) specifically reviewed the effect of dairy processing on virgin n-3 PUFA and highlighted the importance of controlling thermal treatment and prolonged exposure to elevated temperatures. Oxidation of fatty acids leads to the formation of aldehydes, ketones and other secondary oxidation products responsible for undesirable flavours and potentially reduced nutritional quality.

Ruminal biohydrogenation and post absorptive metabolism appear as a barrier between supplemented PUFA and appeared PUFA in milk. Very less percentage of PUFA is appeared in the milk as compared to the supplemented amount. It has been observed that n-3 fatty-acid transfer efficiency to milk averaged approximately 47%, compared with 39% for n-6 fatty acids (Jenkins *et al.*, 2008). Importantly, the n-3 treatment produced positive carryover effects after infusion stopped (Neto *et al.*, 2025). The most crucial challenge is the economic cost of the flaxseed, fish oil, micro algae etc. Protected fat technology increases the feed cost and leads to high input. On the other hand, the value of functional milk i.e. output is determined by the market demand. Hence it is a riskier approach for the small and marginal dairy farmers.

Future prospective

The future aspects of functional milk depend upon the integration of various determinants like animal nutrition, rumen biochemistry, lipid structure and human nutritional requirement (Lawson *et al.*, 2001). A better understanding of these variables ensures targeted manipulation of microbial lipid metabolism rather than high dietary supplementation. The concept of protected and encapsulated lipids allows the selected fatty acids to bypass the ruminal degradation and secure delivery at intestinal site for absorption. Some study provides experimental proof that post-ruminal delivery can markedly alter milk n-3 fatty-acid transfer, with approximately 47% transfer efficiency for the infused n-3 treatment. The idea of complementary dietary strategy of enriching milk with Omega-3 fatty acid and CLA simultaneously is far better than enriching separately. In this aspect, combination of fish oil and plant oil gives the best result.

Conclusion

Functional milk represents an important transition from conventional food production towards nutritional engineering at the farm level. The most promising strategy is therefore not simply to "feed more fat", but to engineer the pathway through which dietary fatty acids move from feed to rumen, intestine, blood, mammary gland and finally milk.

References

- Chilliard, Y., Glasser, F., Ferlay, A., Bernard, L., Rouel, J. and Doreau, M. 2007. Diet, rumen biohydrogenation and nutritional quality of cow and goat milk fat. *European Journal of Lipid Science and Technology*, 109(8): 828-855.
- Gebereyowhans, S. 2024. Potential strategies to enhance conjugated linoleic acid content of milk and dairy products: a review. *Heliyon*, 10(19): e38844
- Huang, G., Li, N., Wu, X., Zheng, N., Zhao, S., Zhang, Y. and Wang, J., 2024. Nutrition, production, and processing of virgin omega-3 polyunsaturated fatty acids in dairy: An integrative review. *Heliyon*, 10(22): e39810.
- Jenkins, T.C., Wallace, R.J., Moate, P.J. and Mosley, E.E. 2008. Board-invited review: Recent advances in biohydrogenation of unsaturated fatty acids within the rumen microbial ecosystem. *Journal of Animal Science*, 86(2): 397-412.
- Lawson, R.E., Moss, A.R. and Givens, D.I. 2001. The role of dairy products in supplying conjugated linoleic acid to man's diet: a review. *Nutrition Research Reviews*, 14(1): 153-172.
- Neto, J.M., Worden, L.C., Boerman, J.P., Bradley, C.M. and Lock, A.L. 2025. Long-term effects of abomasal infusion of linoleic and linolenic acids on the enrichment of n-6 and n-3 fatty acids into milk fat of lactating cows. *JDS Communications*, 6(2): 206-211.
- Shingfield, K.J., Bernard, L., Leroux, C. and Chilliard, Y., 2010. Role of trans fatty acids in the nutritional regulation of mammary lipogenesis in ruminants. *Animal*, 4(7): 1140-1166.