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Economic Importance and Management Strategies for Alleviation of Milk Fat Depression in Dairy Animals: A Review

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ABSTRACT

Dairying is an important service sector in India, contributing 4.11 per cent to national GDP and provides secondary occupation to 69.00 per cent of the farming community. From the decades there is a major concern and research mainly focused on increasing the milk yields while milk fat per cent is largely being ignored. As a result, FSSAI had to decrease cow milk standards by 0.30 per cent from average 3.50 per cent milk fat to 3.20 per cent. Milk fat per cent is the important determinant of milk price both in unorganized and organized sector. Per unit (0.10 per cent) of decrease in milk fat per cent can incur a direct loss of 1.66 per cent to dairy farmer's income. Milk fat depression is largely a nutrition related metabolic disorder and *trans*-10, *cis*-12 CLA isomer has been found to be chief culprit. It is a less attended metabolic disorder in India; which is causing huge losses to the dairy farmers. Not a single factor is responsible for it and generally due to lack of adequate nutritional and management knowledge, farmers are unable to identify and cure this multi factorial disorder. Milk fat depression can be influenced and managed by different factors like particle size of feed / fodder, feed processing, ionophores, dietary fatty acid intake, conditions that cause decrease in rumen pH and overcrowding *etc*.

Key words: Dairy, Dairy farm management, Economic loss, Milk fat depression.

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From the last few decades there is constant concern for increasing milk production by improved genetic selection, breeding programmes, nutrition and other management practices. Nutritional changes have resulted in improved milk production but decreased milk fat percentage under certain situations. Fat is a major contributor to the energy density of whole milk and is essential to many of the physical properties, manufacturing qualities and organoleptic characteristics of dairy products. Milk fat percentage is important to farmers and consumers as it is one of the key factors for deciding milk price almost everywhere in India and consumer's attitude towards dairy product can also affected by its composition and flavor. Moreover, it also forms a significant portion of the energy cost of lactation. First described over 150 years ago, Milk Fat Depression (MFD) or low-fat milk syndrome is a metabolic disorder which is characterized by a decrease in milk fat yield of up to 50.00 per cent, with no change in milk yield or in the yield of other milk components (Bauman and Griinari, 2001). It was first reported by French chemist Jean Baptiste Boussingault in 1845, who observed that when beets were fed to dairy cow butterfat was reduced (Bauman and Griinari, 2003).

Economic importance of milk fat depression

India is world's largest milk producer since 1998 with 70 million small scale producers. These milk producers pour their surplus milk either at cooperatives or to other agencies and so, milk is an important source of income and nutrition to rural households. A total 94,000 tons of dairy products worth 290 million US$ were exported from India in 2018 and butter / dairy fats accounted for 65.00 per cent by volume of this. Both in open market as well as in organized sector, price of milk is largely affected by milk fat percentage besides yield and SNF per cent. As per our knowledge, there is no data available on milk fat depression in Indian dairy animals but it is a fact that FSSAI (2017) has revised its standard for cow milk fat percentage from 3.50 per cent (for most states) to 3.20 per cent (for all India) in just seven years after previous guidelines issued in 2010. Average milk fat per cent in high yielding breeds like Sahiwal, Murrah and Karan Fries is 3.97 per cent, 6.98 per cent and 3.29 per cent, respectively (Saroj, 2015) and there is difference of 1.00 per cent, 0.66 per cent and 0.61 per cent, from ICAR (2011) data for Zebu cattle, Buffalo and cross breed cattle respectively, which should be further studied and verified. So, assuming the unobserved decrease in milk fat percentage in above three dairy animal species is prevailing in India, on an average 1.66 per cent increase in dairy farmer's direct income can be assured by per 0.10 per cent increase in milk fat as shown below in Table 1 (based on the following considerations): Milk production in India is

Table 1: Economic analysis of milk procurement price in normal and milk fat depression situation

	Market milk contribution/ year (MT)	Avg. milk fat per cent	Milk procurement price (Rs. in crores / year)	Milk fat depression by 0.10 per cent	Milk procurement price (Rs. in crores / year)
Buffalo	47.83	7.64	259427.14	7.54	256031.49
Zebu	20.50	4.97	72327.20	4.87	70871.92
Cross bred/exotic	26.35	3.90	72971.68	3.80	71100.61
Total			404726.01		398004.03
% Decrease in income					1.66

187.75 MT per annum (BAHS 2019). 52.00 per cent of household milk is marketable surplus (NAP, 2018) (only this portion is considered for calculating economic impact of MFD). Contribution of buffalo, indigenous cow and cross bred / exotic cow to total milk production of India as 49.00, 21.00 and 27.00 per cent, respectively (DAHandD, 2019). Average milk fat per cent is 7.64, 4.97 and 3.90 for buffalo, zebu and exotic cattle (ICAR, 2011). Average milk yield of Buffalo, Indigenous and cross bred cattle is 6.19 kg, 3.73 kg and 7.61 kg, respectively (DAHandD, 2019). Standard milk procurement price of Rs. 710 per kg milk fat (AMUL, 2019) calculated on pro-rata fat basis. There is assumed milk fat depression of only 0.10 per cent in all three species. In other words, in a herd of 50 buffaloes, indigenous and crossbred milch animals, there is loss of around Rs. 220, 132 and 270 per farm per day, respectively. This clearly indicates the strength of milk fat percentage in Indian economy. So, it is very important to understand the causes of milk fat depression and nutritional interventions for its alleviation.

Milk fat synthesis and influence of nutritional factors

During early days, origin of milk fat was the topic of debate *i.e.,* whether wholly from diet or synthesized by the animal (Jordan and Jenter, 1897). A leading theory based on empirical observations was put forward by eminent lipid chemist, Hilditch (1947), which states that short chain fatty acids arise from the degradation of oleic acid. Ruminant milk contains more than 400 different fatty acids and is largely attributed to extensive lipid metabolism in rumen (Jensen, 2002). Fatty acids in milk arise from two sources, uptake from circulation and de-novo synthesis in mammary epithelial cells (Fig 1) (Bauman and Davis, 1974; Dils, 1986; Neville and Picciano, 1997). Short-chain fatty acids (4 to 8 carbons) and medium-chain fatty acids (10 to 14 carbons) almost exclusively arise from de novo synthesis. Long-chain fatty acids (>16 carbons) are derived from the uptake of circulating lipids, and fatty acids of 16 carbons in length originate from both sources. Average ratio of different fatty acids in cow milk are 19.00, 19.00, 35.00 and 27.00 per cent for short chain, medium chain, long chain and 16 carbon fatty acids, respectively (Jensen, 2002). So, understanding the source of fatty acids can help to better understand effect of dietary or rumen metabolism on composition of milk fat.

For de-novo synthesis of fatty acids, ruminants utilize acetate produced by rumen fermentation of carbohydrates as the major carbon source instead of glucose that is used by non ruminants. In addition, β-hydroxybutyrate, produced by the rumen epithelium from absorbed butyrate, provides about one half of the first four carbons of de novo synthesized fatty acids in the ruminants. Preformed fatty acids used for milk fat synthesis are derived from circulating lipoproteins and NEFA that originate from dietary absorption and mobilization of body fat reserves, respectively (Barber *et al.,* 1997; Bauman and Davis, 1974). When cows are not in negative energy balance, proportion of fatty acids from body reserves account for less than 10.00 per cent of milk fat. Over 95.00 per cent of these fatty acids by mass occur as triglycerides while remaining as phospholipids, cholesterol ester, di-glycerides, mono-glycerides and free fatty acids. Finally, due to hydrophobic nature of esterified fatty acids, milk fat is covered by protein rich polar lipid coat called milk fat globule membrane (MFGM) and is secreted from myoepithelial cells (Keenan, 2001; Mather and Keenan, 1998; Olivier-Bousquet, 2002).

Mechanism of action

Over the time, different theories have been put forwarded to explain the MFD phenomenon (Koch and Lascano, 2018).

1. Acetate and butyrate theory

This precursor-product theory was first introduced by Tyznik and Allen (1951). According to this, due to inadequate rumen fermentation, amount of acetate and butyrate production is reduced which leads to decreased milk fat synthesis (Bauman and Griinari, 2003). It was found that oil supplementation also resulted in decreased milk fat without changes in VFA concentration (Tyznik and Allen, 1951). This theory was disapproved in a number of studies where infusion of acetate didn't cause any change in milk fat concentration or infusion of glucose or propionate caused low milk fat (McClymont, 1950). However, under normal conditions when milk fat depression is not there, acetate appears to alter the milk fat percentage.

2. Glucogenic-Insulin theory

This theory was proposed by McClymont and Vallance (1962). According to this theory, high ruminal propionate concentration and rate of hepatic gluconeogenesis can result in increased circulating insulin spike and due to insulin induced response, precursors for milk fat synthesis may be limited. However, in mammary gland of ruminants, insulin is responsible for normal mammary cell function maintenance and requires only small amount of insulin and moreover insulin level in mammary gland in not affected by diet induced fluctuations in insulin level. Increased insulin level may cause increased movement of acetate, β hydroxybutyrate from mammary gland and their utilization along with dietary LCFA at adipose tissue level. There by causing shortage of milk fat precursors in mammary gland (Bauman and Griinari, 2003). Bauman *et al*. (2008) reported that in negative energy balance, MFD repartition energy for protein and milk synthesis. So, reported MFD in those studies is not due to glucose-insulin theory but due to energetic balance. So, it can be stated that if the animal is in negative energy balance during lactation, then it is susceptible to MFD. That may be one of the reasons for improved milk fat per cent after bypass fat / fat supplementation, as practically observed in some cases.

3. Vitamin B12/Methylmalonate theory

This theory was put forwarded by Frobish and Davis (1977). It is based on reduced production of vitamin B_{12} along with increased production of propionate, would cause accumulation of methylmalonate in liver that would travel to mammary gland and inhibit de novo synthesis of fatty acids by down regulating Acetyl-CoA carboxylase (ACC) and Fatty acid synthase (FAS). It was supported by Walker and Elliot (1972) but Elliot *et al.* (1979) and Croom *et al.* (1981) failed to correlate vitamin B_{12} and MFD.

4. Trans fatty acid theory

This theory was first given by Davis and Brown (1970) when they found that *trans* C18:1 increased in milk fat with variety

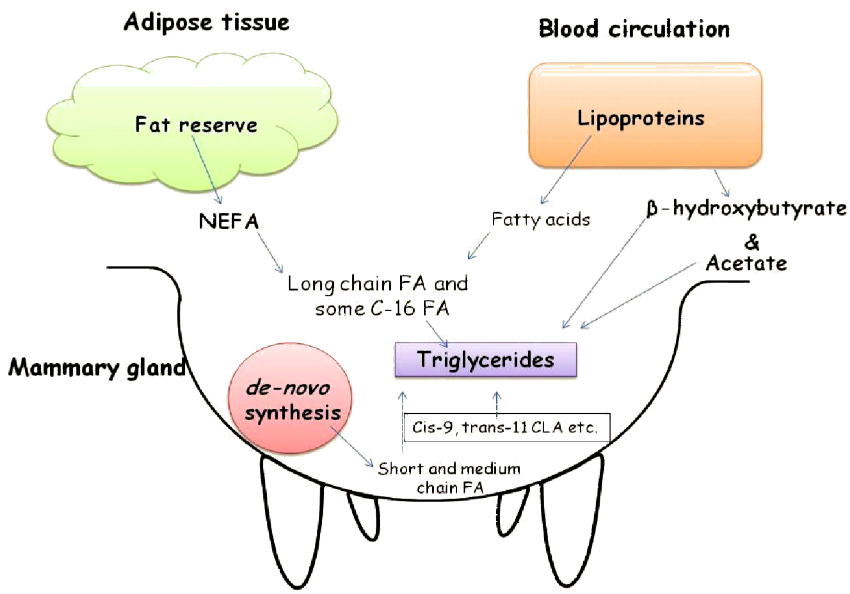

Fig 1: Pathway for milk synthesis in mammary glands of ruminants.

Table 2: Composition of different vegetable oils which are usually/can be used a supplement by farmers is as below table (values are per cent by weight of total fat) (USNND-2016, Nutritiondata.com, *USDA 2020).

Type	Saturated		Unsaturated FA		Polyunsaturated FA	
	FA	Total	Oleic acid	Total	α- Linolenic acid	Linoleic acid
Sunflower	10.3	19.5	19.5	65.7	0	65.7
Soybean	15.6	22.6	22.6	57.7	7.0	51.0
Safflower	-+7.5	75.2	75.2	12.8	0	12.8
Peanut	20.3	48.1	46.5	31.5	-	31.4
Palm	49.3	37.0	40	9.3	0.2	9.1
Palm (hydrogenated)	88.2	5.7	-	0	-	-
Linseed	9.0	18.4	18	67.8	53.0	13.0
Cottonseed	25.9	17.8	19	51.9	1	54.0
Coconut	82.5	6.3	6	1.7	-	-
Mustard*	11.6	59.1	11.6	21.2	15.3	5.9
Canola	7.4	63.3	61.8	28.1	9.1	18.6

of diets fed that caused MFD (Erdman,1999; Gaynor *et al*., 1994 and 1995). Davis and Brown (1970) recognized that concentration of *trans* - C18:1 FA increased in milk fat of cows with low-fat milk syndrome due to incomplete biohydrogenation of unsaturated fatty acids. This relationship was later confirmed in subsequent studies by Bauman and Griinari (2001 and 2003); Shingfield and Griinari (2007). Trans C18:1 is the intermediate in biohydrogenation of linoleic and linolenic acid and most predominant trans octadecoenoic acid isomer in milk fat (Walstra and Jenness, 1984). *Trans* 10C18:1; which is produced from ruminal biohydrogenation of linoleic acid and was important isomer in causing MFD (Griinari *et al*., 1998). This FA does not directly control milk fat production but it may respond to dietary factors (Fuentes *et al*., 2009). Most of current studies have negatively correlated the *Trans* 10 C18:1 fatty acid to milk fat and is the basis for acting as proxy for identifying MFD.

5. Biohydrogenation theory

This theory was put forwarded by Griinari and Bauman (1999) and most current and widely accepted theory of MFD. Unsaturated fatty acids are toxic to many rumen bacteria so lipid undergoes biohydrogenation through a series of fatty acid intermediates that ultimately result in saturated FA being produced (Fig 2) (Palmquist *et al.,* 2005). According to this theory, under certain dietary conditions, pathways of rumen biohydrogenation changes and produce fatty acid intermediates that reduce milk fat synthesis. Baumgard *et al.* (2000) identified the potential culprit of MFD as the *trans*-10, *cis*-12 CLA isomer. This compound was originally found in fried ground beef with anti-mutagenic properties by Pariza *et al.* (1979, 1983, 1985), and was later found to be CLA with many health benefits. So, in order to increase CLA content in milk fat infusion of a CLA supplement that included a mixture of CLA isomers (predominately *cis*-9, *trans*-11 and *trans*-10, *cis*-12 CLA) was tried but severely reduced milk fat (Chouinard *et al*., 1999). Further work by Baumgard *et al.* (2001) and Peterson *et al*. (2002) showed that milk fat yield can be decreased by 40.00 to 50 00 per cent with as little as 10 g/d of *trans*-10, *cis*-12 CLA and Perfield *et al*. (2007) have reported decrease in milk fat yield by 15.00 per cent by infusing 5g/d of trans-9, cis-11 CLA via abomasum. In addition, Baumgard *et al*. (2001) reported changes in milk fatty acid composition and reported a marked decrease in *de novo* fatty acids, a common observation seen with MFD and *trans*-10, *cis*-12 CLA is found to inhibit milk fat synthesis in mammary gland by suppressing responsible gene expression. Dietary supply of PUFA and changes in microbial fermentation leads to diet induced milk fat depression (Griinari *et al*., 1998).

Genetic interactions of trans-10, cis-12 CLA isomer in causing MFD

The concept that *trans*-10, *cis*-12, has been associated with milk fat depression is well accepted and it's believed that it suppresses genes responsible for milk fat production in the mammary gland, such as stearoyl-CoA desaturase 1 (SCD1), fatty acid synthase (FASN), acetyl-CoA carboxylase (ACACA) and glycerol-3-phosphate acyltransferase 6 (AGPT6) (Bionaz and Loor, 2008; Hussein *et al*., 2013). This CLA isomer is potent inhibitor of milk fat synthesis (Baumgard *et al*., 2000) and decreases body fat in chickens and rabbits but not in ruminants suggesting capacity for targeted cellular control (Corino *et al.,* 2002; Hausman *et al.,* 2009; Szymczyk *et al.,* 2001). Although the mechanism

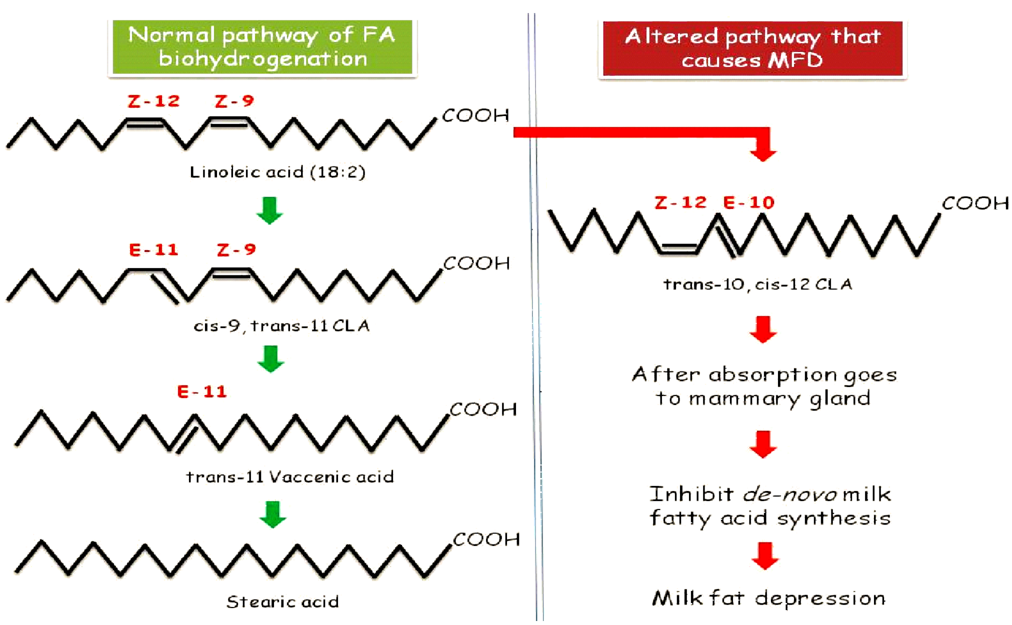

Fig 2: Normal and altered pathways of milk fatty acid biohydrogenation.

by which CLA affects body fat is unknown, it is suggested that it causes a negative energy balance by reducing energy intake, and increasing energy excretion through heat loss (Hausman *et al.,* 2009). By applying nutrigenomics, it is known that the *trans*-10, *cis*-12 CLA isomer is the most potent inhibitor of milk fat synthesis, but *trans*-9, *cis*-11 CLA and *cis*-10, *trans*-12 CLA isomers have also exhibited inhibitory effects only on milk fat synthesis (Perfield *et al.,* 2007; Saebo *et al*., 2005) while other parameters of milk are not affected by these.

Milk fat depression induction and factors affecting it

Diet induced MFD depression can occur by 3-5 days and recovery may take 15-19 days or more. During induction phase, milk fat *trans*isomers like *trans*-11 C18:1 and *cis*-9, *trans*-11 CLA were elevated initially and *trans*-10 C18:1 and *trans*-10, *cis*-12 CLA increased progressively (Rico *et al*., 2013). A decrease of 30.00 per cent or more in milk fat yield can be observed during MFD in just less than 10 days after diet induced changes (Pitta *et al.,* 2016). During induction phase ciliate protozoa and fungi population decreases by 90.00 per cent and increase during recovery phase (Rico *et al.,* 2015a). However, protozoa are directly not involved in biohydrogenation process but they play role in starch sequestration and may alter rumen fermentation (Rico *et al.,* 2015b). *Megasphera elsdenii* which is associated with production of *trans*-10, *cis*-12 CLA is found to increase with induction of MFD (Maia *et al*., 2007, Rico *et al*., 2015b). *Butyrivibrio* which is associated with biohydrogenation of fatty acids can be inhibited by large amount of PUFA in diet (Maia *et al*., 2007). *Lachnospiraceae*, *Butyrivibrio*, *Bulleidia*, and *Coriobacteriaceae* are positively correlated with *trans*-10, *cis*-12 CLA and the *trans*-10 isomer (MFD inducer), suggesting their potential role in altered biohydrogenation reactions (Pitta *et al*., 2016).

Nutritional factors affecting milk fat depression

Particle size

MFD can be induced by feed particle size which influences chewing time, rate of rumination, passage rate, alteration in VFAs and lowering of rumen ph even if qualitative factors like DM or NDF are kept constant. In a study by (Grant *et al*., 1990), where course (3.1 mm), medium (2.6 mm) and fine (2.0 mm) particle sized alfa-alfa silage was fed as 55.00 per cent of dietary DM in form of TMR. Milk production was unaffected but milk fat per cent decreased consistently from course to fine particle size *i.e*., from 3.80 per cent to 3.00 per cent, respectively. In addition, work by O'Dell *et al*. (1968) concluded that grind size of forge at 0.64 cm induces MFD.

Feed processing

Not only a single factor is responsible for MFD but dietary interactions can also lead to it. In a study by Oba and Allen (2003), diets containing high moisture or dry ground corn were fed at high or low starch concentration (average starch was 31.60 per cent and 21.20 per cent of ration DM). At low starch level, there was no significant effect of grain processing on milk fat per cent where as at high starch level, high moisture corn reduced milk fat yield by 15.00 per cent compared to dry ground corn. So, MFD can be induced not only by the change in dietary components but also by their processing or form of presentation to cow.

Ionophores

Ionophores like monensin can affect biohydrogenation as they have ability to shift rumen microbial population (Fellner *et al*., 1997; Rico *et al*., 2014) thus potentially increasing rumen outflow of BH intermediates and result in MFD (Duffield and Bagg, 2000). It should be noted that increased rumen outflow of BH intermediates is not problem but increased passage of alerted BH intermediates can cause MFD. Monensin can increase passage rate of these intermediates to small intestine and risk for MFD (Lock *et al*., 2006b). So, it is advantageous to exclude them from diet susceptible to MFD.

Dietary fatty acid intake

Fatty acid content of most cereals and forages range from 1-3.00 per cent of DM. Majority of these FA are unsaturated fatty acids, mainly oleic, linoleic and linolenic acid. In cereal grains, majority is linoleic acid followed by oleic acid while in forages it is linolenic acid followed by linoleic acid. As unsaturated fatty acids are toxic to some rumen bacterial species so elevating FA in diet can cause a shift in rumen microbial population. This shift can alter carbohydrate and fiber fermentation in rumen (Jenkins, 2002) and accumulation of MFD linked CLA isomers. It is not only the fat supplement that can cause such shift but also the free fatty acids and fatty acids supplied by feed ingredients.

Fat supplementation

As discussed, dietary fatty acid can modify rumen fermentation and alter BH rate and its pathways. Increasing the degree of un-saturation in dietary fat supplementation can also slow down the bio-hrogenation of C18:1 to C18:0 while causing significant decrease in milk fat per cent (Harvatine and Allen, 2006b). Also, long chain n-3 PUFA (particularly docosahexaenoic acid) affect rumen bacteria that catalyze the terminal step in BH, thereby increase the rumen outflow of these intermediates (Abu-Ghazaleh and Jenkins, 2004), though similar FA may have similar effects. Fatty acid profile of different vegetable oils can help us to choose oil for feed supplementation (Table 2).

RUFAL (Rumen Unsaturated Fatty Acid Load) term coined by Adam Lock, to describe the relationship of unsaturated fatty acids with MFD. It is the sum of three primary fatty acids namely, oleic acid (C18:1), linoleic acid (C18:2) and linolenic acid (C18:3) with MFD. RUFAL accounts for unsaturated fatty acids from all ingredients rather than fat supplement only.

Rumen pH

Various factors that may lead to marked change in rumen pH are dietary carbohydrate profile; their degradation rate is affected by source, moisture and processing; physically effective NDF (peNDF) as affected by source and particle size; and production of salivary buffers as function of peNDF source and supply (Shaver, 2005). Although data is limited but decrease in rumen pH causes increased flux of PUFA through alternate pathway as low pH favors bacteria that have alternate BH pathways.

Practical management interventions for MFD alleviation

There is not a single factor that may lead to MFD which make it hard to control it. A holistic approach is required to correct milk fat depression along with good milk records. It may take more than 10 days to see the effect of dietary or management change.

Concentrate feeding

Providing multiple sources of starch and fiber with overlapping rates of digestion is the safest approach. If sugar is given as a substitute for dietary starch, then it reduces risk without any loss of digestibility (Mullins and Bradford, 2010). By replacing starch with sugar sources like sucrose or molasses has shown to reduce the risk for MFD without disrupting performance (Mullins and Bradford, 2010). With diets less than 60.00 per cent fodder, NFC should be 34.00 to 40.00 per cent of total ration dry matter. Limit grain in one feeding to 2.25-3.00 kg to avoid acidosis (Looper, 2012).

Roughage feeding

Feeding of young, fresh pastures is high risk as it contains high amount of unsaturated fatty acids and low in fiber. Level and particle size of fiber determines the effectiveness of forage in rumination and salivation. Cows should have minimum roughage @ 1.40 per cent of body weight and particle size of 1.5-inch-long per day (Looper, 2012). Minimum acid detergent fiber level of 19.00 to 21.00 percent should be in the ration dry matter. Total neutral detergent fiber intake should be maintained>26.00 per cent of the total rations dry matter.

Supplement feeding

Avoid feeding of fat supplement with more unsaturated fatty acids due to toxic effect on rumen bacteria. Fat supplements that are high in saturated fat (palmitic and stearic) do not increase the risk of MFD and 85.00 per cent palmitic acid fat supplementation (@ 2 per cent DM) has been found to increase milk fat by 8.00 per cent (Lock *et al.,* 2011). Calcium salts slows down the release of unsaturated fatty acids but don't provide high inertness in rumen. This also depends on fatty acid profile and interaction of calcium with other dietary components. Feeding of sodium and potassium bicarbonate to cows receiving high-grain rations increases rumen pH and bicarbonates prevented a decline in milk fat (Emery and Brown, 1961). Supplement with potassium carbonate results in increased rumen pH coupled with decrease in *trans*-10 18:1 and *trans*-10, *cis*-12 18:2 (Jenkins *et al.,* 2014).

CONCLUSION

Milk fat depression is a less attended metabolic disorder in India which is causing huge losses to the dairy farmers. Generally due to lack of adequate nutritional and management knowledge, farmers are unable to identify and cure this multi factorial disorder. *Trans*-10, *cis*-12 CLA isomer has been found to be the main culprit for inducing MFD. Adequate dietary and general management can help our farmers to generate more income from dairy business.

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