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Omega (Ω3) and Omega (Ω-6) Fatty Acids Rich Oil in Dairy Ration: Reproductive and Productive Benefits - A Review

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ABSTRACT

For rural Indians, livestock rearing is an important source of employment, income and livelihood. Demand of milk is also ever increasing over time. The dairy animals achieve their genetic potential of production between the second and fifth lactation of their life. After that, milk production declines gradually and prevalence of diseases increases. For sustained milk production round the year and maximum output from dairy farming sector, sound rearing approach of dairy animals including nutrition management and replacement of older and unproductive cows through culling plays a significant role. Supplementing adequate nutrients in proper amount and proper proportion is paramount to the growth, production and reproduction in dairy cows. Among various supplements, energy is the most important one that need to be met for proper biological function. Cereals are generally used as energy rich concentrate for ruminants. However, inclusion of excess cereals impairs the ruminal digestion due to acidosis. Therefore, oil supplements are used for increasing the energy density of fast growing heifers and lactating cows. Certain oils/ oilseeds not only increase the energy density of ration only, but have numerous significant biological functions in addition to providing energy also. This is because of the specific fatty acid composition of these oils. This review compiles the role of unsaturated oils/ oilseeds in improving the performance of cattle.

KEYWORDS: Cattle, Oil, Ω-3 fatty acid, Ω-6 fatty acid, Performance

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INTRODUCTION

Role of polyunsaturated fatty acids (Ω-3 and Ω-6) in various biological process regulations is well studied and documented by many nutritionists in recent past. Different types of polyunsaturated fatty acids have been reported to perform essential role in regulating biological metabolism, endocrine functioning and disease control in various tissues. In the dairy animals, adequate nutrition is paramount requirement for growth, successful productive as well as reproductive functions such as early onset of puberty and ovarian cycle. Prolonged depletion of body reserves in the lactating animals, especially during early lactation and fast growing heifers can have significant detrimental effects on growth, production and recommencement of estrous as well as conception rate. Traditionally, supplemental lipid in the ration of dairy animals is included to increase dietary energy density, but the Ω-6 and Ω-3 polyunsaturated fatty acids in the supplemental fat have encouraging impact on the metabolism of carbohydrate, protein and fat, as well as growth and differentiation of cells by regulating gene expression of reproductive tissues resulting in a noticeable improvement in production and fertility. In recent years, animal nutritionists are more focused on decreasing the ratio of dietary Ω-6 to Ω-3 fatty acids in the diet of bovines because of higher health benefits and improved reproduction efficiency of lower ratios. Fatty acid composition of various oils differs considerably but, in general, the commonly used dairy feedstuff contain high proportion of unsaturated and low proportion of saturated fatty acids. Soybean and sunflower oil are omega-6 rich oil while except for flaxseed, soybean, and fish oils, all other common oils contain least amounts of omega-

3 fatty acid. An appropriate ratio of Ω-6: Ω-3 is required for optimum performance of dairy animals which is ensured by a mixture of oils from a variety of feedstuffs used in their ration (Moallem, 2018). There are different oil-feed ingredients (Table 1) that are rich in polyunsaturated fatty acids and can be used in the dietary regimen of dairy animals.

Table 1. Major sources of unsaturated fatty acids for dairy animals (Thatcher and Staples, 2007)

Sr. No.	Oil	C18:1 (%)	C18:2 (Ω-6, %)	C18:3 (Ω -3, %)
1.	Canola	64	19	8
2.	Palm	39	10	1
3.	Safflower	12	77	0
4.	Cottonseed	21	50	0
5.	Corn	25	60	1
6.	Sesame	42	45	0
7.	Soybean	24	53	7
8.	Sunflower	20	69	0
9.	Linseed/Flaxseed	19	14	58
10.	Fish oil	25	4	45

In ruminants, a major hurdle for delivery of polyunsaturated fatty acids is ruminal bio-hydrogenation. In fact, greater than 80% of Ω-6 and Ω-3 from the diet are modified/ hydrogenated by the ruminal microflora. However, not withstanding extensive bio-hydrogenation of unsaturated FA, feeding increased amounts of Ω-6 and Ω-3 has been reported to alter tissue composition thereby influencing production and reproduction (Silvestre et al., 2011). Therefore, despite limitations in delivery of specific amounts of Ω-6 and Ω-3 for absorption, altering the fatty acid composition of the diet is capable of influencing animal performance.

EFFECT OF Ω6 AND Ω-3 ON NUTRIENT UTILIZATION AND GROWTH

Results from various studies regarding the effect of the dietary Ω-6 and Ω-3 on nutrient utilization in ruminants are inconsistent. The effect of different oils containing varying proportion of unsaturated fatty acids on DMI of the animals largely depends upon the amount fed. Pirondini et al. (2015) fed cows fish oil at a rate of 0.8% of dietary DM and observed no negative effect on intake of feed. According to Dirandeh et al. (2014), average postpartum dry matter intake was not affected by dietary inclusion of roasted soybean and linseed as a source of Ω-6 and Ω-3, respectively. According to Martin et al. (2008), feeding whole flaxseed has no negative effect on DMI and milk yield because of low release of VFA in the rumen fluid. Whereas Zachut et al. (2010) showed the postpartum dry matter intake and energy intake were greater in animals fed extruded flaxseed. Similarly, Petit et al. (2007) found that a diet containing a high proportion of saturated fatty acids caused reduced feed intake than one rich in unsaturated fatty acids. However, several other studies have found that decreased intake resulted from abomasal infusion of unsaturated fatty acids or from feeding the cows increasing amounts of unsaturated fatty acids at the expense of saturated fatty acids. However, Chilliard et al. (2009) also reported that body condition score (BCS) was not affected up to 40 days post-partum when cows were fed flaxseed as Ω-3 fatty acid source as compared to control. According to Len et al. (2016), dietary supplementation of rumen protected fat sources rich in Ω-6 and Ω-3 has positive effects in the improvement of digestibility of ether extract and organic matter in calves. Kumar and Thakur (2007) supplemented bypass fat with varying degree of unsaturation and reported increased growth rate in supplemented calves as compared to non &!-3 supplemental group. They also found that *in vivo* nutrient digestibility was not affected by dietary Ω-6/Ω-3 fatty acid ratio. On contrary to this, Kim et al. (2016) reported that *in vitro* dry matter digestibility and the concentrations of total volatile fatty acids as well as propionate decreased linearly with increasing Ω-6/Ω-3 FA ratio in cattle diet. In a similar study, Len et al. (2016) observed no significant effect on digestibility of nutrients except that EE and OM digestibility was higher in CaSFA and CaLFA (Ω-6 and Ω-3 rich source, respectively) group as compared to the PFA (saturated fatty acid source) group. Calcium salts of palm oil as a source of saturated and monounsaturated fatty acids cause the similar effects.

Whitney et al. (2000) studied the effect of inclusion of soybean oil at 3% of a forage-based diet, and reported that there was increased total VFA concentration, improved blood metabolites, ADG and feed efficiency. Childs et al. (2008c) fed graded level of fish oil to crossbred heifers and reported that DMI and ADG was higher ($P<0.05$) at 140g of fish oil compared to diet containing higher level of fish oil or diet without fish oil. Fiorentini et al. (2013) found that adding soybean oil to the diets of crossbred heifers did not affect nutrient intakes and utilization. Diets containing high fatty acid content (>7%), especially unsaturated fatty acids can adversely affect the ruminal feed degradation, which in addition to being toxic to rumen microflora, adhere to the food particles and cause a physical barrier between microbes and feed particles preventing their action, consequently impairing the performance of growing animals. A study by Muller et al. (2004) showed that Ω-3 and Ω-6 fatty acids supplementation in crossbred heifers resulted in no differences in DM, OM, NDF and ADF intakes.

Effect of Ω-6 And Ω-3 Supplementation on Rumen Parameters, Rumen Microflora and Fauna

Ruminant Diets containing Ω-6 and Ω-3 rich oil alter the kinetics of rumen fermentation. Fiorentini et al. (2013) reported that soybean oil reduce the rumen ammonia-N concentration and numbers of fungi and protozoa and thus improve the efficiency of microbial protein synthesis.

As per the findings of Ivan et al. (2001), dietary fats with higher level of unsaturated fatty acids cause greater variability on ruminal pH, being more subjected to hydrolysis by rumen bacteria. A moderate reduction in the rumen pH to approximately 6.0 reduces the fiber digestion, but the population of fibrolytic microorganisms is not usually affected. Animals fed a rumen Ω-3 protected fatty acid rich diet had larger numbers of ruminal protozoa and fungi than those supplemented with unprotected Ω-6 and Ω-3 rich oils. It is because of defaunation process caused by the consumption of unsaturated fatty acids. Defaunation could be related to improved microbial efficiency (Ivan et al., 2001) because of decreased competition between bacteria and protozoa for substrates. A decreased protozoa concentration also leads to a decrease in the NH_3-N concentration in the rumen, which is due to a reduction in the proteolytic activity of the protozoa. Additionally, defaunation break the symbiotic relation between protozoa and methanogenic archaea leading to reduced growth of methane producing bacteria. Methanogenesis is a wasteful process that leads to loss of around 7% feed gross energy. Ω-6 and Ω-3s have little influence on microbial protein synthesis, and the efficiency of microbial protein synthesis increases more frequently when there is a reduction in the number of ruminal protozoa. Dewhurst et al. (2000) depicted that dietary unsaturated fats can affect microbial protein synthesis directly by replacing fermentable energy sources for the microorganisms or indirectly by promoting defaunation and consequently increasing bacterial-origin protein synthesis.

Milk Composition and Production Performance of Cows Ω-6 And Ω-3 Supplements

Supplementation of Ω-6 and Ω-3 in the diet of lactating cow has been found to be positively associated with total milk yield of the animal. Additionally, increased milk protein content with no effect on fat content has been found to lower the milk fat/protein ratio significantly as observed by Gonzalez et al, 2015. In a similar research, Zachut et al. (2010) also reported greater milk yield with reduced fat content during early lactation in flaxseed fed cows compared to the cows fed iso-caloric diet without flaxseed, while total fat yield, fat-corrected milk yield, and energy corrected milk yield remained unaffected. Petit et al. (2007) observed higher milk production in flaxseed having higher unsaturated fat fed cows than those fed an iso-energetic diet supplemented with saturated fatty acids. Some researchers have reported on additional benefit of supplementing cows diet with Ω-3 fatty acid rich feedstuff over low Ω-3 diets. For example, Suksombat et al. (2016) fed cows with pure Ω-3 rich flaxseed oil that resulted in no improvement in milk yield relative to palm oil.

The milk fat is composed of numerous type of fatty acids with varying chemical nature subject to the extent of bio-hydrogenation. The intermediate products of ruminal bio-hydrogenation process alter the composition of the milk. Fuentes et al. (2008) observed that *trans* 10 and *cis* 12 CLA formed during the bio-hydrogenation decreased the milk fat contents. Whitlock et al. (2002) reported no negative effect on concentrations of protein, lactose, total solid, or solid-not-fat in the milk with fish oil or soybean oil supplementations. On contrary to it, Pirondini et al. (2015) reported a reduction in milk protein content in cows fed fish oil. Feeding ruminants with seeds and oil containing unsaturated fatty acids has been reported to be associated with the change in CLA, which have health-promoting role in human. Greater concentrations of CLA and C18:1 *trans* isomer in milk fat has been reported from cows fed extruded flaxseed (Gonthier et al., 2005). Similarly, dietary supplements of rapeseed, soybean and linseed oils or fish oil (AbuGhazaleh et al., 2003) have also been shown to decrease the concentration of saturated fatty acids and increase unsaturated fatty acids including CLAs in milk fat. Two to three fold increase in the total concentration of milk CLAs has been reported in extruded soybean and fish oil based diets in cattle. Dietary unsaturated fatty acids have hypocholesterolemic effects and therefore it is desirable to elevate the content of MUFA and PUFA and to lower the SFA in milk through dietary managements. Rego et al. (2005) observed that fish oil (rich in Ω-3 FA) supplementation had no effect on medium chain FA but caused a decrease in concentration of short (C6:0 to C12:0) and long chain FA (stearic and oleic acid) and increase in *trans*-vaccenic and Ω-3 FA in the milk fat. Decreased short chain FA suggests a reduced de-novo FA synthesis in mammary gland of the animal. A high content of CLAs in milk is also beneficial because of their desirable physiological properties (Banni et al., 2002). But, large amounts of fat in the diet of ruminants (in excess to 6% of total DMI) is not recommended because of its negative effect on the activity of the rumen microflora, which results in a significant drop in the milk yield, milk fat and protein percentage (Bauman and Griinari, 2001).

Plasma Metabolites and Reproductive Parameters of Cows Ω-6 and Ω-3 Supplements

Changing the content of individual dietary fatty acids in ruminants are reflected as the change in the concentration of various plasma metabolites and hormones. Blood concentrations of NEFA are an indicator of fat mobilization from the adipose tissues (Roberts et al., 1981) and they are related to the mechanism of energy balance of cows. Increased plasma cholesterol and NEFA concentrations in the heifers fed whole raw soybean diet as source of Ω-6 fatty acids was reported by Gonthier et al. (2005). Further, the change in the plasma metabolites may also be affected by the form of Ω-6 and Ω-3 presented in the rumen i.e. either in rumen protected or unprotected form. For example, Childs et al. (2008b) showed that heifers' diet supplemented with Ω-3 Ω-6 and Ω-3 in a partially protected form did not affect NEFA and glucose. Childs et al. (2008c) found that there was a linear increase in blood cholesterol with no effect on the concentrations of triglycerides and glucose level in cows supplemented with graded levels of polyunsaturated fatty acids. NEFA can be used as an energy source by different tissues like skeletal muscle and hepatocytes, re-packaged into triglycerides and exported as very LDL-cholesterol or stored within the liver, or can also be converted to ketones. Grummer and Carroll (1991) proposed that increased plasma NEFA resulted from one or more of the following: 1) incomplete removal of fatty acids by tissues after lipoprotein lipase hydrolysis of triglyceride contained within circulating lipoproteins; 2) increased net fatty acid release from adipose; 3) decreased NEFA clearance by tissues. Improvement in the reproductive efficiency of the animals Ω-6 and Ω-3 rich feeds has been testified by various studies. Supplemental fatty acids have often been used to increase the dietary energy density to minimize NEB in animals, which is related to low fertility in cows (Butler, 2005). However, Lucy et al. (1991) stated that improved reproductive performance of animals Ω-6 and Ω-3 is independent of the increased energy as the different diets were kept iso-energetic in nature and it was supported by the unchanged plasma NEFA concentrations between the groups fed different diets. Additionally, Ω-6 and Ω-3 have benefits that are independent of changes on the energy status of animals (Santos et al. 2008). For example, Ω-3 and Ω-6 FA are reported to be associated with prostaglandins' metabolism in dairy cows (Leroy et al., 2014).

Feeding diets containing high level of Ω-3 fatty acids also have positive effects on reproductive functions of post-partum cows. According to Sinedino et al. (2017) feeding the early lactating cows a diet enriched with algae containing 10% Ω-3 fatty acids resulted in early resumption of estrous, pregnancy at first insemination and increased pregnancy per insemination which reduced days to pregnancy by 22 d compared to other cows. Gulliver et al. (2012) postulated that polyunsaturated fatty acids might influence the synthesis and metabolism of important reproductive hormones. Thomas et al. (1997) reported that dietary supplemental soybean oil increased the serum concentrations of insulin and GH as well as follicular IGF-I concentrations, which might positively affect reproduction by stimulating ovarian granulosa cell proliferation (Len et al., 2016). Feeding cow supplemental dietary fat with varying saturation increase serum progesterone and cholesterol concentrations. The circulating cholesterol acts as precursor for luteal progesterone synthesis (Staples et al., 1998). Various studies have confirmed increased diameter of the dominant ovarian follicle of lactating dairy cows fed with unsaturated fat supplements (Ambrose et al., 2006). In addition to these benefits, Ω-6 and Ω-3, or their bio-hydrogenated metabolites, are also supposed to be absorbed by the uterus and inhibit the production and release of PGF2á in the endometrium at the beginning of pregnancy. This prevents the regression of the corpus luteum in the ovary and thus, continuous production of progesterone encouraging favorable condition for survival of embryo (Bilby et al., 2006). Inhibition of $PGF_{2\alpha}$ by Ω-3 preventing regression of the CL resulting in sustained progesterone release has been reported by other researchers also. Wathes et al. (2007) found that diets rich in Ω-6 are coupled with elevated cholesterol, steroidogenic acute regulatory (StAR) protein and PGE_2, which might stimulated progesterone production. Mattos et al. (2000) also proposed that Ω-3 fatty acids may reduce uterine PGF2α secretion and decrease the sensitivity of the CL to $PGF_{2\alpha}$ thereby improving the fertility by reducing the degree of embryonic loss in early pregnancy. Post-breeding polyunsaturated fatty acids supplementation modulates PGF2α synthesis, luteolysis, and enhances maternal recognition of pregnancy (Wathes et al., 2007).

On contrary to this, Dirandeh et al. (2014) reported that the overall plasma progesterone concentrations did not differ between groups fed soybean and linseed oil but were greater than control treatments fed saturated fat. Thomas et al. (1997) showed that dietary polyunsaturated fat stimulated a significant increase in serum insulin with increased growth rate of ovarian follicles in cattle compared to animals fed saturated fats. Gandra et al. (2017) supplemented lactating cows' diet with Ω-3 and Ω-6 rich oil and found greater blood cholesterol concentration and increased number of small and total ovarian follicles in early lactating cows. Westwood et al. (2002) observed a positive correlation between blood cholesterol concentration and reproductive performance including the expression of estrus and conception rate in dairy cows. Similar to this, Ghasemzadeh-Nava et al. (2011) reported that the size of dominant ovarian follicle was significantly greater in cows that consumed fish oil or soybean oil in diet. The size of dominant follicle was significantly greater in soybean oil supplemented group compared with the control cows, and intermediate values were noted in diet supplemented with fish oil. While, mean diameter of ovulatory follicle (Mendoza et al., 2011) and CL (Petit et al., 2002; Childs et al., 2008c) was found significantly higher in cows were fed higher dietary Ω-3. Garcia et al. (2003) reported moderate increase in circulating concentrations of IGF-1 during pubertal development in cattle by feeding Ω-6 and Ω-3. Increased number of medium-size follicles in cycling heifers fed soybean oil was also seen by Thomas and Williams (1996). Whitney et al. (2000) concluded that inclusion of soybean oil at 3% of a forage-based diet in heifers increased plasma cholesterol and growth hormone and; decreased the time to conception. Increasing the Ω-6/ Ω-3 ratio also increases plasma insulin and progesterone (Kim et al., 2016). Regarding the economic analysis of reproductive efficiency, the higher AI/conception rate observed in polyunsaturated fatty acids supplemented heifers may account for a reduction of one insemination, compared to the SFA supplemented group. The proportion of Ω-6 and Ω-3 fatty acids in the diet of dam also affects the fatty acid profile of new born calves sampled prior to colostrum feeding Garcia et al. (2014). Transfer of these essential fatty acids from maternal blood to newborn possibly exert a positive effect on calf health and performance at early stage (Hill et al., 2011).

CONCLUSION

This comprehensive review demonstrates the involvement and influence of Ω-3 and Ω-6 FA in biological metabolism and the promising effects of their dietary supplementation to dairy animals. Dietary supplementation of these unique FA either decreased or not affected the DMI, milk yield, and milk protein, however, milk fat decreased in most of the studies. Beneficial effects of dietary supplementation of omega FAs on the reproductive system in dairy animals have been consistently reported. But, delivery of the right amount of these FA to the dairy animals still need further studies to avoid their probable effects on the intake and rumen fermentation.

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