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Augmentation of Milk Production by Supplementing Bypass Fat in Dairy Animals

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ABSTRACT

Pregnancy and lactation are the physiological states which modify metabolism in animals and induce stress. The period of transition between late pregnancy (-3 weeks) and early lactation (+3 weeks) presents huge metabolic challenges in terms of energy balance, plasma metabolites and hormonal changes. High rates of Body Condition Score (BCS) losses are associated with a severe negative energy balance conditions immediately after the calving. Energy deficiency due to decreased dry matter intake during the periparturient period results in increased lipolysis of body fat. The release of non-esterified fatty acids and higher β-hydroxybutyrate concentrations are indicative of lipid mobilization and fatty acid oxidation. Animals have to utilize their body reserves to support lactogenesis and milk production resulting in metabolic disorders and sub-optimal milk yield under these conditions. Most of the lactating animals are fed crop residues in the tropical countries, which are generally low in energy, protein and minerals. Increased amount of energy secreted into milk fat and lesser feed intake puts high yielder cows and buffaloes in negative energy balance (NEBAL), metabolic disorders and suboptimal milk production. Maximizing the energy intake by increasing the energy density of diet is a logical feeding strategy during transition period and in early lactating animals. Feeding large amounts of cereal grains decrease ruminal pH, ruminal fiber digestibility, acetate/propionate ratio, milk fat concentration and increase the risk of ruminal acidosis. Scientific interventions have been carried out from time to improve energy balance by supplementing bypass fat and proteins. Bypass fats are commonly referred to as ruminal inert fat, protected fat and escape fat and are more expensive per unit of energy provided compared to commodity fats. Calcium salts of fatty acids increase milk yield and fat contents but partially degrade in the abomassum. Prill fat, a bypass fat is available in different forms and augments productive performance of lactating animals by getting digested in the small intestine. However response varies depending upon the milk production levels and the body condition of animals. The present review discusses the role of bypass fat in enhancing the milk production performance and its effect on hormones, digestibility coefficients and energy balance.

Key words: Bypass fat, milk, yield, lactating animals, energy balance, reproduction

INTRODUCTION

Livestock is an integral part of India's agricultural economy and plays a multifaceted role in providing livelihood support to the rural population. It is estimated that about 70 million rural households own livestock of one species or the other (Livestock census, 2013). Nutrition of transition cows and management has received much attention in the research and popular literature in recent years because of its importance in the productivity and health of cows (Block, 2010). The occurrence of health problems during the transition period is a major complicating factor for subsequent reproductive performance resulting in additional economic losses (Ferguson, 2001; Remppis *et al*., 2011). Poor transitions also result in losses from milk income. Indian cows and buffaloes are reared on a crop-residue system where as organized livestock farms manage animals as per the scientific requirements. The gap between the requirement and availability of feed and fodder is increasing primarily due to decreased area of fodder under cultivation and reduced availability of crop residues. The milk production potential of lactating animals varies and is not fully expressed under these conditions. Metabolic disorders like ketosis, retention of placenta occurs due to disturbed energy balance (Bargo *et al*., 2002). Attempts have been made to augment milk production from dairy animals with bovine somatotropin which is galactopoietic in nature (Bachman *et al*., 1992; Singh and Ludri, 1994). Because of the environmental hazards and secretion of hormone into milk, the application of this technology could not become popular (Prasad and Singh, 2010). Subsequently researchers focused on the use of non-hormonal preparations and herbal medicine to augment lactation because they augment milk yield without affecting the energy balance (Singh *et al*., 2012). The use of bypass fat and protein has been the topic of research to augment milk production for many years (Singhal *et al*., 2011; Kumar *et al*., 2014). Bypass fat supplementation increases energy density of the diet which is reflected in improved BCS and productive performance of animals (Ganjkhanlou *et al*., 2009). The high-yielding modern dairy cow is a product of many years of genetic selection that continually placed emphasis on milk yield through the utilization of progeny tested bulls, sexed semen technology improved management technologies and better nutrition (Rodriguez-Martinez *et al*., 2008). Such cows need better energy supplements to minimize the deleterious effect of less dietary intake and body weight losses during transition period. This could be achieved to a greater extent by providing high energy diet like rumen protected or inert fat during transition and early lactation. The high yielding crossbred cows and elite buffaloes face big challenge in meeting their nutrient requirements and sustaining milk production due to their subsistence on poor quality native grasses, crop residues and agro-industrial by-products (Goff and Horst, 1997). There are 190.90 and 108.7 million cattle and buffaloes in India out of which only 43.95 and 36.57 million produce milk. Taking an average 10% increase in milk production by feeding of bypass fat, about 13 million tons of milk can be obtained. This could further improve the production potential of over one billion breedable dairy animals in India.

BYPASS FAT

Over the years several methods have been developed to produce rumen inert fatty acids like prilled fatty acids, calcium salt of fatty acids etc. (Schauff and Clark, 1989). Calcium salts of fatty acids are most commonly used as they are cheaper in price. Prilled Fat (PF) is prepared after liquefaction and spraying the solution of saturated fatty acids under pressure into a cooled atmosphere. Saturated fat like animal fats, palm oil have a higher melting point viz, 50-60°C in contrast to the temperature of 38-39°C in the rumen (Chalupa *et al*., 1986). That is why PF is not affected by the ruminal temperature. Calcium salts of fatty acid are produced by double decomposition and fusion method. The calcium soaps are insoluble in rumen pH of 6.2-6.8 but soluble in the abomasum where the pH ranges between 2-3. In double decomposition method, fat source is heated in a metal container followed by addition of aqueous sodium hydroxide solution with constant stirring until the fatty acids are dissolved. Calcium chloride solution is added slowly with constant stirring, while the contents are still warm. This causes the precipitation of calcium soaps. The calcium soap is dried at low temperature and grounded before mixing into the ration.

ADVANTAGES OF BYPASS FAT

Energy density of the diet can be increased by fat supplementation but high dietary fat results in the reduction of fibre digestion in the rumen and a decline in milk fat percentage (Palmquist and Jenkins, 1980). Bypass fat supplementation in the ration of lactating animal, enhances the energy intake and reduces the adverse effect of NEBAL during early lactation (Drackley, 1999; Ganjkhanlou *et al*., 2009) without affecting rumen cellulolytic bacterial activity (Thakur and Shelke, 2010). Unprotected fats cause physical and chemical changes in the microbial fermentation of feed and depress rumen cellulolytic microbial activity (Palmquist, 1991). So, the feeding of rumen inert fat is partially resistant to bio-hydrogenation by the rumen microbes and reduces risk of metabolic acidosis (Naik, 2013). Supplementation of bypass fat before parturition could reduce the detrimental effects of NEBAL (Fig. 1) which could improve lactation as well as the metabolic performance (Duske *et al*., 2009). Adding protected fat to dairy rations can positively affect the efficiency of dairy cows through a combination of caloric and non-caloric effects. Caloric effects are attributed to higher energy content and energetic efficiency of lipids as compared to carbohydrates with the overall benefits of increased milk production and the persistency of lactation. The non-caloric effects include improved reproductive performance and altered fatty acid profile of milk (Tyagi *et al*., 2010). Rajesh (2013) reported that supplementation of PF during early lactation improved milk yield and reproductive performance in crossbred cows.

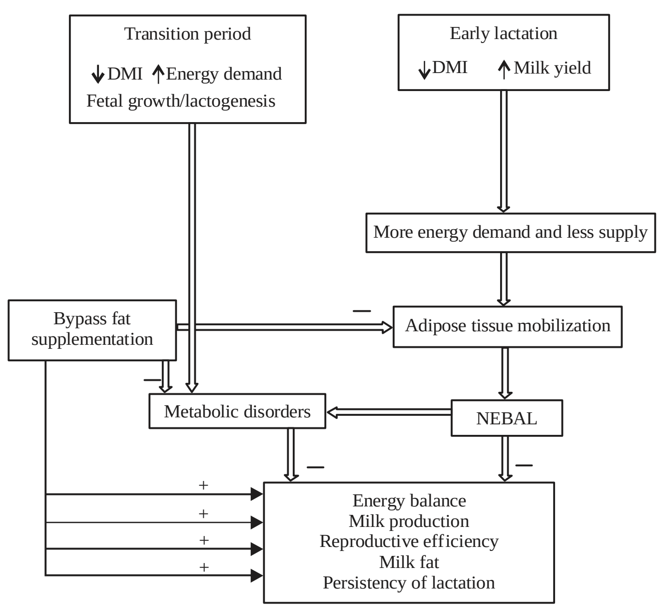

Fig. 1: Energy balance of dairy animals during transition and early lactation

FEEDING OF BYPASS FAT

The ration of high producing animals may contain 4-6% fat, which should include fat from natural feed, oil seed and bypass fat in equal proportions (Sharma, 2004). Under Indian feeding conditions different doses like 200 g bypass fat (Naik *et al*., 2009), 300 g (Sirohi *et al*., 2010), 150-200 g calcium salts of rice bran fatty acid oil (Wadhwa *et al*., 2012) and 75 g PF (Rajesh, 2013) have been used in the daily diet of lactating crossbred cows. Supplementation of bypass fat at 2.5% of total DM intake in the lactating crossbred cows has also been reported by Tyagi *et al*. (2009). There can be 3-4% fat in the dietary DM in the form of supplemental fat. The milk and fat yield in crossbred cows can further be enhanced by feeding of bypass fat with rumen protected choline chloride (Garg *et al.,* 2012). Although, PF can be incorporated up to 9% of the dietary DM due to its inertness in rumen (Sharma, 2004), yet feeding of Ca-LCFA at 9% of the dietary DM has not benefitted the lactating dairy cows (Schauff and Clark, 1992). Supplementation of 6-8% of ration on DM basis with Ca-LCFA had no adverse effect on rumen fermentation of dairy animals (Naik *et al*., 2010). Use of dietary fat spares energy by increasing metabolic efficiency for milk production by generating ATPs more efficiently than VFA or protein. It lowers heat production, incorporate preformed FA into milk fat and optimize forage fiber intake and rumen function by substituting the rapidly fermentable carbohydrate (Palmquist, 1994). Milk fat of dairy animals consists of a mixture of short, medium and long chain Saturated Fatty Acids (SFA) and Unsaturated Fatty Acids (USFA). Milk fat of less than 16 carbons is synthesized *de novo* in the mammary glands. The Fatty Acids (FA) of more than 16 carbons are synthesized from diets while FA with 16 carbons are synthesized from both diet and *de novo* synthesis (Castaneda-Gutierrez *et al*., 2005). Thus feeding of prilled or bypass fat either increases milk fat content or the efficiency of milk production.

Supplementing rumen bypass fat might affect the following attributes in the dairy animals.

RUMEN FERMENTATION

Supplementation of bypass fat has no adverse effect on rumen fermentation even at 5-15% of the dietary DM (Chalupa *et al*., 1985, 1986). Parameters like ruminal pH, NH_3-N and TVFA level have no adverse effect on the supplementation of Ca soaps up to 5% of dietary DMI in lactating cows (Ohajuruka *et al*., 1991) and buffaloes (Naik *et al*., 2010). However, molar percentage of acetate and acetate to propionate ratio increased linearly (Schauff and Clark, 1992). The effectiveness of PF supplementation on rumen metabolism depends upon the level of inclusion, roughage to concentrate ratio and type of roughage fed. The mixture of cereal grains and forages usually contain about 3% fat, so that the total dietary fat does not exceed 6-7% of the total DMI (NRC., 2001).

DIGESTIBILITY OF NUTRIENTS

As parturition approaches, there is a progressive decrease in DMI with an overall decrease of 30% in the last 3 weeks of gestation and almost 90% of this decrease occurring in 5-7 days before calving (Ingvartsen and Andersen, 2000). There was no adverse effect of rumen protected fat and protein supplementation on DMI of buffaloes and cows during mid lactation (Singh *et al*., 2014) and prior to calving (Shelke *et al*., 2012). The digestibility of ADF may increase (Naik, 2013) or may not change (Thakur and Shelke, 2010) on supplementation of bypass fat. The PF supplementation did not affect the digestibility of DM, OM, CP, CF, NFE, TCHO, NDF and cellulose (Rajesh, 2013; Singh, 2015). However, EE digestibility increases with Ca salts of palm FA or PF in dairy cows (Thakur and Shelke, 2010; Weiss *et al*., 2011; Rajesh, 2013). The lower fat digestibility at higher level of supplementation may be due to the limited capacity of small intestine to absorb fat or masking effect of endogenous faecal fat (Ngidi *et al*., 1990). The digestibility of the SFA decreases with an increase in the chain length and unsaturation of fatty acids increases the digestibility; therefore, palmitic acid is more digestible and stearic acid is less digestible than the average fatty acid mixture in the ruminants (Palmquist, 1994). The NDF digestibility increased linearly on increasing the level of Ca soap in diet (Ngidi *et al*., 1990) due to the increase in the post-ruminal degradation (Chouinard *et al*., 1998). Naik *et al*. (2007) reported no influence of bypass fat supplementation on the cellulose digestibility of buffaloes. Hemicellulose digestibility remains unchanged (Schauff and Clark, 1992), increases (Garcia-Bojalil *et al*., 1998) or decreases (Naik *et al*., 2007) with the inclusion of bypass fat in the diet. Prilled Fat (PF) feeding enhances energy balance of buffaloes by improving DE, ME and net energy of lactation.

MILK YIELD AND ITS COMPOSITION

Bypass fat supplementation at 1.4% of DMI (200 g day^{-1}) increased the milk production and feed efficiency in lactating Murrah buffaloes (Ranjan *et al*., 2012). There was an improvement of 6.02% in milk yield of early lactating crossbred cows fed 75 g day^{-1} per animal PF (Rajesh, 2013). Similar amount of PF feeding to Murrah buffaloes resulted in 10% increase of milk yield in organized herd (Singh, 2015) and 17% increase under field conditions (Khan *et al*., 2015). Effect of supplemental bypass fat on milk yield depends upon breed, parity, stage of lactation of animal, level of supplementation and the type of protected fat, i.e., PF or Ca-LCFA.

Among all milk components, fat is the most sensitive variable to dietary changes. An increase in the proportions of LCFA (C18:1, C18:2, C18:3) takes place due to more uptake of preformed LCFA from blood (Mishra *et al*., 2004). The supplementation of bypass fat increases milk fat in lactating cows (Fahey *et al*., 2002; Purushothaman *et al*., 2008; Rajesh, 2013; Yadav *et al*., 2015). The average daily milk yield increased by 1.13 kg day^{-1} (20.42 vs. 21.55 kg day^{-1}) in the bypass fat (150-200 g day^{-1} per cow) supplemented group (Wadhwa *et al*., 2012). The increased milk yield in prilled fat supplemented cows is due to improved persistency of lactation (Fig. 2). Milk yield was not affected by dietary supplementation of Ca alts of CLA in lactating dairy cows (Castaneda-Gutierrez *et al*., 2005).

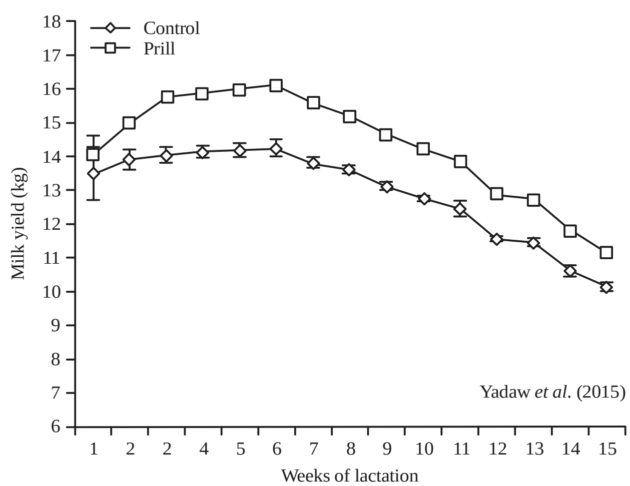

Fig. 2: Lactation curve of PF supplemented cows

BODY WEIGHT AND BCS

The body weight of the animals improved in the bypass fat supplemented group as compared to the control group (551 vs. 508, kg), though the differences were non-significant (Wadhwa *et al*., 2012). Feeding of calcium salt of palm oil fatty acids significantly reduced ($p<0.05$) the loss in body weight (11.72 vs. 38.30) in comparison to that of control group (Vahora *et al*., 2013). Metabolic body weight at the beginning of experiment was more ($p<0.05$) in the control cows; however after 90 days of experiment the metabolic weight increased significantly ($p<0.05$) in the PF supplemented cows (Singh *et al*., 2014).

Body Condition Score (BCS) provides better estimate of body fat distribution than the body weight. The decline in BCS ($p<0.01$) was more in control than the PF supplemented cows (Singh *et al*., 2014). Lipid mobilized from body reserves makes a substantial contribution to the energetic cost of milk production during early lactation. Dairy cows are successively mobilizing and storing body reserves during the lactation cycle. However, additional dietary fat could result in better energy partitioning and improved energy balance in dairy animals (Friggens *et al*., 1993; Sharma *et al*., 2015). The amount of body fat mobilized to meet the energy deficit was equivalent to 50% of the milk fat output over the first 5 weeks of lactation in high yielding dairy cows. The cows under NEBAL mobilized 50-60 kg of fat during the first 16 weeks of lactation which works out to about 10% of their body weight.

GLUCOSE AND NON-ESTERIFIED FATTY ACIDS (NEFA)

Glucose is the primary metabolic fuel required for vital organ function, foetal growth and milk production (LeBlanc, 2010). Plasma glucose levels remain unaffected by PF supplementation in KF cows during mid-lactation (Singh *et al*., 2014). NEFA concentration of plasma is also a stronger indicator based on risk and odds ratios, of disease, reproductive performance and milk production than blood BHBA concentration (Huzzey *et al*., 2011). As a consequence body fat stores are mobilized for milk production leading to NEBAL. LeBlanc (2010) reported a period of NEBAL during early lactation in dairy cows. Blood concentration of NEFA reflects the balance between release of FA from adipose tissue and lipoproteins and utilization of NEFA by tissues such as mammary gland. Chapinal *et al*. (2012) found that multiparous cows with high concentrations of NEFA at weeks 1 or 2 post-partum produced less milk than cows with normal NEFA concentrations, but such association was not found in primiparous cows. The NEFA levels in PF supplemented cows were different ($p \leq 0.05$) in comparison to that of control (0.14 vs 0.20 mM L^{-1}, Singh *et al*., 2014) while Shelke *et al*. (2012) have not reported any difference in plasma concentrations of NEFA in bypass fat supplemented cows. Prepartum NEFA and postpartum BHBA were significantly associated with the development of clinical diseases in dairy cows including retention of placenta, displaced abomasum and ketosis (Ospina *et al*., 2010). However, plasma BHBA did not vary significantly in the control and PF supplemented group (Singh *et al*., 2014).

TOTAL CHOLESTEROL AND TRIGLYCERIDES

Cholesterol is produced mostly in the small intestinal epithelium to transport dietary lipid. Possible explanations for the prepartum decrease in cholesterol concentrations include the foetal utilization of cholesterol for progesterone synthesis (Guedon *et al*., 1999). Higher cholesterol level may have favorable effect on the synthesis of reproductive hormones, thus leading to a better reproductive performance of animals in the bypass fat supplemented group (Wadhwa *et al*., 2012). Plasma cholesterol in the control and PF fed did not vary significantly in the cows during mid lactation (Singh *et al*., 2014). Similarly, plasma HDL cholesterol did not differ in PFG cows; however, plasma VLDL cholesterol concentration increased ($p<0.05$) in PF cows as compared to the control group (80.54 vs 86.13 mg dL^{-1}).

The term "Fat" usually stands for a triglyceride that is solid or semi-solid at typical environmental temperatures, whereas, "Oil" is a triglyceride that is liquid at working temperatures. Triglyceride level was improved ($p<0.01$) in the bypass fat supplemented group (Wadhwa *et al*., 2012). The plasma triglyceride concentration in control and PF cows during mid lactation did not vary significantly (Singh *et al*., 2014). There was no significant effect of prepartum and postpartum PF supplementation on plasma triglycerides, HDL and VLDL concentrations; however, cholesterol levels were higher ($p<0.05$) in the PF cows (Yadav *et al*., 2015).

PLASMA HORMONES

Insulin is an essential peptide product of pancreas which primarily controls blood glucose levels and regulates its uptake by peripheral tissues, most notably in muscles and adipose tissue (Kraft and Durr, 2005). Early lactation is characterized by a decrease in plasma insulin accompanied by a decrease in NEBAL during early lactation in cows (Ingvartsen and Andersen, 2000). The supplementation of Ca-salt of fatty acids (Tyagi *et al*., 2009) or prill fat did not influence the plasma insulin concentration of cows (Singh *et al*., 2014). The regulation of GH secretion has been the focus of intensive research for years (McMahon *et al*., 2001). It inhibits lipid storage in adipose tissue and increases the blood flow to mammary glands. Plasma GH concentration increased ($p<0.05$) in PFG cows during mid lactation (Singh *et al*., 2014) and postpartum. The GH has been found to be galactopoetic in the cows (Yadav, 2014) and buffaloes (Prasad and Singh, 2010).

Leptin concentration varies from 5-9 ng mL^{-1} in dry pregnant cows just 1 month before calving (Kokkonen *et al*., 2004); it decreased between weeks 4 and 1 prepartum and reached a nadir (3-6 ng mL^{-1}) during the first week postpartum. Plasma leptin concentration did not vary significantly in PFG cows during mid-lactation (Singh *et al*., 2014). However, prepartum PF feeding increased ($p<0.05$) postpartum plasma levels of leptin (Yadav, 2014). Ghrelin prepares the body to consume and store energy (Litwack *et al*., 2008). After parturition, ghrelin decreased in rats below levels that are typically detected before pregnancy (Litwack *et al*., 2008). Ghrelin signals the deposition of fat by increasing food intake and reducing the fat oxidation (Bradford and Allen, 2008). Ghrelin is also involved in the control of prolactin secretion, which stimulates milk production (Litwack *et al*., 2008). Therefore, ghrelin levels increased the milk production which helped to gain the body weight of the offspring (Litwack *et al*., 2008). The plasma ghrelin concentration did not vary significantly in PFG cows during mid lactation (Singh *et al*., 2014). The postpartum ghrelin concentration decreased ($p<0.05$) in PFG cows, however it remained unaffected during prepartum (Yadav, 2014). Plasma T_3 and T_4 concentration was higher ($p<0.05$) in PFG cows during mid-lactation (Singh *et al*., 2014). However prepartum PF supplementation significantly influence plasma T_3 and T_4 concentrations in cows (Yadav, 2014). There was no significant difference between the cortisol levels of control and PFG cows during early (Yadav, 2014) and mid-lactation (Singh *et al*., 2014).

REPRODUCTION

The NEBAL lead to an altered metabolism which affects production of IGF during early lactation in cows (Fig. 3). NEBAL may also influence IGF availability in the oviduct indirectly through changes in specific IGFBP expression due to low circulating IGF-I after calving (Fenwick *et al*., 2008).

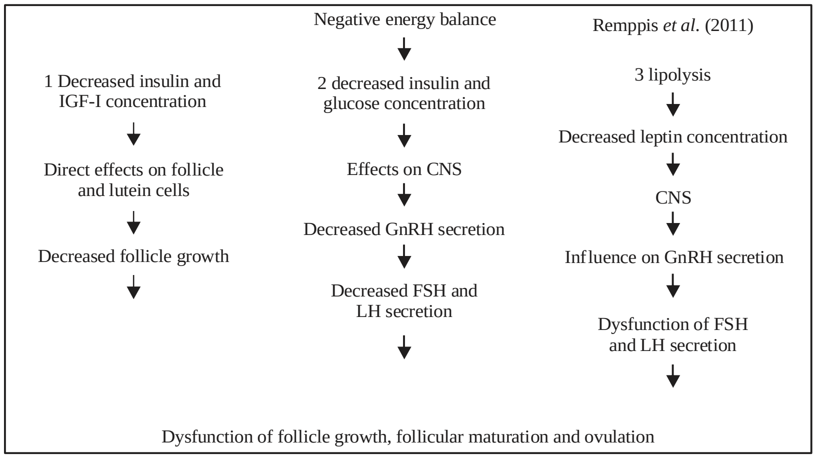

Fig. 3: Effect of NEBAL on reproduction

It has been observed that higher leptin concentrations associated with shorter intervals to first observed estrus might indicate a relationship between leptin and expression of estrus (Liefers *et al*., 2003). Supplementation of prill fat resulted in significantly ($p<0.05$) reduced service period in the urban buffaloes than rural ones (Khan, 2015). The conception rate and service period was 46.8% and 80.3 days, respectively in buffaloes (Khan, 2015). Yadav (2014) reported that prepartum supplementation of prilled fat in KF cows significantly ($p<0.01$) increased calf birth weight and minimized the cases of retention of fetal membrane and metritis. The prilled fat feeding also resulted in earlier resumption of estrous cyclicity, less number of AI per conception and improved conception rate in KF cows (Rajesh, 2013).

PRODUCTION ECONOMICS

The cost of indigenously prepared bypass fat depends upon the cost of its raw materials; However, feeding of bypass fat to dairy animals have reportedly given an additional profit of Rs. 34.50/- (Naik *et al*., 2009), Rs. 11.60/- (Gowda *et al*., 2013) and Rs 94.46 per cow per day (Yadav *et al*., 2015). Similarly, bypass fat feeding of buffaloes yielding 8-9 kg of milk daily resulted in Rs. 26.61 more income per day during early lactation (Parnerkar *et al*., 2010). The cost benefit ratio of 1.5 has been reported under field conditions (Khan, 2015). It is possible to formulate a strategy in future to get desirable milk yield from the lactating cows through different levels of supplementation with bypass fat. However, further studies may be taken up to investigate the role of various hormones on partitioning of nutrients for lactation and long term consequences of bypass fat feeding to dairy animals.

CONCLUSION

Supplementation of bypass fat improves the energy balance of lactating cows. However, feeding bypass fat during transition results in inconsistent and contradicting results which may be related to the level of fat feeding relative to body condition of the animal. It helps in achieving early metabolic and physiological adaptation in the freshly calved animals by reducing the adipose tissue mobilization. There has been a horizontal growth in lactating animals and now it is essential to achieve a vertical growth in terms of milk production performance by feeding bypass fat.

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