Effect of the Supplementation with Protected Fats in the Diet of Dairy Cows on The Quantity and Quality of Milk

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Abstract
The objectives of this paper were to analyze studies on the effects of supplementation with protected fats in the diet of dairy cows on milk production and its chemical composition. Many fats can be used in the diet of dairy cows as sources of protected fatty acids. Adding of protected fats in the diet of dairy cows were significant effect on milk production and were influenced by some factors such as supplemental fat sources, the stage of lactation, dry matter intake. However, some authors reported an insignificant effect on milk production and the chemical composition of milk (fat, protein and lactose) as a result of supplementing the diet with protected fats. In other studies, have shown that the use of unsaturated fatty acids in the diet of dairy cows had effect on the biohydrogenation process in rumen and reduction of the total content of saturated fatty acids in milk. In this review, based on the works analyzed we can conclude that the diet supplemented with protected fats in dairy cows had effect on the quantity and quality of milk.

Keywords: dairy cow, fatty acids, milk, protected fats

1. Introduction

The biological cycles of milk production and reproduction in dairy farms determine their profitability, thus making management decisions dynamic and time dependent. In general, high yielding dairy cows are in a state of negative energy balance (EEB), especially after calving. The energy deficit is due to the fact that the energy required to produce milk and maintain body tissue functions exceeds the amount of energy available from the ration [1].

More than 200 compounds have been detected in the composition of milk, some in large quantities (water, fats, carbohydrates, proteins) and others in very small quantities, but all the components of milk are in a mutual correlation and have an important role in the manufacturing technology dairy products [2, 3]. The components of milk are mostly formed in the mammary gland of the cow, from precursors resulting from the digestion of ingested food. Milk composition is important economically and nutritionally to milk producers and processors, respectively to consumers [2, 4]. Milk is a yellowish-white liquid with a sweet taste and characteristic pleasant smell. From a chemical point of view, milk is a mixture in well-defined proportions of water, lipids, proteins, carbohydrates (lactose), minerals, vitamins and other components [2]. Due to the complex and balanced chemical composition in nutrients, milk is considered the most complex food, its nutritional value is mostly preserved in processed products [2-4].

Therefore, milk and dairy products, due to their chemical composition and high degree of

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assimilation, occupy an important place in the rational human diet, being one of the most accessible sources of protein of animal origin [2-4]. The chemical composition varies according to several factors such as: species, breed, diet, age, state of health, stage of lactation. Nutrient substances in milk are synthesized at the level of the mammary gland, among which the most important are protein substances, fat and lactose [2]. Milk proteins are part of the group of complex proteins, which contain all the essential amino acids not only in sufficient quantities and in an optimal correlation for rational nutrition. Milk lipids, due to their chemical composition and high degree of dispersion, are more easily assimilated by the body, compared to other types of fat. Milk lipids largely condition the organoleptic properties of most dairy products, and the cholesterol content of milk fat is low compared to other fats. Carbohydrates in milk are represented, in particular, by lactose - a carbohydrate that is found only in milk and determines its pleasant sweet taste. The process of forming the milk protein molecule in the mammary gland consists in the grouping of several amino acids into peptide chains and then into the protein complex molecule [2]. Milk fat is the component with the largest quantitative variations (3.5 – 8.0%) being influenced by several factors as: breed, individual, diet, season, state of health, etc [2]. Chemically, fat is composed of simple lipids (neutral fats) and complex lipids. Simple lipids are formed, for the most part, from a mixture of glycerides and steroids in a very small proportion. Complex lipids are mostly represented by phosphatides or phospholipids and make up 1% of total milk fat. Milk phospholipids contain more unsaturated fatty acids compared to glycerides. More than 60 fatty acids with an odd number of carbon atoms (between 15 and 23 carbon atoms) were identified in milk. The most important fatty acids that make up milk glycerides are: butyric, caproic, caprylic, lauric, myristic, palmitic, stearic, arachidonic, behenic, oleic, linoleic [2-4].

Significant changes in fatty acids and especially long-chain fatty acids can be achieved by including fats containing these acids in the diet. Including fat in the diet of dairy cows, and especially protected fat, is the most effective way to change the fatty acid profile of milk. However, in order to avoid affecting the digestion of other dietary constituents in the rumen, the fats introduced in the diet must be controlled quantitatively and qualitatively [5].

Also, milk proteins, especially the casein and lactoglobulin fractions, can be quantitatively and qualitatively modified by genetic selection and diet. By including fat in the diet the total milk protein percentage can be reduced or increased relative to the milk fat percentage. However, dietary protein percentage has minimal effect on milk protein percentage when within practical feeding limits [6].

The studies of Palmquist and Jenkins [5] showed that in order to obtain high milk yields, cows' rations should contain additional fats that increase the energy level of the diet and maintain an adequate supply of fibers necessary for the synthesis of milk fats [5]. Weiss and Pinos-Rodriguez [7] showed that the inclusion of fat in the feeding of dairy cows improves milk production and the amount of milk fat.

Fat sources commonly used in the diet of dairy cows include oilseeds (whole cottonseed and soybean), animal fats, palm oils and their preparations which have the role of reducing the availability of nutrients for biohydrogenation in the rumen [8]. Also, fat sources have effects on rumen fermentation and nutrient digestion. Thus, some sources cause the biohydrogenation of rumen fats and the formation of intermediates, such as trans-10 C18:1 or trans-10, cis-12 C18:2, which have been shown to affect milk fat synthesis [9-13]. Also, Bauman and Griinari, [12] showed the effects of trans-10, cis-12 18:2 on both milk fat synthesis and arachidonic acid metabolism and the immune system, and Calder [14] indicate that fat is highly active biological agents.

The composition of milk can change due to differences in the relative rates of synthesis and secretion of milk components by the mammary gland. Variations are due to differences between species, races and conditions affecting an individual. Conditions affecting cows may include weather factors or seasons and stage of lactation [15].

The aim of this review was mainly to evaluate the main sources of fat used in the feed of dairy cows and their effect on milk production as well as on the main constituents of milk.

2. Materials and Methods

The data presented in this review were collected from the scientific papers studied.

3. Results and discussions

Milk production peaks approximately six weeks after calving, while feed consumption peaks four weeks later, at ten weeks after calving. During this ten-week period, the cow is in an EEB [16, 17], as the animal forces the mobilization of body fat reserves and the breakdown of skeletal muscle to meet high energy requirements [18-20]. However, excessive grain feeding increases ration energy, which could disrupt rumen function (i.e. acidosis) and cause decreased milk fat [21]. Santoshi et al. [22] reported that combined supplementation with trisodium citrate (25 g) and vitamin E (1000 IU)/animal/day during transition period improved body condition score and productivity of indigenous dairy cows.

The effectiveness of protected fatty acids in improving the quantity and quality of milk, especially their fatty acid profiles, has been shown in several studies [5, 23]. Under normal feeding conditions, the intake of lipids through fodder rations for ruminants is quite low, being evaluated at around 2-5% of the SU of the ration. In order to satisfy the energy requirements of performing cows, in the first 10 weeks after calving, it is possible to include fats in the ration. To be used successfully, these fats must not significantly affect the ruminal fermentation nor the digestibility of the nutrients necessary for milk production [19, 20].

Thus, there are two potential ways of intervention:

The first supplement with lipids of large amounts of rations; in this case, long-chain fatty acids resulting from lipolysis can reduce ruminal fermentations. This is explained either by the adhesion of long-chain fatty acids to the fibrous cellulose particles, which become impermeable, or by the fact that they cover the surface of bacterial cells, which they can inactivate. Since the cations available in the rumen fluid, especially Ca^2+, can be reduced, the addition of calcium (carbonates, chlorides) and magnesium salts prevents the reduction of digestibility due to the addition of fat [24]. Dietary lipid supplementation of 3-5% has been found to have a good effect in high yielding dairy cows.

The second use of protected lipids in the diet - protected fats escape the lipolytic action of microsymbionts, their digestion being produced by lipases from bile secretions. As a rule, unsaturated lipids are used for protection, preferably of vegetable origin, so that as much fatty acids as possible remain unchanged by the action of ruminal symbionts. Among lipids of animal origin, seul and osanza are used more frequently, the digestive efficiency being, in these cases, greater in the case of their protection [25].

Feeding fat to dairy cows can increase the energy density of the diet, but large amounts of unprotected fat can be toxic to microbial populations and exert detrimental effects on rumen fermentation. Therefore, other energy sources such as protected fats, full-fat soy and glucogenic supplements have additional effects rather than increasing the energy density of the diet [19].

Fats can be protected by treating them with some salts, e.g. calcium salts/long-chain fatty acid salts, resulting in a type of fat protected from ruminal digestion, especially for high yielding dairy cows. Several studies have found that the binding of unsaturated fatty acids with calcium salts protects these acids from biohydrogenation and allows them to reach ruminant milk intact, additionally protecting bacterial populations from the toxic effects of unsaturated fatty acids [24, 26]. Raw, roasted, extruded, rolled or ground soybeans can be used successfully in feeding dairy cows. The type of processing can affect product quality, oil release in the rumen and influence nutrient utilization [27]. On the other hand, extrusion has been shown to increase the ruminal availability of soybean oil, however, roasting may slow the rate of release of soybean oil into the rumen [28].

Privé et al. [29] showed that heat processing of oilseeds can have effects on ruminal lipid digestion, which could be caused by a change in seed coat protection, a reduction in the amount of polyunsaturated fatty acids undergoing biohydrogenation or lipid oxidation. Extruded soybean meal (ESBM) has the potential to be a source of high-quality protein and oil if properly processed. ESBM after extrusion, soybeans (~18% fat) are expelled (pressed) to remove oil [30]. ESBM (the final product) is approximately 7% fat compared to <1% fat in conventional soybean meal and has the potential to be an excellent feed ingredient. Full fat Soya is a processed extruded/pressed SBM (Soybean meal) supplied by Tutweer Animal Nutrition Products Co., Shareholders' Company Giza, Egypt.

Commercial products, such as MAGNAPAC and MEGALAC, obtained by reacting palm fatty acid distillate with calcium hydroxide to form calcium salts. This process protects the fats and allows them to pass through the rumen, reducing degradation and allowing the fats to be used efficiently by the cow [31]. Also, MEGALAC contains high levels of polyunsaturated fatty acids (PUFA).

Sallam et al, [32] conducted a complex study which aimed to explore the impact of protected fat and full fat soy product on dry matter intake, milk production and composition, blood metabolites and reproductive traits of early lactating cows. Eighteen early lactating dairy cows were randomly assigned to two equal groups. The cows were housed in an open semi-shaded barn with free access to water and salt blocks. Cows in the first batch were fed the basal diet with a mixed concentrate containing 10% soybean meal and a MEGALAC supplement with 600 g protected fat/cow/day, and green fodder was administered three times a day. Cows in group two had a diet in which soybean meal was replaced by extruded soybeans with 10% fat without MEGALAC supplement and green forage three times a day. The profile of fatty acids in MEGALAC (total saturated and unsaturated fatty acids 49.21, respectively 41.40) and Full fat soy (total saturated and unsaturated fatty acids 12.44, respectively 87.50) was different. The authors through the fat sources used, aimed to minimize the occurrence of EEN in dairy cows during the early lactation period [32]. Regarding consumption indices, it was shown that the average value of dry matter intake increased slightly ($P>0.05$) in the MEGALAC group (20.9 kg/day), compared to the cows in the Full-fat soy group (19.59kg /day). In addition, feed efficiency was improved ($P=0.07$) in the MEGALAC group (1.12 kg milk/kg SU ingested) compared to the Full-fat soybean group (1.07 kg milk/kg SU ingested). Although cows in both groups consumed the same amount of feed, as indicated by similar value of dry matter intake, feed efficiency was better ($P = 0.07$) in cows fed MEGALAC. This could be due to increased fat digestibility when protected fat is included in the diet [33]. These authors suggested that the value of fat digestibility was high because added fat is characterized by higher digestibility and availability than fatty acids in feed particles.

Jenkins et al. [34], showed that fat supplementation improved the energy efficiency of the ration because it reduced energy loss as heat, methane and urine. Similarly, cows fed heat-treated full-fat soybeans regained postpartum weight earlier than cows fed soybean meal and raw soybeans [35]. Bypass fat feeding reduces the chances of a negative energy balance in early lactation or at peak production and also improves the efficiency of fatty acid absorption which ultimately increases milk production. As explained in another study, feeding more energy and protecting fat increases the energy density of the feed, which reduces the chance of negative energy balance [36].

The mode of action leading to decreased dry matter intake (DMI) from feeding Ca-SFA to dairy cows was identified in three possible domains: palatability and effects on rumen and gastrointestinal motility. Grummer et al. [18] determined the palatability effects of four different fat products (dried tallow encapsulated with sodium alginate, tallow, FFA - free fatty acids and Ca-SFA - unsaturated fatty acids bound with calcium salts) on four dairy farms (209 lactating dairy cows). The authors observed that cows showed a better intake of fatty products except for Ca-SFA, similar to what is recorded in the current study. This observation indicated a possible inhibitory mechanism beyond palatability or general adaptation that led to a continuous and prolonged depression of DMI. A second possible mode of action in terms of DMI depression due to the inclusion of Ca-SFA is the interruption of rumen fermentation due to the effects of unsaturated fatty acids. Although Ca-SFA was observed to be inert in the rumen in vitro. Wu et al. [37] reported that 58% of the 18-carbon unsaturated fatty acids in Ca-SFA were biohydrogenated in vivo. The researchers stated that biohydrogenation could only occur after the dissociation of the calcium salt. Hawke and Silcock [38] had similar findings and concluded that a free carboxyl group of the fatty acid is required for biohydrogenation to proceed. Consequently, in reality Ca-SFA is not inert in the rumen. Therefore, the negative effects of unsaturated fatty acids on rumen fermentation are very likely. The third possible mode of action on DMI depression in cows fed Ca-SFA is the effect on gastrointestinal motility.

Bauman and Griinari [12] noted that digestibility did not differ significantly between C16 and C18 saturated FA and was lower for longer chain saturated fatty acids compared to PUFA.

Several studies have shown that feeding dairy cows with rumen-protected fat (rumen-bypass) in early lactation increased fat-corrected milk yield [39], milk yield and corrected milk yield for fat [24, 40] and milk fat percentage [41], without affecting the digestibility of other dietary nutrients.

Maeng et al. [42] reported that feeding 3% protected fat to dairy cows increased milk production from 18.88 kg per day to 22.48 kg per day. Similarly, increased milk production was achieved by providing polyunsaturated FA (fatty acids with calcium salts) to lactating cows [43, 44]. Gargouri et al. [45] found the positive effects of feeding calcium (Ca+) salts of fatty acids (FA) to dairy animals in early lactation. They observed a maximal response when adding 150-300 g/day of bypass fat to the ration of dairy cows. Also, Kirovski et al. [46] they observed that the level of milk production increased in the group supplemented with 300 g protected fat/cow/day.

Souza et al. [47] also observed that intake of 2850 Kcal ME/kg dry matter was very good to improve milk production, improving the lactation curve. Lactation duration was improved by protected fat supplementation, which could be due to high energy intake and lower stress effect during early lactation [48], increased lactation duration also increases total milk production milk. It is also recommended by previous studies that bypass fat supplementation improved milk production [49-54].

Mobeen et al., [52] conducted research on four experimental groups (G1, G2, G3 and G4), administering in addition to the basic ration 0, 250, 350 and 450g protected animal fat/day, respectively. The experimental results revealed a significant effect ($P<0.05$) on milk production, obtaining an extra 3.14 kg of milk per day in the G2 group compared to the control group. Milk yield corrected for fat was also improved ($P<0.05$) from 8.25 (G0) to 12.36 kg/day (G2).

However, a small number of research have concluded that some of the sources presented do not significantly affect the quantity or quality (chemical composition) of the obtained milk. Bailoni et al. [55] reported that feeding dairy cows extruded or roasted soybeans (full fat) as a replacement for soybean meal had no effects on milk production or milk composition. Also, Ure et al. [56] found that feeding cows extruded soybean meal or extruded soybean meal treated with calcium oxide alone, or calcium oxide plus lingon sulfonate, did not improve feed intake, milk production, or milk composition.

A supposed beneficial effect of feeding whole extruded soybeans is the increase in rumen undegraded protein (PNR). Increasing the PNR content of high-degradation protein forages can have a positive influence on milk yield and milk composition in high-producing dairy cows by allowing a greater flow of essential amino acids available for absorption in the small intestine [57].

Gulati et al. [58] reported that milk fat percentage was improved by feeding bypass fat to animals. Also, Barley and Baghel [59] found a significant increase in milk fat percentage by feeding buffaloes with protected fat for up to five weeks of the experimental period. The increase in milk fat is due to the greater availability of easily absorbable fat in the gut, which is not degraded or modulated in the rumen due to its inert nature. Addition of inert fat to the diet effectively increased milk and fat production in crossbred dairy cows [49].

Nasim et al. [60] identified that rumen-protected fat and vegetable oil supplements increased milk fat percentage compared to the control group.

Mobeen et al. [52], showed that milk composition, in terms of fat percentage, was significantly improved [5.25 (G0) to 5.78 (G2)]. While mean protein content, SNF% and total dry matter percentage were not affected. Similarly, the change in body weight was insignificant. Milk value (Rs./day) was significantly ($P<0.05$) increased from 512.25 to 747.75 in G0 to G2 group.

In contrast, Scott et al. [28] found no effects on milk composition when different soybean products (whole or extruded soybean) were used. Eifert et al. [61] detected a decrease in milk fat content from 3.34 to 3.13% when soybean oil was included in the concentrate feed mixture. Radivojević et al. [62] found that partial replacement (not full replacement) of extruded whole soybeans with soybean meal did not change milk fat or protein percentage. Another study concluded that the addition of inert rumen fat to the ration of dairy cows showed no significant effect on milk composition, including lactose content, fat-free solids and total solids [63].

If in the case of milk fat there are different opinions, it seems that the same does not happen in the case of protein, total dry matter and SNF.

Wrenn et al. [64] fed dairy cows a ration supplemented with protected fat for 18 weeks after calving and found no difference in milk protein. No significant effect on protein and dry matter was observed by supplementing with rumen protected fats in the study by [65]. Also, Sharma et al. [48], did not observe significant improvements in milk protein and total dry matter with bypass fat supplementation.

Also, Sallam et al., [32], noted that there were no obvious effects on milk composition (fat, protein, lactose, total SU, fat-free SU and ash), even though SNF and lactose percentages showed slight improvements in the group with Full-fat soy compared to the MEGALAC group. Fat/protein ratio was the only parameter that increased ($P < 0.05$) in the Full fat soy group compared to the MEGALAC group based on the increase in milk fat percentage. Radivojević et al. [62] showed an opposite trend to those observed, with the inclusion of FullFat soy increasing the fat/protein ratio of milk, compared to diets containing both soy and extruded whole soy.

It is interesting to know that fat/protein ratio is an important indicator of lipomobilization and EEN status in postpartum cows. An early lactation fat/protein ratio greater than 2.0 showed an increase in postpartum diseases such as placental retention, left-shifted abomasum, metritis and clinical endometritis, but also a decrease in milk production in lactation early [23]. It could be argued that both diets used by Sallam et al, [32] were adequate to meet the energy requirements of the animals as the fat/protein ratio was less than 2.

Sallam et al (2021), full-fat extruded soy had a higher percentage of unsaturated fatty acids compared to the commercial product MEGALAC. However, analysis of the fatty acid content of the milk fat showed that the percentage of unsaturated fatty acids in the milk of the Full fat soy group was not increased compared to the MEGALAC group. This finding can be a proof regarding the occurrence of biohydrogenation in the rumen of unsaturated fatty acids from Full fat soy.

By including fats or oils in the diet, energy intake can be increased. The inclusion of vegetable fat in the diet reduced the percentage of milk protein, and animal fat had either no effect or minimal effect on the amount of milk protein [59].

In the studies of Dunkley et al. [21] was highlighted the depressing effect was on the casein fractions. It is assumed that the mechanism of milk protein reduction is related to altered glucose metabolism [5], or changes in rumen metabolism [66], or both. Therefore, the high intake of food energy in the diet of dairy cows had a significant effect on the change in the amount of protein in milk.

Hartfoot [67], reported that under normal conditions, unsaturated FAs that escape biohydrogenation in the rumen are selectively esterified into plasma cholesteryl ester fractions and phospholipids. This process makes those FAs unavailable for milk fat synthesis. However, when large amounts of PUFA reach the intestines, the mechanism for segregating these components is not adequate, and the excess is incorporated into triacylglycerol. Triacylglycerols are the primary source of preformed FAs for milk fat synthesis in the mammary gland [67].

Similarly studies by Sallam et al, [32] showed that Full fat soy increased serum cholesterol concentrations, while milk fat and unsaturated (total) fatty acids in milk did not change significantly, supporting the hypothesis previous. It is interesting to note that although the percentage of unsaturated fatty acids in milk was not different in both experimental groups (32.32% in the commercial product and 34.20% in Full fat soy), the ratio of unsaturated fatty acids ω-3 and ω-6 was different. The percentage of ω-3 fatty acids was higher in the MEGALAC group, and this increase was mainly due to the increase in the percentage of alpha-linolenic acid. ∝-Linolenic acid (C18:3 ω-3) was 3.260% in the MEGALAC group and only 0.635% in the Full-Fat Soy group. Consequently, the ω-6/ ω-3 ratio was lower in the MEGALAC group (3.46) than in the Full fat soy group (17.51). This change in the fatty acid profile is beneficial for human health. The problem is not that ω-6 fatty acids are unhealthy; they are considered "good" fats and an important part of a healthy diet. However, a high level of ω-6 can interfere with how the body uses ω-3 fatty acids and therefore limit their health benefits, such as reducing the risk of cardiovascular disease, diabetes and obesity [68, 69]. The Full-Fat Soy diet also decreased ($P<0.05$) capric acid (C10:0) from 0.204 to 0.105% and increased oleic acid (C18:1) from 2.143 to 7.033%.

The composition of the cows' diet and the feeding technique mainly affect the milk fat content and composition. High-fat and/or low-fat diets can reduce the fat content of milk. However, the effect of diet on protein content is small and negligible on lactose content.

Although we are used to usually researching productive and quality indices of milk, it is at least as important to take a look at how the use of bypass fat affects the economic efficiency of the dairy farm.

Naik et al. [70], reported an additional profit of about 34.50/day with increased milk production.

Similarly, a profit of about 39.66/day was achieved through improved productive efficiency due to bypass fat feeding in previous studies [71-73]. Iqbal et al. [73] also reported a positive response in increasing milk production and profitability by feeding bypass fat to lactating animals.

Mobeen et al. [32], obtained the maximum feeding cost at the level of supplementation with 450 g bypass fat/day and the minimum in the control group. The highest cost of milk (cost/kg milk) was observed at a supplementation level of 450g and the lowest at 350 g. Improved profitability was observed in all fat groups except the 450g supplementation level, and the maximum profit was obtained at 350g, i.e. 31.40% more profit than the control group.

Results of milk protein content by fat feeding for tallow, oilseed and Megalac were different, and the estimated mean differences were all small effects, except for other Ca salts, which had a more obvious negative effect.

In milk production, the nutritional component is the most important factor and accounts for approximately 60-70% of the costs [74]. To achieve maximum profitability, feed must be nutritionally balanced and also economical.

4. Conclusions

In this review, based on the works analyzed we can conclude that the diet supplemented with protected fats in dairy cows had effect on the quantity and quality of milk.

Based on the data presented, it can be concluded that supplementing the ration with bypass fat in dairy cows can be a good option to increase milk production, without compromising milk quality and animal health.

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