PERSPECTIVES ON THE INFLUENCE OF PUMPKIN SEED MEAL AND PUMPKIN SEED CAKE AS ALTERNATIVE SOURCES FOR ENHANCING THE NUTRITIONAL VALUE OF MILK

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Abstract

The growing interest in functional dairy products and the need to reduce dependence on conventional feeds have led to increased research on alternative feed sources for dairy cows. Among these, pumpkin seed meal and pumpkin seed cake (Cucurbita pepo L.) stand out due to their high protein content, balanced essential amino acids, and richness in unsaturated fatty acids, carotenoids, and natural antioxidants. This article explores the impact of using pumpkin seed meal and cake as alternative feeds in dairy cow diets, focusing on their chemical composition, nutritional differences, and effects on milk yield, composition, and fatty acid profile. Studies show that adding pumpkin seed meal or cake does not affect milk production, digestibility, or rumen fermentation. Moreover, high-oil pumpkin seed cake can improve the antioxidant status of cows and slightly change the milk fatty acid profile, increasing unsaturated fatty acids. These results highlight the nutritional, economic, and sustainable value of pumpkin seed meal and cake in dairy cow diets. Including these by-products in modern feeding strategies can help produce value-added milk that meets consumer demand for healthier and functional products.

Key words: *dairy cows, fatty acids, functional milk, pumpkin seed cake, pumpkin seed meal*

INTRODUCTION

The dairy industry is undergoing a continuous transformation, increasingly influenced by consumer demands for healthy, functional, and sustainable products [1, 2]. In recent years, the global trend of reducing the use of conventional feed has led to intensified research on alternative sources of proteins and fats used in dairy cow nutrition [3]. Particular interest has been given to oilseed by-products obtained after vegetable oil extraction, due to their high nutritional value and potential to improve the quality and functional properties of milk [3, 4].

Pumpkin meal and pumpkin cake have attracted attention due to their high protein content, balanced profile of essential amino acids, and significant levels of unsaturated fatty acids, carotenoids, phytosterols, and compounds with antioxidant potential [3, 5]. These ingredients are obtained from pumpkin seeds (*Cucurbita pepo L.*), and their chemical composition depends significantly on the variety, geographical area, and the technology used for oil extraction [3, 4, 5].

Although in common language the terms “meal” and “cake” of pumpkin are often used interchangeably, from a technological perspective they designate two different products, obtained through distinct processing methods, which give them different nutritional characteristics

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and, implicitly, variable effects on feed rations intended for dairy cows. Understanding these differences is essential for formulating effective nutritional strategies and for the optimal valorization of their functional potential [2, 6, 7].

Pumpkin meal is generally obtained by extracting oil from pumpkin seeds using solvents or by a mechanical pressing process followed by additional defatting. This procedure results in a low residual fat content, usually between 5% and 12%, while maintaining a high crude protein level, which can reach up to 65–70%, depending on the method used [8]. Due to its high protein concentration, pumpkin meal is considered a valuable protein source and is preferred in situations where the main objective of ration formulation is to increase protein intake while maintaining a moderate energy content [9].

In contrast, pumpkin cake is obtained by cold mechanical pressing of the seeds, a method frequently used in the artisanal pressed oil industry [10]. This technology results in a product with a higher residual fat content, usually between 8% and 15%, and a moderate protein content, generally ranging between 40% and 55%. Therefore, pumpkin cake can be considered a mixed source of energy and protein, with the additional advantage of providing significant amounts of unsaturated fatty acids, beneficial for ruminant health and potentially influencing the lipid composition of milk [11].

These technological and nutritional differences make pumpkin meal and pumpkin cake distinct ingredients in the formulation of dairy cow rations. Their choice depends on the pursued nutritional objectives, the local availability of by-products, and economic considerations regarding their cost. Moreover, the method of production influences not only the protein profile and lipid content but also the supply of bioactive compounds such as phytosterols, tocopherols, and carotenoids, which can positively affect milk quality and its functional properties [1, 10, 11].

The integration of pumpkin meal and pumpkin cake into dairy cow rations represents a strategy with multiple nutritional, economic, and ecological advantages. First, these by-products serve as alternative protein sources and can partially or fully replace soybean meal, thereby reducing dependence on an expensive raw material subject to price fluctuations on the global market. Second, due to their high content of unsaturated fatty acids and natural antioxidants, pumpkin meal and cake can contribute to improving the lipid profile of milk, increasing the proportion of beneficial fatty acids and enhancing the antioxidant activity of dairy products [3, 5, 12].

In addition to nutritional advantages, the use of these by-products also offers economic benefits. Since pumpkin meal and cake are derivatives of the oil industry, they may be more affordable compared to other conventional protein sources. Moreover, their inclusion in cow nutrition promotes sustainability by valorizing secondary resources and reducing food waste through the implementation of the circular economy concept [11, 13].

The results of recent studies highlight that the partial or total replacement of soybean meal with pumpkin meal or cake does not negatively affect milk production, nutrient digestibility, or ruminal fermentation. Furthermore, research has reported significant improvements in the antioxidant status of cows fed with these by-products, as well as subtle changes in the fatty acid composition of milk, particularly through an increase in the proportion of unsaturated fatty acids. These findings suggest promising potential for the development of functional dairy products tailored to modern consumer demands [3, 5, 12].

Over the past decade, the dairy market has undergone a significant transformation

driven by changes in consumer behavior and a shift toward healthy and sustainable nutrition. Interest in functional milk and dairy products has increased considerably, with preference for foods that provide additional health benefits beyond their basic nutritional value. More and more consumers are seeking dairy products with an improved lipid profile, rich in unsaturated fatty acids and natural antioxidants, associated with positive effects on lipid metabolism, cardiovascular health, and immune function [14, 15].

This trend creates important opportunities for the livestock sector and the dairy industry through the development of innovative nutritional strategies that optimize milk composition from the primary production stage. The integration of pumpkin meal and cake into dairy cow rations can contribute to obtaining milk with added value, meeting current market demands for functional dairy products and foods with a positive impact on health. In this context, a comprehensive review of the scientific literature is necessary to highlight the real potential of these by-products and to substantiate their use in dairy cow nutrition [12, 13, 16].

MATERIAL AND METHOD

This review was conducted as a systematic literature analysis focused on the use of pumpkin seed meal and pumpkin seed cake in dairy cow nutrition and their effects on milk yield, fatty acid composition, and functional properties.

Relevant scientific articles were searched in databases including Web of Science, Scopus, PubMed, Google Scholar, MDPI Journals, and Sci-Hub. The search strategy employed combinations of keywords such as "pumpkin seed meal," "pumpkin seed cake," "dairy cows," "milk fatty acids," "antioxidants," "functional milk," and "oilseed by-products." Data were extracted and synthesized by categorizing findings into the following main topics: nutritional profile of pumpkin seed meal and cake, effects on cow performance and ruminal parameters, modifications in milk fatty acid composition, antioxidant properties and oxidative stability of milk, and the comparative role of pumpkin seed cake versus other oilseed by-products.

RESULTS

Nutritional profile of pumpkin seed meal and pumpkin seed cake

The analysis of available literature indicates that pumpkin seed by-products are characterized by high concentrations of crude protein, variable lipid fractions, considerable fiber content, and relevant levels of bioactive compounds. The reported nutritional values vary depending on the crop, growing conditions, and processing technology.

A summary of the proximate composition of pumpkin seed meal and pumpkin seed cake reported in recent literature is presented in Table 1, highlighting the main differences in protein, lipid, fiber, and energy content.

Table 1. Comparative proximate composition of pumpkin seed meal and pumpkin seed cake

Component (%)	Pumpkin seed meal	Pumpkin seed cake	Source
Crude protein	45–65%	40–55%	[3, 5, 8, 9, 13, 20]
Crude fat	5–12%	8–15%	[3, 5, 12, 17, 19]
Crude fiber	10–25%	8–18%	[8, 9, 13, 17]
Ash	4–8%	4–7%	[8, 9, 17]
Energy (MJ/kg DM)	18–20	19–22	[3, 5, 20]

As shown in Table 1, pumpkin seed meal is generally richer in crude protein, while pumpkin seed cake retains more residual fat due to cold-pressing. Reported values for crude protein in pumpkin seed meal range between 45% and 65%, with the variation

largely dependent on the degree of oil extraction [8, 9, 13]. Essential amino acids such as arginine, glutamic acid, and leucine are consistently present in high proportions, supporting the recognized biological value of these proteins [10, 13, 17].

The crude fat content differs significantly between products: defatted meals generally contain 5–12% lipids, while cold-pressed cakes retain 8–15% [3, 5, 12]. The lipid profile is dominated by unsaturated fatty acids, primarily linoleic acid and oleic acid, which together exceed 70% of the total fatty acid composition. α-Linolenic acid is present at lower concentrations but remains nutritionally relevant [2, 7, 9].

A detailed comparison of the fatty acid profile and selected bioactive compounds in pumpkin seed meal and cake is provided in Table 2.

Table 2. Fatty acid profile and bioactive compounds in pumpkin seed meal and pumpkin seed cake

Parameter	Pumpkin seed meal	Pumpkin seed cake	Source
Linoleic acid (C18:2, ω-6)	40–55% of total FA	45–60%	[2, 5, 7, 9, 17, 19]
Oleic acid (C18:1, ω-9)	20–30%	25–35%	[5, 7, 9, 17]
α-Linolenic acid (C18:3, ω-3)	0.5–3%	1–4%	[2, 5, 7]
Saturated fatty acids (SFA)	15–20%	12–18%	[5, 9, 19]
Tocopherols	40–80 mg/100g oil basis	60–100 mg/100g oil basis	[17, 18, 19]
Carotenoids	5–20 mg/kg	10–25 mg/kg	[8, 19]
Phytosterols	150–250 mg/100g	200–300 mg/100g	[8, 9, 17]

The data in Table 2 confirm that both products are valuable sources of unsaturated fatty acids and natural antioxidants, with pumpkin seed cake generally exhibiting higher levels of tocopherols, carotenoids, and phytosterols due to its greater lipid retention. These bioactive compounds contribute to the nutritional quality of the by-products and may enhance the functional properties of milk when included in dairy cow diets.

Crude fiber levels reported in pumpkin seed by-products range from 10% to 25%, while ash content varies between 4% and 8% [8, 9, 17]. The mineral fraction includes appreciable amounts of magnesium, phosphorus, zinc, and iron, which enhance the nutritional value of these ingredients [9, 18].

Several phytochemicals with antioxidant potential are consistently identified, including carotenoids, tocopherols, and phytosterols. Their concentration is influenced by the extraction method, with cold-pressed cakes generally exhibiting higher levels due to their lipid-rich matrix [8, 13, 19].

Both pumpkin seed meal and pumpkin seed cake provide high-quality proteins, valuable unsaturated fatty acids, and bioactive components. The compositional variability observed across studies highlights the role of processing and seed characteristics in determining their nutritional profile.

Effects of pumpkin seed meal and pumpkin seed cake on dairy cows and milk

Several studies have investigated the impact of pumpkin seed meal and cake inclusion on total milk yield in dairy cows. Substitution of soybean meal with pumpkin seed by-products has generally shown no adverse effect on overall milk production. Li et al. [3] reported that replacing soybean meal with pumpkin seed cake in Holstein diets maintained stable milk yield while improving the antioxidant status of cows. Similarly, Li et al. [5] observed that high-oil pumpkin seed cake did not reduce daily

milk yield, confirming its suitability as a protein source. Comparative studies with soybean meal suggest that pumpkin seed products can partially or completely replace soybean without compromising lactation performance [2, 3, 5, 12].

The incorporation of pumpkin seed by-products has been associated with modest changes in milk composition. Studies indicate that milk protein, fat, and lactose levels remain largely unaffected when pumpkin seed meal or cake is included in the diet [3, 5]. However, significant effects are reported on the fatty acid profile of milk. Li et al. [5] demonstrated that diets containing high-oil pumpkin seed cake increased the proportion of unsaturated fatty acids, particularly linoleic and oleic acids, and reduced the proportion of saturated fatty acids. Similar findings were confirmed by Kokić et al. [2], who highlighted improvements in the omega-6 to omega-3 ratio and the potential for functional milk with enhanced nutritional properties.

Beyond production traits, pumpkin seed by-products exert positive effects on cow health and metabolic responses. Studies consistently report improvements in the antioxidant status, with reduced oxidative stress markers in cows fed pumpkin seed cake [3, 5]. This is attributed to the high content of natural antioxidants such as tocopherols and carotenoids [8, 19]. Moreover, research has shown that inclusion of pumpkin seed products does not impair ruminal fermentation or nutrient digestibility, supporting their compatibility with ruminant physiology. Long-term feeding trials remain limited, but available evidence suggests predominantly beneficial outcomes, with no significant adverse effects observed on animal health or productivity [3, 5, 12, 20].

The main effects of pumpkin seed meal and pumpkin seed cake supplementation on milk yield, composition, fatty acid profile, and antioxidant status are summarized in Figure 1.

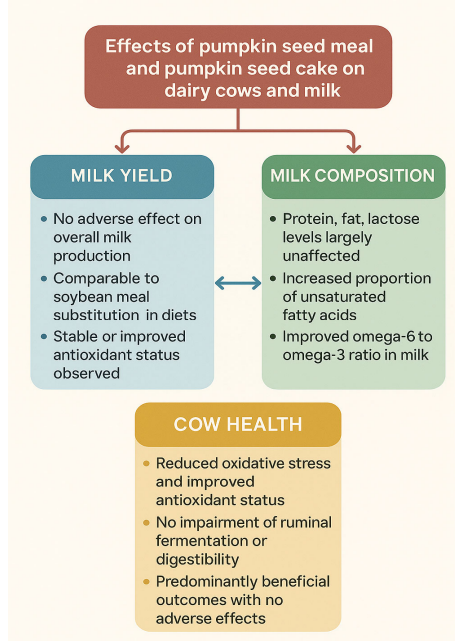

Fig. 1 Schematic representation of the effects of pumpkin seed meal and pumpkin seed cake on dairy cows and milk quality.

Functional impact of pumpkin seed meal and pumpkin seed cake on cow's milk

The incorporation of pumpkin seed meal and pumpkin seed cake into dairy cow diets not only sustains production performance but also introduces functional improvements to milk quality. These benefits extend beyond basic nutrient provision and address the growing demand for dairy products with health-promoting properties and enhanced technological stability [3, 5, 21].

One of the key functional impacts of pumpkin seed cake is its ability to modulate the fatty acid composition of milk. Compared with conventional rations, diets enriched with pumpkin seed cake consistently increase the proportion of unsaturated fatty acids, particularly linoleic acid and oleic acid, while reducing the levels of atherogenic saturated fatty acids such as myristic acid and palmitic acid.

These changes lead to a more favorable polyunsaturated-to-saturated fatty acid

ratio, aligning with dietary guidelines aimed at lowering cardiovascular disease risk [2, 20, 22]. Moreover, modest but consistent increases in vaccenic acid and conjugated linoleic acid have been reported, arising from ruminal biohydrogenation of pumpkin-derived lipids. Such shifts enhance the nutritional value of milk fat, positioning it as a functional food ingredient with potential benefits for human lipid metabolism, cardiovascular health, and immune function [12, 20, 23].

In addition to fatty acid modulation, pumpkin seed cake contributes to improving the antioxidant status of milk. Pumpkin seeds are naturally rich in tocopherols (vitamin E isomers), carotenoids (β-carotene and lutein), and phenolic compounds [8,19], many of which are retained in pumpkin seed cake due to its residual lipid fraction. Feeding trials indicate that cows supplemented with pumpkin seed cake exhibit higher plasma antioxidant capacity, which may partly translate into increased oxidative stability of milk. Enhanced tocopherol and carotenoid levels in dairy fat can delay lipid oxidation, thereby extending shelf life and preserving sensory quality. This property is particularly relevant for functional dairy markets, where oxidative stability is a prerequisite for fortifying milk with unsaturated fatty acids [3,11, 24].

Comparative studies show that pumpkin seed cake exerts distinct effects compared with other oilseed by-products. For example, sunflower seed cake is efficient in elevating conjugated linoleic acid levels but may reduce milk protein percentage when fed at high inclusion rates. Flaxseed by-products enrich milk with alpha-linolenic acid and other omega-3 fatty acids but sometimes depress milk yield and fat content [5, 23, 25]. In contrast, pumpkin seed cake maintains stable milk yield and protein levels while primarily enriching omega-6 fatty acids and antioxidants. This complementary role suggests that pumpkin seed cake could be strategically combined with flaxseed or hempseed products to achieve balanced enrichment of both omega-6 and omega-3 fatty acids in milk [3, 26, 27, 28].

The functional properties of milk derived from pumpkin seed cake feeding also hold promise for dairy innovation. By producing milk naturally enriched with unsaturated fatty acids and antioxidants, farmers and processors can respond to consumer demand for healthier dairy foods.

Recent surveys highlight that consumers value dairy products marketed with claims such as source of omega-3 and omega-6, contains natural antioxidants, or supports cardiovascular health. Incorporating pumpkin seed cake into feeding strategies could therefore contribute to the development of premium dairy products targeted at health-conscious markets, while simultaneously supporting sustainability goals by valorizing agro-industrial by-products [5, 29, 30, 31].

DISCUSSIONS

The synthesis of the literature clearly indicates that pumpkin seed meal and pumpkin seed cake represent valuable alternatives to conventional protein sources in dairy cow nutrition. The results obtained in the studies reviewed confirm that their inclusion in feed rations does not negatively affect milk yield or basic composition, a finding that is in agreement with broader research on oilseed by-products used in ruminant diets. This aspect is particularly relevant in the current context, where the dairy industry faces the dual challenge of maintaining productivity while simultaneously meeting consumer demands for healthier and more sustainable products [32, 33].

One of the main functional outcomes emphasized by the literature is the modulation of milk fatty acid composition. Pumpkin seed cake supplementation consistently leads to an increase in the

proportion of unsaturated fatty acids, particularly linoleic acid and oleic acid, while reducing the proportion of atherogenic saturated fatty acids such as palmitic and myristic acid. These changes result in an improved polyunsaturated-to-saturated fatty acid ratio, a nutritional trait highly valued for human health due to its potential role in reducing cardiovascular risk [31, 34, 35]. Similar effects have been reported for flaxseed and rapeseed cakes, although flaxseed often enriches milk in omega-3 fatty acids at the expense of milk yield, whereas pumpkin seed cake maintains stable production levels. This complementary nutritional role suggests that pumpkin seed cake could be used in combination with other oilseed by-products to achieve a more balanced enrichment of both omega-3 and omega-6 fatty acids [2, 5, 36].

Another important contribution of pumpkin seed cake is its effect on antioxidant status, both in animals and in milk. The elevated levels of tocopherols, carotenoids, and phytosterols, often retained after cold-pressing, contribute to enhanced oxidative stability of milk fat. This has significant technological and economic implications, as higher oxidative resilience directly translates into improved shelf life and sensory stability of dairy products [27]. Comparable improvements in oxidative stability have also been observed with sunflower and rapeseed cakes, but pumpkin seed cake stands out due to its simultaneous effect on fatty acid enrichment and antioxidant content. However, detailed metabolomic and lipidomic investigations are still scarce, and further studies are needed to confirm the transfer of pumpkin-derived bioactive compounds into milk in biologically active forms [30, 34, 37, 38].

At the practical level, the integration of pumpkin seed by-products into dairy cow rations supports the transition towards circular economy models in agriculture. By valorizing agro-industrial residues, producers can simultaneously reduce feed costs and the environmental footprint of dairy production. The relevance of this approach has also been highlighted in studies analyzing the correlation between feed quality and milk productivity in Romanian farms, where alternative feed sources were associated with stable yields and improvements in milk quality.

Furthermore, research conducted on sunflower, rapeseed, and linseed cakes in Romanian contexts confirms the potential of oilseed by-products to modulate milk fatty acid composition, with implications for functional dairy development. These findings strengthen the argument for considering pumpkin seed meal and cake as part of the same nutritional strategy [3, 5, 34, 38].

From a consumer-oriented perspective, the enrichment of milk with unsaturated fatty acids and natural antioxidants offers significant opportunities for innovation in the dairy sector. Recent studies on consumer perception underline a growing preference for functional dairy products marketed with health-related claims, such as source of omega-3 and omega-6, rich in antioxidants, or upports cardiovascular health. This trend has also been documented in Romanian literature, which highlights increasing consumer awareness of the link between milk composition and human health [14, 35, 36]. Thus, the functional improvements associated with pumpkin seed cake supplementation can be directly translated into added value for dairy products, supporting the development of premium, health-oriented markets.

Nevertheless, several limitations should be acknowledged. The majority of studies on pumpkin seed meal and cake are short-term and focus primarily on production performance and milk fatty acid composition. There is still limited evidence regarding long-term effects on cow health, fertility, or the technological behavior of enriched milk in processing.

CONCLUSIONS

The current review highlights the nutritional and functional potential of pumpkin seed meal and pumpkin seed cake as alternative feed ingredients in dairy cow nutrition. Their balanced protein profile, high content of unsaturated fatty acids, and presence of natural antioxidants position them as valuable by-products that can simultaneously support productive performance and contribute to improved milk quality.

Evidence from recent studies indicates that pumpkin seed by-products can be safely included in rations without compromising milk yield, while promoting favorable modifications in the fatty acid profile and oxidative stability of milk. These characteristics open opportunities for producing dairy products with added value, aligned with consumer demands for healthier and more sustainable foods.

At the same time, variability in chemical composition due to cultivar, growing conditions, and processing technology underlines the need for further research aimed at standardization and optimization of their use. Long-term feeding trials and comparative analyses with other oilseed by-products remain necessary to fully assess their potential and to define best practices for practical implementation.

Overall, pumpkin seed meal and pumpkin seed cake represent not only a sustainable alternative to conventional protein sources but also a promising tool for innovation in the dairy sector, offering both nutritional and economic benefits within the framework of a circular economy.

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