Alternative Feed Sources in Response to Climate Change and Their Impact on Milk Production in Dairy Cows

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Abstract

Climate change and the increasing frequency of droughts over recent decades have significantly affected the availability of traditional forage crops in Central and Eastern Europe, leading to higher production costs and reduced profitability of dairy farms. In this context, the volatility of imported raw material prices and the instability of conventional forage supply make it necessary to diversify feeding sources by exploiting alternative ingredients with local availability and demonstrated nutritional value. This review critically analyses the nutritional potential of milk thistle (*Silybum marianum*) cake, pumpkin seed (*Cucurbita pepo L.*) cake and linseed (*Linum usitatissimum*) meal, evaluating their effects on milk production and composition, dry matter intake and digestibility in dairy cows, as well as the economic implications of their integration into rations. Milk thistle cake is distinguished by its silymarin content, a flavonolignan complex with hepatoprotective and antioxidant properties, with favourable effects on peripartum metabolic health and the improvement of milk composition. Pumpkin seed cake, rich in crude protein and unsaturated fatty acids, can completely replace soybean meal without negatively affecting productive performance, while also contributing to the improvement of the antioxidant status of animals. Linseed meal exerts the strongest documented effects on the lipid profile of milk, significantly enriching the omega-3 fatty acid and conjugated linoleic acid fractions, with direct benefits for the nutritional value of milk and animal health. The integration of these agro-industrial by-products into dairy cow rations reduces dependence on volatile imported protein markets, valorises local resources within a circular economy framework and stabilises feed costs. The synthesis of available literature confirms the genuine nutritional and economic potential of these alternative sources, recommending them as viable solutions for milk production systems adapted to current climate challenges.

Keywords: alternative feed, dairy cows, linseed cake, milk thistle cake, oilseed by-products, pumpkin seed cake

1. Introduction

Milk represents one of the most important food products of animal origin, recognised both for its high nutritional value and for its significant economic role in agro-food systems. Rich in high-biological-value proteins, calcium, fat-soluble and water-soluble vitamins, and essential minerals, milk contributes directly to meeting human nutritional requirements at all stages of life [1]. The nutritional quality of milk, particularly its fatty-acid composition, is a topic of growing interest because it can vary with feeding system, season, breed and farming conditions [2, 3].

The global context in which the dairy sector operates is increasingly marked by the pressures exerted by climate change on agricultural systems. Increases in average global temperatures, changes in precipitation regimes and the amplification of extreme weather events, prolonged droughts, heat waves, torrential rains, directly affect the production capacity of agricultural crops, including

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those intended for animal feed [4, 5]. Europe, and particularly its central-eastern and south-eastern regions, is experiencing a worrying intensification of these phenomena: recurrent droughts over the past decade have severely affected both crop production and the economic balance of livestock farms [5, 6]. Romania falls within this trend, with repeated droughts in recent years causing significant damage to traditional fodder crops [6].

These climate realities overlap with structural trends already visible in European agriculture: the progressive reduction of areas cultivated with conventional fodder plants, increased production costs and increasingly uncertain availability of the main raw materials used in dairy cow feeding. Classical fodder crops, maize silage, alfalfa, triticale, fodder wheat are becoming more vulnerable to climate variability, generating growing difficulties in ensuring the quantitative and qualitative balance of daily rations [7, 8].

Faced with these challenges, the adaptation of feeding systems in the dairy sector is a necessity. Diversification of feed sources, through the integration of alternative ingredients with proven nutritional potential, is one of the most accessible and effective strategies to respond to the instability of the conventional feed supply [9, 10]. Agro-industrial by-products and unconventional oilseed cakes, including milk thistle (*Silybum marianum*) cake, pumpkin seed (*Cucurbita pepo*) cake and linseed (*Linum usitatissimum*) meal are of growing interest in the specialised literature, due to their favourable chemical composition and local availability [11].

The aim of the present review is to analyse the impact of recurrent droughts on traditional fodder crops and to highlight the potential of alternative feeding sources for dairy cows. The work characterises the nutritional value of milk thistle, pumpkin seed and linseed cakes, evaluates their effects on milk yield and quality, and discusses the economic implications of diversifying the feed base.

The conceptual relationship between climate-change-induced drought, the vulnerability of traditional fodder crops and the need to diversify feed sources in dairy cow nutrition is summarised in Figure 1.

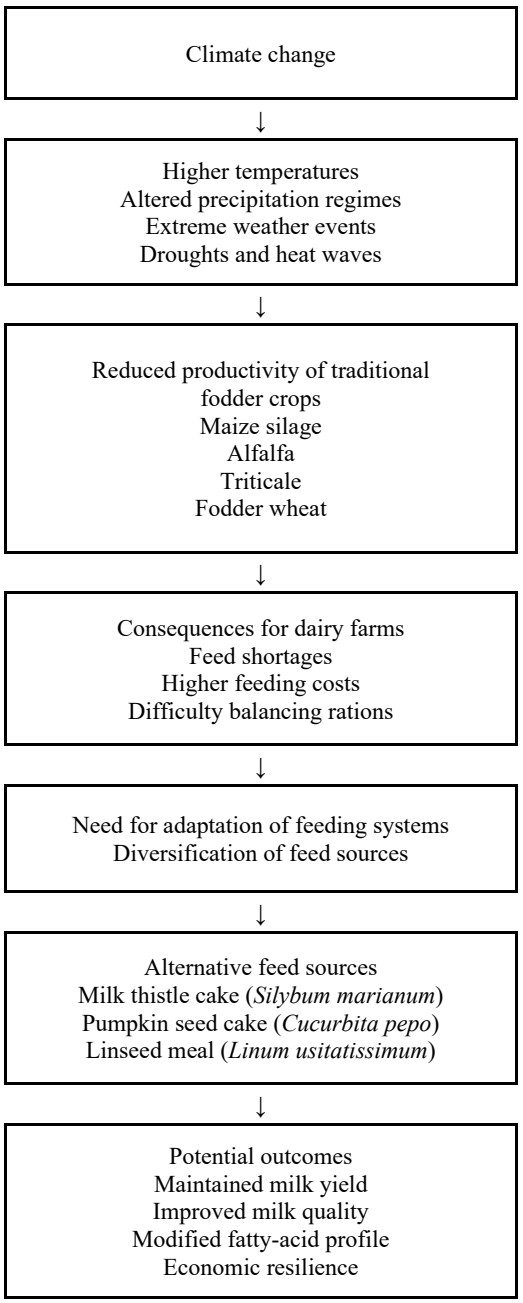

Figure 1. Conceptual framework for alternative feed use under drought conditions.

2. Materials and methods

This paper is a systematic review based on the analysis of relevant scientific literature. Peer-reviewed articles available in reputable databases such as Web of Science, Scopus, Google Scholar, PubMed and MDPI were screened. The research focused on studies investigating the agronomic adaptability, chemical composition, in vivo digestibility and effects on milk yield, milk composition and animal health of milk thistle cake,

pumpkin seed cake and linseed cake/meal in dairy cow rations. Selection criteria included peer-reviewed publications, studies that directly measured productive parameters and milk fatty-acid profiles, and works providing quantitative data. Information was extracted, compared and synthesised to highlight similarities, differences and trends.

3. Results and discussion

3.1. Impact of recurrent droughts on traditional fodder crops

Extreme climatic phenomena, particularly droughts and heat waves have become an increasingly prominent feature of the European agricultural landscape, with frequency and intensity rising compared with previous decades. In recent years, drought-affected areas have expanded considerably relative to the 1981-2017 reference period, with atmospheric evaporative demand contributing significantly to this evolution [12]. Climate model simulations project the continuation of these trends, with a high level of certainty that both temperature increase and precipitation reduction have already led to accelerated aridification in central and southern Europe [13]. Even under moderate warming scenarios, extreme heat and drought levels that were practically impossible two decades ago could reach occurrence probabilities of one in ten as early as the 2030s [14]. Drought is the most costly natural hazard for European agriculture, and without firm climate action annual EU-level losses are projected to grow markedly through the end of the century [5].

The economic impact of recent droughts has been considerable. The extreme drought of summer 2022 in the European Union caused production reductions for maize, soybean and sunflower compared with the five-year average [7]. Romania bore some of the most severe consequences: the 2022 drought severely affected the Romanian agricultural sector, generating losses exceeding EUR 1 billion, with the country recording its worst maize harvest since 2007 [6].

The principal crops intended for dairy cow feeding are also among the most sensitive to water deficit. Maize silage, the cornerstone of dairy rations in intensive Central and Eastern European systems is the fodder crop most vulnerable to drought, particularly during flowering and grain-filling stages [7]. Alfalfa (*Medicago sativa L.*) shows relative drought resistance through its deep tap-root system, but under prolonged drought combined with high temperatures green-mass yield drops significantly and nutritional quality is compromised through accelerated lignification. Triticale (*x Triticosecale Wittm.*) and fodder wheat (*Triticum aestivum L.*) are also negatively affected by prolonged water deficit. In summer 2018, approximately 40% of the cultivated areas in northern and eastern Europe recorded winter wheat and barley yields below the historical 10th percentile [8]. Up to 44% of steep-slope cropland in Europe has been classified as vulnerable to drought, further limiting the resilience of the conventional forage base [15]. Climate change therefore poses a serious challenge to milk production even in the temperate climatic zones of Central Europe [16].

A comparative synthesis of the main fodder crops affected by drought is presented in Table 1.

Table 1. Effects of drought on the main fodder crops used in dairy cow rations

Fodder crop	Role in the dairy cow ration	Drought sensitivity	Effects on yield and forage quality	References
Maize silage	Main energy source; backbone of rations in intensive systems	Very high, especially at flowering and grain-filling	Reduced biomass and grain yield; lower silage availability; higher substitution costs	[6, 7]
Alfalfa	Important source of protein, fibre and minerals	Moderate; more tolerant due to deep root system, but vulnerable to prolonged drought	Reduction of green mass; fewer cuts; accelerated lignification; loss of nutritive value	[16]
Triticale	Green forage, silage or grain; balanced energy and protein contribution	Moderate; more tolerant than common wheat, but affected by prolonged water deficit	High yield variability; reduced predictability of supply; possible changes in digestibility	[16]
Fodder wheat	Concentrated component of rations; energy source	High during the critical grain-formation and grain-filling stages	Reduced grain yield; lower availability of feed cereals; price pressure	[7, 8]

The reduction in conventional forage production translates directly into rising feed costs and compresses the economic margins of dairy farms. Feed represents the most significant itemised cost of dairy operations, often accounting for the majority of operating costs, so any disruption in conventional feed supply rapidly erodes farm profitability [16].

3.2. Milk thistle (*Silybum marianum*) cake

Milk thistle exhibits agronomic features that make it an exceptional crop in the context of climate change. Its biological and agronomic traits, late spring flowering, very low fertiliser requirements, drought resistance and good adaptability to poor soils make it a reliable alternative for low-input agriculture, capable of delivering acceptable yields in sustainable agricultural systems [17]. Under severe drought conditions in Mediterranean environments, irrigation becomes necessary only at the seed-growth and seed-filling stages [17]. This ecological plasticity makes milk thistle one of the few crops that can be economically valorised on areas where conventional fodder crops fail.

Milk thistle seeds contain a high oil content, low moisture and ash, crude fibre and a total protein content of around one quarter of dry matter. The cake remaining after oil extraction, a by-product of the pharmaceutical industry that produces silymarin concentrates the residual protein and continues to contain bioactive compounds from the flavonolignan complex.

The defining bioactive component of milk thistle is silymarin, a flavonolignan complex with well-documented antioxidant, anti-inflammatory and hepatoprotective properties. In farm animals, silymarin has been shown to improve productive performance and product quality, support oxidative stability, sustain liver function throughout the productive cycle, improve gut health and morphology, and reduce intestinal pathogens [18]. These effects are particularly valuable in transition (peripartum) dairy cows, when animals are predisposed to severe metabolic disorders, particularly ketosis and fatty liver, caused by negative energy balance. Silymarin supplementation in Jersey cows increased milk fat content (4.27% versus 4.02% in controls) and consequently fat-corrected milk yield, without affecting dry-matter intake or feed efficiency [19]. In dairy cattle, silymarin supplementation also improved milk and blood parameters and favoured earlier achievement of peak lactation [20]. In small ruminants, dietary milk thistle oil supplementation positively modulated animal performance and milk fatty-acid composition in dairy ewes [21]. Earlier work demonstrated that the inclusion of milk thistle cake in the ration of cows with peripartum ketosis significantly reduced blood and milk ketone bodies and maintained milk yield versus controls [22].

An important practical aspect is the rumen digestibility of flavonolignans. Studies in dairy cows showed that the digestibility of silybin-A and silybin-B was 40.0% and 45.5% respectively, while the digestibility of other flavonolignans, sosilybin A and B, silydianin, silychristin and taxifolin reached 100% [23], confirming that a substantial fraction of the bioactive compounds remains available for absorption after ruminal fermentation.

3.3. Pumpkin seed (*Cucurbita pepo L.*) cake

Pumpkin offers significant agronomic advantages in the context of climate change, including a relatively short vegetation cycle, tolerance to varied pedoclimatic conditions and good performance on lands less suitable for classical fodder crops. Pumpkin seed cake is a by-product of the pumpkin seed oil extraction industry, a well-established sector in Central and Eastern Europe, including Romania.

The crude protein and ether extract contents of pumpkin seed cake on a dry-matter basis are considerably higher than those of soybean meal, with oleic and linoleic acids identified as the principal fatty acids [24]. Pumpkin seed cake also exhibits the highest crude and soluble protein contents among pumpkin by-products, supplying important nitrogen sources for ruminants, including rumen-undegradable (bypass) protein at levels relevant to the productive requirements of dairy cows [25].

Research on the inclusion of pumpkin seed cake in dairy cow rations has consistently shown that conventional protein sources can be substituted without negatively affecting milk yield. Replacing soybean meal with pumpkin seed cake and dried distillers' grains did not influence ruminal degradability, productive performance, rumen fermentation, dry-matter intake or apparent total-tract digestibility, while nitrogen partitioning between milk, faeces and urine did not differ between experimental groups [26]. These results were confirmed in small ruminants: pumpkin seed cake completely substituted soybean meal in

lactating goat rations without any decrease in milk yield or commercially or human-health-relevant changes in fatty-acid profile [27]. More recently, replacing soybean meal with high-oil pumpkin seed cake in lactating Holstein cow diets modulated rumen bacterial community and milk fatty-acid profile without negatively affecting productive performance or milk quality [28]. In addition, pumpkin seed cake substitution increased total antioxidant capacity and antioxidant enzyme activities in the plasma of cows while reducing malondialdehyde concentrations and hepatic transaminase values [26], effects that translate indirectly into improved mammary-gland health and udder function.

3.4. Linseed (*Linum usitatissimum L.*) meal and cake

Flax has a long-standing tradition in European agriculture, valorised both for fibre and for oilseed. From the standpoint of climatic adaptability, linseed has moderate water requirements and tolerance to thermal variability, allowing successful cultivation in areas where water deficit limits other forage crops. Linseed cake, the by-product of oil extraction is a feed ingredient with local availability in Romania and Central Europe.

Linseed cake stands out for a solid protein content (30-39% in dry matter) and an exceptional polyunsaturated omega-3 fatty-acid profile. The residual oil is predominantly composed of polyunsaturated fatty acids, particularly alpha-linolenic acid (ALA, an omega-3 fatty acid), with omega-3 fatty acids representing more than 50% of total lipids [29]. This composition makes linseed the most efficient natural feed ingredient for improving the omega-6/omega-3 ratio in milk, with direct benefits for nutritional quality.

Linseed and its by-products have been the subject of numerous studies in dairy cows, with consistent results regarding benefits to milk fatty-acid profile and metabolic health. Supplementation with extruded flaxseed in dairy cows increased milk yield, reduced incidence of ketosis and severe metritis, decreased mortality rate and tended to improve reproductive performance, while producing healthier milk, lower in saturated and higher in unsaturated fatty acids [30]. Cold-pressed linseed cake supplementation during the winter period led to significant increases in alpha-linolenic acid, conjugated linoleic acid (CLA), docosapentaenoic acid and docosahexaenoic acid concentrations in the milk lipid fraction [31]. Whole or ground flaxseed feeding in the first half of lactation also improved the milk fatty-acid profile without compromising productive performance [32]. Replacing canola meal partially with flaxseed by-products increased dry-matter intake, raised crude protein content and improved apparent total-tract crude protein digestibility, without affecting ruminal pH, ammonia or volatile fatty-acid concentrations [33].

A comparative synthesis of the agronomic, nutritional and functional features of the three alternative sources is presented in Table 2.

Table 2. Agronomic, nutritional and functional characteristics of the three alternative feed sources

Alternative source	Origin and availability	Nutritional potential	Functional / nutritional potential	Limitations / aspects to monitor	References
Milk thistle cake (*Silybum marianum*)	By-product of oil and/or silymarin extraction; crop adapted to poor soils and drought conditions	Valuable protein content; residual oil, fibre and bioactive compounds; seeds contain ca. 23% protein	Hepatoprotective, antioxidant and anti-inflammatory potential; supports metabolic status during demanding physiological periods	Monitoring of silymarin doses; need to define optimal inclusion levels	[17, 18, 23]
Pumpkin seed cake (*Cucurbita pepo L.)*	By-product of pumpkin seed oil extraction; available in pumpkin processing chains, including Central and Eastern Europe	High crude protein and ether extract; rich in unsaturated fatty acids, especially oleic and linoleic; contains minerals and tocopherols	Potential as alternative protein-energy source; favourable lipid profile through unsaturated fatty acids	Possible high phytate content; need to balance with mineral supply and total dietary fat	[9, 24]
Linseed cake / meal (*Linum usitatissimum L.)*	By-product of linseed oil extraction; available in Romania and Central Europe	30-39% protein in dry matter; rich in alpha-linolenic acid (omega-3), linoleic and oleic acids; contains ruminally fermentable mucilages	Important source of omega-3 fatty acids; potential to improve the nutritional value of milk	Presence of cyanogenic glycosides, mucilages and tannins; cautious inclusion depending on processing and dietary level	[29]

3.5. Effects on milk yield, composition and intake

Cows receiving oilseed-cake diets exhibited slightly higher dry-matter intake than those on cake-free diets [34], suggesting that palatability is adequate and the effect on intake is neutral or slightly positive.

For milk thistle, effects on milk yield depend on the form of administration, dose and lactation stage. Silymarin supplementation in early lactation accelerated metabolic adaptation and led to higher peak production, supporting its use particularly during the transition period [20]. In late lactation, silymarin did not modify dry-matter intake, feed efficiency or mean milk yield, but significantly increased milk fat content and consequently fat-corrected milk yield [19]. For pumpkin seed cake, complete substitution of soybean meal did not affect ruminal degradability, rumen fermentation or apparent total-tract digestibility [26]; the cake's high crude and soluble protein contents support adequate nitrogen supply, including bypass protein [25], explaining the maintained productive performance observed across studies.

Linseed exerts the strongest documented effects on the lipid profile of milk. Flaxseed-derived feeds can decrease saturated fatty acids, increase unsaturated fatty acids, raise CLA and ALA proportions, and lower the omega-6/omega-3 ratio [30, 31]. At the rumen level, polyunsaturated fatty acids in oilseed cakes can modulate fermentation, with a tendency to increase propionate proportion and reduce enteric methane production, an effect documented for high-oil rapeseed cake supplementation [35] and consistent with findings reported for linseed.

Voluntary dry-matter intake (DMI) is a basic parameter for evaluating the palatability and suitability of alternative feed ingredients. Available data indicate that oilseed cakes are generally well accepted by dairy cows when included at moderate levels [34]. Pumpkin seed cake demonstrated compatibility with bovine rations by maintaining DMI at levels comparable to control groups [26], while replacing canola meal with flaxseed by-products increased DMI and improved crude protein digestibility without altering rumen pH, ammonia or volatile fatty-acid concentrations [33]. The integrated picture of productive, compositional and animal-health effects across the three alternative sources is summarised in Table 3.

Table 3. Effects of the alternative feed sources on milk yield, composition and quality

Alternative source	Effect on milk yield	Effect on milk composition	Metabolic / milk-quality effects	Practical interpretation	References
Milk thistle cake / extract (*Silybum marianum*)	Positive effect particularly in the peripartum; can accelerate the achievement of peak production; neutral on gross yield in late lactation	Increased milk fat content and fat-corrected milk yield (4% FCM)	Hepatoprotective, antioxidant and possible favourable effect on somatic cell count; supports metabolic adaptation in early lactation	Useful especially during the transition period and in cows at higher metabolic risk	[17, 18, 19, 20]
Pumpkin seed cake (*Cucurbita pepo L.*)	Does not reduce milk yield when replacing conventional protein sources; neutral on productive performance	Can favourably modify the fatty-acid profile through oleic and linoleic acid contributions	Increases total antioxidant capacity and antioxidant enzyme activity; reduces oxidative-stress markers	Can serve as a protein replacement for soybean meal, with potential to improve antioxidant status	[26, 27, 28]
Linseed cake / meal (*Linum usitatissimum L.*)	Positive or neutral effect; can increase yield in the transition period; does not negatively affect yield in active lactation	Increases ALA[1], CLA[2], DPA[3] and DHA[4] concentrations; reduces saturated fatty acids and improves the omega-6/omega-3 ratio	Can reduce the risk of metabolic disorders, including ketosis and severe metritis; supports inflammatory and metabolic status	Valuable ingredient for producing milk with an improved lipid profile	[30, 31, 32]

[1] Alpha-Linolenic Acid
[2] Conjugated Linoleic Acid
[3] Docosapentaenoic Acid
[4] Docosahexaenoic Acid

3.6. Economic implications and integration into the circular economy

Feeding represents the dominant cost item in dairy production. Composite indicators such as Income Over Feed Cost (IOFC) summarise the gross margin obtained after subtracting feed costs from milk revenue, and recent multivariate aggregation methods enable quantification of feeding and economic efficiency at the farm level [36]. Diversification of protein sources, with reduced dependency on imported soybean meal, has become an economic priority in the European context, where soybean prices have shown high volatility in response to logistical disruptions and severe European drought.

Local oilseed cakes provide reasonable economic alternatives. Pumpkin seed cake offers a high protein content, local availability in Central Europe (including Romania) and a competitive per-unit-protein price during periods of protein-market pressure; experimental evidence confirms that complete substitution of soybean meal does not compromise production [26, 28]. Linseed cake is economically attractive in integrated cropping-livestock systems. The omega-3 enrichment of milk also opens access to premium markets for nutritionally enhanced dairy products [29, 31]. Milk thistle cake holds a distinct position because of its dual value, as a moderate protein source and as a bioactive ingredient with demonstrated effects on liver and metabolic health with potential to lower veterinary costs and stabilise productive performance during the transition period [18, 20].

A further benefit of oilseed cakes is their integration into circular-bioeconomy logic, which valorises local agro-industrial by-products. Livestock convert non-edible biomass, agricultural residues and food-industry by-products into high-value animal-source foods while supporting bio-based industries through the valorisation of animal by-products [37, 38]. Redesigning the European food system on circularity principles can generate significant environmental benefits [39, 40, 41]. Applied to dairy-cow feeding, this means that cakes remaining after oil extraction from milk thistle, pumpkin or linseed seeds by-products that might otherwise be discarded or used as fertilizer, gain superior economic value when integrated as protein ingredients in dairy rations. The main economic implications of using these alternative sources are summarised in Table 4.

Table 4. Economic implications of using the three alternative oilseed cakes in dairy cow rations

Alternative source	Main economic mechanism	Potential economic advantages	Economic limitations / risks	References
Milk thistle cake (*Silybum marianum*)	Valorisation of a by-product with protein contribution and bioactive compounds	Possible reduction of losses associated with metabolic disorders; support of production during critical periods; functional value through silymarin content	Availability dependent on the silymarin extraction industry; possibly higher price than other cakes; need to define optimal doses	[18, 19]
Pumpkin seed cake (*Cucurbita pepo L.*)	Partial or total replacement of conventional protein sources	Reduced dependency on soybean meal; valorisation of a local by-product; possible competitive price per unit of protein in regions with pumpkin seed processing	Seasonality linked to harvest; need for storage; compositional variability between batches	[9, 26, 28]
Linseed cake / meal (*Linum usitatissimum L.*)	Protein and lipid contribution with potential for milk differentiation	Possible cost reduction in local systems; added value through improved milk fatty-acid profile; good integration into short supply chains	Sensitivity to storage conditions; risk of lipid oxidation; need for batch quality analysis	[29, 30, 31]

4. Conclusions

Climate change is a structural, not transitory, threat to the European fodder sector. Recurrent droughts of the past decade exceed the threshold of isolated phenomena and form a systematic trend. Romania, with its high drought vulnerability and significant documented agricultural losses, stands at the forefront of this phenomenon.

Conventional fodder crops are inadequate as a sole feeding source under climate instability. Maize silage, alfalfa, triticale and fodder wheat exhibit increased sensitivity to water deficit at critical growth stages, generating significant production losses in drought years.

The three alternative sources analysed, milk thistle cake, pumpkin seed cake and linseed cake exhibit confirmed nutritional potential. Milk thistle cake stands out for its dual value, with silymarin exerting favourable effects on peripartum metabolic health and reducing the incidence of ketosis and fatty liver. Pumpkin seed cake can completely substitute soybean meal in dairy cow rations without negatively affecting milk yield, while providing demonstrated antioxidant benefits. Linseed meal exerts the strongest and best-documented effects on milk composition, particularly through substantial enrichment of the omega-3 fatty-acid fraction,ALA, CLA, DHA with direct benefits for the nutritional quality of milk.

The overall impact on milk production is neutral or positive: oilseed cakes can partially replace maize or soybean in rations without reducing productive performance. Diversification of feeding is economically justified by reduced dependence on volatile soybean-meal markets, valorisation of local resources, integration into short supply chains and contribution to circular-economy objectives. Implementation of new crop-rotation systems and adaptation of feeding strategies to local and climatic conditions are essential for maintaining milk production under climate change.

5. Future perspectives

Studies on milk thistle cake in dairy cows are still relatively few and need replication under European commercial farm conditions, with breeds and feeding systems representative of Romania and Central Europe. The long-term effects of continuous use of these alternative ingredients, the interactions when they are combined in the ration, and the optimisation of doses for different lactation stages remain insufficiently studied. Applied research on the real formulation and logistics costs of feed diversification in small and medium farms, predominant in Romania is also limited. Climate-smart livestock nutrition strategies, combining precision feeding with dietary approaches that increase animal thermal resilience and adapting production systems to declining availability of conventional forages through sustainable alternatives represent the principal direction for the response of the dairy sector to climate challenges. Integration of livestock with crop production and forestry can also generate synergistic benefits for soil properties and nutrient cycling.

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