Review

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Comparative analysis of milk composition and nutritional characteristics of cervids and domesticated dairy species

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Abstract

This review compared the milk composition and quality of five deer species; red deer (*Cervus elaphus*), reindeer (*Rangifer tarandus*), fallow deer (*Dama dama*), roe deer (*Capreolus capreolus*), and moose (*Alces alces*); with a range of domesticated dairy species, including cattle, sheep, goats, buffaloes, yak, camel, donkey, and horse. Cervid milks are characterised by high total solids, elevated protein and fat, low lactose, and high casein and mineral content, reflecting ecological adaptations for rapid neonatal growth, thermoregulation, and species-specific maternal strategies. Roe deer, reindeer, and moose produce the most nutrient-dense milks, while red and fallow deer occupy intermediate positions. Compared with domesticated species, cervid milks show exceptional energy density and coagulation properties, offering potential for niche, high-value dairy products on small farms where conventional dairy is less competitive. This comparative analysis indicates the interaction of evolutionary, ecological, and physiological factors in shaping milk composition and provides a basis for the potential use of non-traditional milks in specialized dairy systems.

Keywords: Cervidae; milk composition; nutritional characteristics; domestic dairy species; comparative analysis

Introduction

In recent decades, global food systems have changed substantially, largely due to shifting consumer expectations and growing recognition of the connections between diet, health, and environmental impact (Bobo, 2024). Consumers are increasingly looking for foods with improved nutritional profiles, functional properties, and credible sustainability narratives. These trends that have fueled interest in alternative animal-derived products and diversified protein sources beyond conventional livestock species (Searby, 2025). These changes have increased pressure on the agri-food sector to diversify production systems and explore new food sources capable of meeting both nutritional needs and sustainability objectives (United Nations Development Programme (UNDP), 2024; United Nations Food Systems Summit (UNFSS), 2025). Within this context, the concept of functional foods has gained particular importance, defined as foods that provide health benefits above basic nutrition (Martirosyan and Singh, 2015). Milk and dairy products have received considerable scientific attention as functional foods, owing to their content of high-quality proteins, lipids, minerals, and a wide range of bioactive compounds (Park, 2009; Gantner et al., 2024). While bovine, goat, and sheep milk dominate global dairy production (Park and Haenlein, 2013; Food and Agriculture Organization of the United Nations (FAO), 2020), milk from unconventional mammalian species has been recognised as a potential source of distinctive functional components and often reflects species-specific physiological and evolutionary adaptations (Uniacke-Lowe, 2011; Claeys et al., 2014). Milk from deer species (family *Cervidae*) and their close relatives represents one of the least researched but potentially promising alternatives (Arman et al., 1974; Li et al., 2023). Historically, deer farming has been primarily oriented toward meat production, velvet antler harvesting, and ecosystem management (Pérez-Barbería et al., 2022). However, several deer species can be managed under controlled or semi-controlled farming systems to produce milk with exceptionally high concentrations of protein, fat, as well as notable mineral content of calcium, phosphorus, and bioactive peptides (Arman et al., 1974; Li et al., 2023). These compositional characteristics suggest a strong potential for deer milk to be positioned as a high-value functional food or as a raw material for specialised dairy products (Li et al., 2023).

From a sustainability perspective, diversification of dairy species aligns with FAO and Intergovernmental Panel on Climate Change (IPCC) recommendations aimed at improving the resilience of livestock systems, optimising resource-use efficiency, and reducing the environmental footprint of animal production (FAO, 2018; IPCC, 2019). Although complete life-cycle assessments of deer milk production are currently lacking, deer are often well adapted to marginal environments, exhibit efficient feed utilisation, and can be integrated into low-input or extensive systems (Arman et al., 1974; Pérez-Barbería et al., 2022). Those characteristics may offer advantages in specific agroecological contexts, especially under conditions of climate variability and land-use constraints. Despite these beneficial properties, scientific knowledge on deer milk remains fragmented and largely confined to individual species. Comparative analyses spanning different deer species, as well as their comparison with established farmed dairy species, are scarce limiting a comprehensive understanding of the biological, nutritional, and technological characteristics of this milk. The lack of an integrated synthesis consequently constrains both scientific evaluation and practical assessment of deer milk as a potential component of future sustainable food systems. Accordingly, the aim of this review was to compare the milk composition and quality of different deer species; red deer (*Cervus elaphus*), reindeer (*Rangifer tarandus*), fallow deer (*Dama dama*), and roe deer (*Capreolus capreolus*), as well as the related ungulate moose (*Alces alces*), and to evaluate these traits in comparison with domesticated species commonly used in dairy production, including cattle (*Bos taurus*), sheep (*Ovis aries*), goats (*Capra hircus*), buffalo (*Bubalus bubalis*), yak (*Bos grunniens*), camel (*Camelus dromedarius*), donkey (*Equus asinus*), and horse (*Equus caballus*).

Characteristics of milk of red deer (Cervus elaphus)

Red deer milk is a highly concentrated, nutrient-dense secretion that reflects the ecological and reproductive strategy of *Cervus elaphus*. It is characterized by a short lactation period, rapid calf growth, and relatively low daily milk yield. Compared with bovine milk, it contains substantially higher levels of total solids, fat, protein, and minerals. This prompted growing interest in its potential as a functional ingredient and as a model for studying cervid lactation biology (Arman et al., 1974; Li et al., 2023). Total solids in red deer milk are consistently higher than in bovine milk and typically range around 19.6-26 %, compared with approximately 12–13 % in cow milk (Arman et al., 1974; Malacarne et al., 2015). This is largely due to elevated fat and protein fractions, while lactose remains relatively low. The dense composition allows calves to obtain sufficient energy and nutrients from small volumes of milk, which is advantageous in free-ranging conditions where mothers spend limited time suckling (Arman et al., 1974).

Crude protein concentrations are elevated compared with bovine milk and generally range from approximately 6.8-10.6 g/100 g, and are dominated by caseins, which confer strong coagulation properties and high potential cheese yield (Arman et al., 1974; Malacarne et al., 2015; Li et al., 2023). Whey proteins, including ß-lactoglobulin, α-lactalbumin, serum albumin, and immunoglobulins, are also abundant, with immunoglobulin levels particularly high in early lactation, supporting both rapid tissue growth and immune protection in neonates (Arman et al., 1974; Li et al., 2023). Fat content is elevated relative to bovine milk, with mean values ranging from 7 to 19.7 g/100 g,

depending on lactation stage and maternal nutrition (Arman et al., 1974; Malacarne et al., 2015; Li et al., 2023). The lipid fraction includes long-chain saturated and monounsaturated fatty acids, as well as polyunsaturated fatty acids essential for neural and visual development. Lactose concentrations are moderate, typically around 4 g/100 g (range 2.6–6.2 g/100 g), contributing to the high total solids and osmotic stability of the milk (Arman et al., 1974; Malacarne et al., 2015). Mineral content is also elevated, particularly calcium and phosphorus, which are important for skeletal and antler development, while magnesium, potassium, and trace elements support rapid bone growth (Arman et al., 1974; Malacarne et al., 2015).

Red deer milk contains bioactive components, such as immunoglobulins, lactoferrin, growth factors, and peptides released from caseins and whey proteins, which may exert immunomodulatory, antimicrobial, and mineral-binding effects (Korhonen, 2009; Li et al., 2023). Composition changes throughout lactation: early milk is rich in protein, immunoglobulins, and minerals, with moderately lower fat, whereas later milk shows increasing fat content and altered protein dynamics, with milk solids becoming more concentrated as lactation progresses (Arman et al., 1974; Landete-Castillejos et al., 2000; Li et al., 2023). Daily milk yield decreases over time, reflecting a strategy of producing highly concentrated milk in small volumes, ensuring efficient nutrient transfer to the calf while minimizing maternal energy expenditure (Arman et al., 1974). High casein content and strong gelation properties make red deer milk suitable for cheese production and other high-protein dairy products (Li et al., 2023). Heat treatment and homogenization affect casein micelle structure and gelation behaviour in red deer (*Cervus elaphus*) milk, and processing conditions may require adaptation compared with bovine milk to avoid excessive firmness or syneresis (Berruga et al., 2021). Despite these technological advantages, practical utilisation remains limited by low production volumes, underdeveloped supply chains, and the need for further studies addressing food safety and allergenic potential before wider application (Aslam and Faiz, 2020).

In summary, red deer milk (*Cervus elaphus*) is a nutrient-dense secretion with elevated protein, fat, and mineral content, moderate lactose concentrations relative to other cervids, and a promising profile of bioactive compounds. Its composition reflects the ecology and reproductive strategy of cervids and provides interesting technological properties for high-protein and high-calcium dairy products. Although literature is limited, current evidence indicates that red deer milk represents a valuable and functionally promising resource, warranting further investigation in both basic research and applied food technology.

Characteristics of milk of reindeer (Rangifer tarandus)

Reindeer milk is among the most nutrient-dense mammalian milks and occupies an extreme position within the *Cervidae* family in terms of total solids, fat, and protein content. Its composition reflects the ecological pressures of Arctic and sub-Arctic environments, where calves must achieve rapid growth and thermoregulation during a short lactation season. Compared with temperate cervids such as red deer (*Cervus elaphus*), reindeer milk contains higher concentrations of energy-rich components, consistent with broader ecological patterns in cervid lactation biology (Aschaffenburg et al., 1962; Holand et al., 2002).

Total solids in reindeer milk are exceptionally high and reported at approximately 27 g/100 g, markedly exceeding bovine milk and most other cervids (Park and Haenlein, 2013). This high solid content is largely due to elevated fat and protein fractions and represents a key adaptation to cold climates and short suckling intervals. Crude protein concentrations are markedly elevated and typically range around 11 g/100 g, particularly in early lactation (Park and Haenlein, 2013; Malacarne et al., 2015). Caseins dominate the protein fraction, resulting in a high casein-to-whey ratio and strong coagulation properties, which support rapid tissue growth in calves and contribute to the milk's suitability for high-yield cheese production (Aschaffenburg et al., 1962; Holand et al., 2002). Immunoglobulins are abundant in early lactation, providing essential passive immunity to neonates. Fat content in reindeer milk is high, with mean values commonly around 11 g/100 g, depending on lactation stage and maternal condition (Park and Haenlein, 2013; Malacarne et al., 2015). This high lipid concentration supplies dense metabolic energy required for thermoregulation and rapid growth in Arctic environments. Fat content generally increases over the course of lactation, while marked compositional changes occur during lactation, including increasing fat and protein concentrations and decreasing lactose content (Holand et al., 2002; Gjøstein et al., 2004). Earlier studies reported even higher concentrations of milk constituents in reindeer, with fat contents reaching up to 17–25 %, protein 9.7–11.5 %, and lactose as low as 2.2–2.8 % in mid to late lactation, reflecting an extreme form of energy-dense milk adapted to Arctic environments (Aschaffenburg et al., 1962). Lactose concentrations are low relative to bovine milk and typically range around 3 g/100 g, which reduces osmotic pressure and metabolic water requirements, an advantageous adaptation in cold, resource-limited habitats (Park and Haenlein, 2013; Malacarne et al., 2015). Low lactose further contributes to the high total solids characteristic of cervid milk. Mineral concentrations in reindeer milk are also high, particularly calcium, phosphorus, magnesium, and potassium, supporting rapid skeletal development and early mobility in calves. Ash content is consistently higher than in bovine milk and among the highest reported for cervids, according to comparative datasets (Malacarne et al., 2015).

Reindeer exhibit a short lactation period, with peak milk yield occurring early and declining as calves begin grazing. Despite decreasing volumes, nutrient density remains high throughout lactation. Studies in modern dairy management indicate that milking frequency and calf presence can influence yield and composition; however, the fundamental pattern of high solids and low lactose persists across systems (Holand et al., 2002). Within *Cervidae*, reindeer milk represents an ecological extreme, surpassing red deer and fallow deer in energy density and occupying the upper range of fat and protein concentrations reported for cervid milks (Malacarne et al., 2015). The combination of very high fat, protein, and mineral content suggests potential for specialized dairy applications, including high-energy formulations and niche cheeses. Nevertheless, practical utilization is constrained by small herd sizes, extensive management systems, and cultural priorities in reindeer husbandry.

Characteristics of milk of fallow deer (Dama dama)

Fallow deer milk occupies an intermediate position within the *Cervidae* family in terms of nutrient density, being generally less concentrated than roe deer milk and overlapping in composition with red deer milk. Although fallow deer are not widely farmed for dairy production, studies on captive or semi-managed populations provide reliable data on milk composition and lactational dynamics. These data indicate that fallow deer milk is rich in protein, fat, and minerals relative to bovine milk, reflecting a cervid lactation strategy based on the production of nutrient-dense milk to support early growth in fawns (Oftedal and Iverson, 1995; Park and Haenlein, 2006; Malacarne et al., 2015). Total solids in fallow deer milk are high, with reported mean values generally ranging from approximately 19.6 to 28 g/100 g, clearly exceeding those reported for bovine milk and being comparable to other temperate cervid species (Malacarne et al., 2015). The elevated solids content is primarily attributable to high protein and fat fractions, enabling fawns to acquire sufficient energy and nutrients from relatively small milk volumes during the relatively short lactation period (Oftedal and Iverson, 1995; Malacarne et al., 2015).

Protein concentrations in fallow deer milk typically range from approximately 6.5 to 8 g/100 g and are dominated by caseins, a characteristic feature of cervid milks (Malacarne et al., 2015). Immunoglobulins are abundant during early lactation, supporting passive immunity in the neonate. Fat content generally ranges from about 8.4 to 15 g/100 g, contributing substantially to the energetic value of the milk. As observed in other cervid species, fat content generally increases as lactation progresses, while protein concentrations tend to decline over time (Oftedal and Iverson, 1995; Malacarne et al., 2015). Lactose concentrations in fallow deer milk are relatively low, with values typically between 4.4 and 6.1 g/100 g, lower than in bovine milk and comparable to other cervid species, contributing to the high total solids content of the milk (Oftedal and Iverson, 1995; Malacarne et al., 2015). Mineral content is elevated, particularly calcium, phosphorus, and magnesium, with ash values consistently exceeding those reported for cow milk and comparable to other cervids of similar body size (Malacarne et al., 2015).

Fallow deer lactation typically lasts approximately 12 to 14 weeks, with modest milk volumes but consistently high nutrient density. Early lactation is characterised by higher protein and immunoglobulin concentrations, while fat content increases toward later stages, reflecting a cervid reproductive strategy in which fawns rely on infrequent but highly nutritious nursing bouts (Oftedal and Iverson, 1995; Park and Haenlein, 2006; Malacarne et al., 2015).

Overall, fallow deer milk is compositionally intermediate within *Cervidae*, being less concentrated than roe deer and reindeer milk but more concentrated than red deer milk and characterised by higher total solids content than that of most domesticated ruminants (Malacarne et al., 2015). Its combination of elevated protein, fat, and mineral content suggests potential for specialised nutritional or dairy-oriented applications, particularly in high-protein or high-energy formulations. However, practical utilisation remains limited due to the absence of established dairy production systems and the logistical challenges associated with milk collection from wild or semi-wild populations.

Characteristics of milk of roe deer (Capreolus capreolus)

Roe deer milk is a highly concentrated and nutrient-dense milk within the *Cervidae* family. Although roe deer are not domesticated and milk collection is limited to research on wild or captive animals, available studies provide consistent insights into its composition. Comparative data indicate that roe deer milk has high total solids, protein, and fat concentrations relative to bovine milk and falls within the upper range of cervid milk composition, reflecting a lactation strategy based on the production of nutrient-dense milk in small volumes (Oftedal and Iverson, 1995; Malacarne et al., 2015).

Total solids in roe deer milk are high compared with bovine milk, with reported values of approximately 24-24.3 g/100 g reported in comparative datasets. This reflects a general cervid lactation pattern characterised by the production of nutrient-dense milk in relatively small volumes (Oftedal and Iverson, 1995; Malacarne et al., 2015). Protein content in roe deer milk is elevated, with average concentrations of around 7-9.4 g/100 g, and is dominated by caseins, a characteristic feature of cervid milks. Immunoglobulins are abundant during early lactation, supporting passive immunity in neonates (Oftedal and Iverson, 1995; Malacarne et al., 2015). Fat content is also high, with reported mean values of approximately 6.6-11.9 g/100 g, contributing substantially to the energetic value of the milk. As observed in other cervid species, fat concentrations tend to increase as

lactation progresses, while protein concentrations gradually decline over time (Oftedal and Iverson, 1995; Malacarne et al., 2015). Lactose concentrations in roe deer milk are moderate, with reported mean values of approximately 3.5-3.9 g/100 g, and are comparable to those of other cervid species. This lactose level, combined with high fat and protein content, contributes to the overall high total solids content of the milk (Malacarne et al., 2015). Mineral concentrations are elevated, particularly calcium, phosphorus, and magnesium, with ash values consistently exceeding those reported for bovine milk and being comparable to other cervids of similar body size (Malacarne et al., 2015). Roe deer exhibit a relatively short lactation period of approximately 8–10 weeks. Milk yield is low, but nutrient density remains high throughout lactation. Early milk is characterised by higher protein and immunoglobulin concentrations, while fat content increases toward later stages, reflecting a cervid reproductive strategy in which fawns rely on infrequent but highly nutritious nursing bouts (Oftedal and Iverson, 1995; Park and Haenlein, 2006).

Within the *Cervidae* family, roe deer milk is characterised by a high nutrient density and a composition typical of cervid milks, with elevated total solids, protein, fat, and mineral content compared with bovine milk. Comparative data indicate that roe deer milk falls within the upper range of cervid milk composition, although it does not consistently exceed that of all other cervid species (Oftedal and Iverson, 1995; Malacarne et al., 2015). Its composition reflects selective pressures associated with rapid neonatal growth and limited milk intake per nursing event, consistent with general cervid lactation strategies. Although roe deer milk is not available for commercial use, its biochemical characteristics provide valuable comparative insights into cervid lactation biology and the evolution of nutrient-dense mammalian milks.

Characteristics of milk of moose (Alces alces)

Moose milk is characterized by a high energy density, representing a key ecological adaptation to boreal and sub-Arctic environments. As the largest extant cervid, moose produce milk with high concentrations of protein, fat, and minerals, supporting rapid early growth in calves that must quickly achieve mobility and thermoregulatory capacity. Although moose are not domesticated, comparative analyses of non-bovine milks provide insights into the general composition and functional characteristics of moose milk (Oftedal and Iverson, 1995; Park and Haenlein, 2013).

Total solids in moose milk are high relative to bovine milk and comparable to other large cervids. According to comparative compositional data summarized by Park and Haenlein (2013), based on data originally reported by Park (2006b), total solids are around 23.6 g/100 g, depending on stage of lactation and sampling conditions. The high solids content reflects an ecological strategy of producing small volumes of nutrient-dense milk to support calves that nurse infrequently (Oftedal and Iverson, 1995). Protein concentrations are high and dominated by caseins. Reported protein contents are around 11 g/100 g (Park and Haenlein, 2013), conferring favorable coagulation properties and suggesting potential for efficient curd formation. Immunoglobulin levels are elevated in early lactation, providing passive immunity to the neonate (Oftedal and Iverson, 1995). In this context, recent biochemical studies demonstrated that recombinant chymosin derived from moose (*Alces alces*) exhibited effective milk-clotting activity, indicating that the protein composition of moose milk is suitable for enzymatic coagulation processes relevant to dairy technology (Balabova et al., 2022; Balabova et al., 2023). Fat content is substantial and constitutes the main source of metabolic energy. Fat concentrations in moose milk are approximately 8.5 g/100 g, supplying dense metabolic energy for thermoregulation and rapid growth (Park and Haenlein, 2013). Fat levels increase over the course of lactation, while protein gradually declines, consistent with patterns observed in other cervids (Oftedal and Iverson, 1995). The fatty acid profile is dominated by long-chain saturated and monounsaturated fatty acids, with moderate proportions of polyunsaturated fatty acids. Lactose concentrations are relatively low compared with bovine milk. The mean reported lactose concentration is approximately 3.3 g/100 g (Park and Haenlein, 2013), reducing osmotic load and supporting the high total solids content characteristic of cervid milks (Oftedal and Iverson, 1995). Mineral concentrations, particularly calcium, phosphorus, magnesium, and potassium, are high and support rapid skeletal development. Ash content ranged from 1.5 to 1.6 g/100 g, exceeding that of bovine milk and being comparable to values reported for other cervids of similar body size (Park and Haenlein, 2013).

Moose exhibit a lactation period of approximately five to six months, longer than in roe deer or fallow deer but shorter than in domesticated ruminants. Milk yield peaks early and gradually declines, while nutrient density remains high throughout lactation. Calves rely heavily on milk during the first months of life, and its high energy density supports rapid weight gain and thermoregulation in cold environments (Oftedal and Iverson, 1995). Within *Cervidae*, moose milk is compositionally closer to reindeer milk than to that of smaller species, particularly with respect to protein and fat content, whereas roe deer produce more concentrated milk in smaller volumes (Oftedal and Iverson, 1995; Park and Haenlein, 2013). The combination of high fat, high protein, and elevated mineral content suggests potential for specialized dairy applications. Historically, small-scale moose dairies in Russia have produced fermented products and therapeutic milks; however, practical utilization is limited due to low milk yield, the species' solitary behavior, and the challenges of moose husbandry.

Comparison of milk across Cervidae

Across the *Cervidae* family, pronounced interspecific differences in milk composition reflect distinct ecological settings, maternal investment strategies, and patterns of neonatal growth. Species inhabiting cold and climatically demanding environments, such as reindeer (*Rangifer tarandus*) and moose (Alces alces), produce exceptionally energy-dense milk characterised by very high total solids, fat, and protein content. This compositional profile represents a clear adaptation to Arctic and boreal conditions, where rapid postnatal growth and effective thermoregulation are essential for calf survival during a relatively short and energetically demanding lactation period (Aschaffenburg et al., 1962; Oftedal and Iverson, 1995; Malacarne et al., 2015). Roe deer (*Capreolus capreolus*) also produce highly concentrated milk, reflecting a lactation strategy based on low milk yield and infrequent nursing. Although roe deer milk falls within the upper range of cervid milk composition rather than representing an absolute extreme, its elevated protein, fat, and mineral content supports rapid growth between nursing events and is consistent with a reproductive strategy adapted to high predation pressure and limited maternal attendance (Oftedal and Iverson, 1995; Malacarne et al., 2015).

Red deer (*Cervus elaphus*) and fallow deer (*Dama dama*) occupy an intermediate position within the cervid spectrum. Their milk is consistently richer than that of domesticated ruminants but less concentrated than that of reindeer or roe deer. Elevated protein and fat concentrations, together with moderate lactose levels, reflect a balance between energy density and sustained milk provision under temperate ecological conditions (Arman et al., 1974; Malacarne et al., 2015). In particular, red deer milk is notable for its high casein content and favourable coagulation properties, which confer strong technological potential despite relatively modest milk yields (Park and Haenlein, 2013; Li et al., 2023).

Despite these interspecific differences, cervid milks share several unifying characteristics that clearly distinguish them from the milk of domesticated dairy species. Across the family, lactose concentrations remain consistently lower, while protein fractions are dominated by caseins and mineral content, especially calcium and phosphorus, are markedly elevated. These shared features reflect common evolutionary pressures shaping cervid lactation, favouring the transfer of large amounts of energy and nutrients in small milk volumes to support rapid neonatal development in challenging environmental contexts (Oftedal and Iverson, 1995; Park and Haenlein, 2013; Malacarne et al., 2015). The integration of milk energy density and climatic-ecological adaptation across cervid species is summarised conceptually in Figure 1.

Conceptual diagram illustrating interspecific differences in milk energy density across selected cervid species along a climatic-ecological gradient from temperate to boreal and Arctic environments. Species positioning reflects published compositional data and highlights contrasting lactation strategies among cervids. The figure was prepared by Boris Ljubojević based on data from Oftedal and Iverson (1995), and Park and Haenlein (2013), Malacarne et al. (2015).

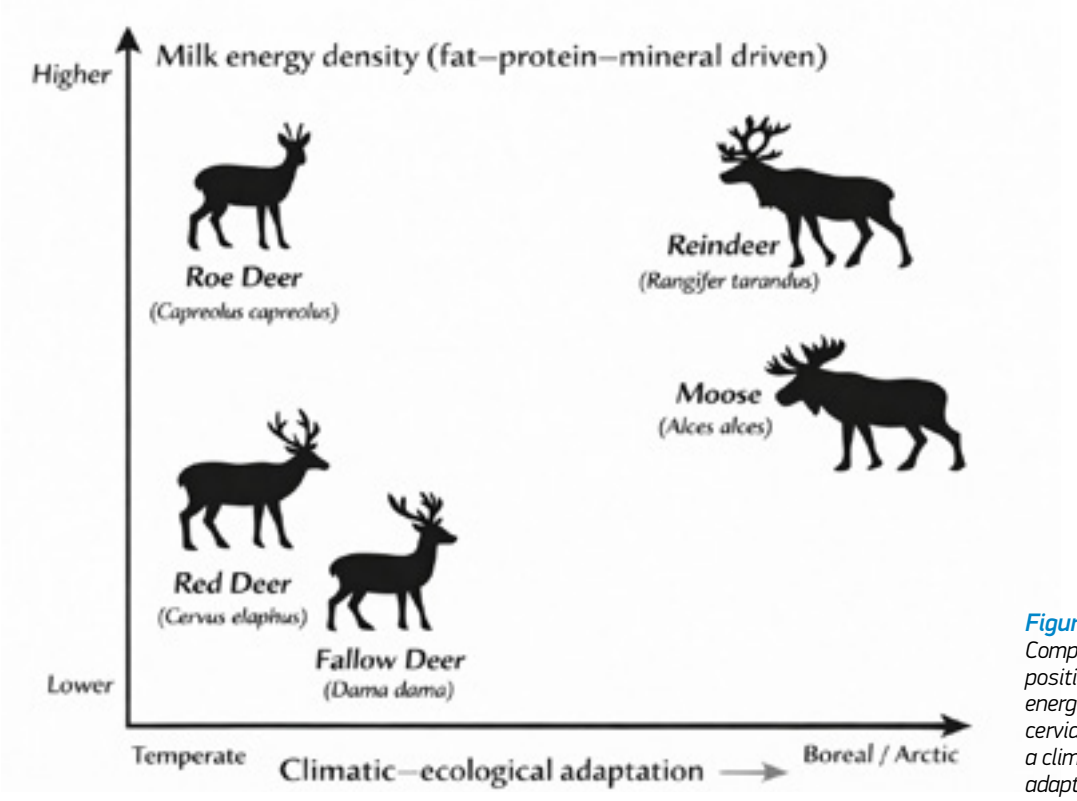

Figure 1. *Comparative positioning of milk energy density across cervid species along a climatic-ecological adaptation*

Comparison of milk composition across Cervidae and domestic dairy species

Milk composition among cervids and domestic species reflects strong evolutionary, ecological, and physiological pressures shaping neonatal growth, maternal investment, and adaptation to environmental conditions. An overview of the principal differences in milk composition between cervid species and selected domestic and wild mammalian species is presented in Table 1.

Within *Cervidae*, red deer (*Cervus elaphus*) produce moderately concentrated milk with high casein and substantial fat content, supporting moderate neonatal growth rates (Arman et al., 1974; Li et al., 2023). Reindeer (*Rangifer tarandus*) and moose (*Alces alces*) produce highly energy-dense milk, characterised by elevated total solids, fat, and protein content, reflecting adaptations to Arctic and boreal climates that facilitate rapid thermoregulation and tissue accretion (Aschaffenburg et al., 1962; Oftedal and Iverson, 1995; Park and Haenlein, 2013). Fallow deer (*Dama dama*) produce milk of intermediate nutrient density, with a balanced fat-protein ratio and high mineral content, consistent with their temperate ecology (Oftedal and Iverson, 1995; Malacarne et al., 2015). Roe deer (*Capreolus capreolus*) produce the most concentrated milk among cervids, reflecting their "hider" reproductive strategy and infrequent nursing pattern (Oftedal and Iverson, 1995; Malacarne et al., 2015).

Domestic ruminants exhibit a contrasting lactation strategy. Cow (*Bos taurus*) and goat (*Capra hircus*) milk are relatively less concentrated than cervid milks, with similar total solids and moderate fat and protein contents, while lactose remains comparatively higher, consistent with their overall milk composition patterns (Park, 2006a). Sheep (*Ovis aries*) and buffalo (*Bubalus bubalis*) produce richer milk with higher solids and strong coagulation properties, supporting traditional cheese-making (Park and Haenlein, 2013; Ahmad et al., 2013). Yak (*Bos grunniens*) milk shows high solids, fat, and CLA content, reflecting adaptation to high-altitude cold environments (Wang et al., 2023). Equid milks (donkey, *Equus asinus*; horse, *Equus caballus*) are low in fat and protein but high in lactose and whey proteins, including albumin and immunoglobulins, resembling human milk in terms of lower protein and fat content and higher lactose proportion (Malacarne et al., 2002; Guo et al., 2007; Potočnik et al., 2011; Gantner et al., 2015). Camel (*Camelus dromedarius*) milk has moderate solids, enriched MUFAs, and elevated immune globulins, reflecting adaptation to arid climates (Konuspayeva et al., 2009; Brezovečki et al., 2015).

Collectively, cervid milks form a distinct cluster characterised by high energy density, low lactose, high

Table 1. Comparative milk composition across cervids and selected domestic and wild mammalian species

Species	Total solids (%)	Protein (%)	Fat (%)	Lactose (%)	Key biochemical traits	References
Red deer (*Cervus elaphus*)	19.6-26	6.8-10.6	7-19.7	2.6-6.2	High protein and mineral content, casein-rich milk	Malacarne et al., 2015
Reindeer (*Rangifer tarandus*)	27.1	11.1	11.1	3.0	Highly energy-dense milk adapted to Arctic conditions	Park and Haenlein, 2013
Fallow deer (*Dama dama*)	19.6-28	6.5-8.0	8.4-15	4.4-6.1	High fat content, intermediate cervid milk type	Malacarne et al., 2015
Roe deer (*Capreolus capreolus*)	24-24.3	7.0-9.4	6.6-11.9	3.5-3.9	Concentrated milk, high ash and protein, hider strategy	Malacarne et al., 2015
Moose (*Alces alces*)	23.6	11.0	8.5	3.3	Extremely high protein content, low lactose	Park and Haenlein, 2013
Cow (*Bos taurus*)	12.9	3.4	4.3	4.47	High lactose, diluted milk adapted to high yield	Aslam and Faiz, 2020
Goat (*Capra hircus*)	14.4	3.7	4.8	5.0	Higher digestibility, rich in medium-chain fatty acids	Aslam and Faiz, 2020
Sheep (*Ovis aries*)	16.7	5.7	6.8	3.24	High solids, excellent coagulation properties	Aslam and Faiz, 2020
Buffalo (*Bubalus bubalis*)	17.8	4.2	7.8	5.0	High fat and calcium content	Aslam and Faiz, 2020
Bison (*Bison bison*)	13.46	4.8	1.7	6.0	Low fat and high ash content	Aslam and Faiz, 2020
Yak (*Bos grunniens*)	16.3-19	4.7-6.5	5.6-7.5	3.5-5.4	High solids and CLA, cold-environment adaptation	Wang et al., 2023
Donkey (*Equus asinus*)	11.5	1.8	1.8	7.4	Low fat, high lactose, human-milk-like profile	Aslam and Faiz, 2020
Horse (*Equus caballus*)	9-12	1.3-2.0	0.4-7.2	6.0-7.2	Low fat and protein, high lactose, whey-dominant milk	Gantner et al., 2015
Camel (*Camelus dromedarius*)	13.5	3.9	5.4	3.3	High MUFA and immune proteins, arid adaptation	Aslam and Faiz, 2020

**Values are reported as ranges or mean percentages depending on data availability and reporting format in the original sources.*

casein proportion, and elevated mineral and globulin content, reflecting ecological strategies for rapid neonatal growth and thermoregulation. Domestic species, by contrast, display a broader compositional spectrum shaped by domestication, environmental adaptation, and human selection for yield, digestibility, or technological use.

Conclusions

This review aimed to compare the milk composition and quality of different deer species, including red deer (*Cervus elaphus*), reindeer (*Rangifer tarandus*), fallow deer (*Dama dama*), and roe deer (*Capreolus capreolus*), as well as the related ungulate moose (*Alces alces*), and to evaluate these traits in comparison with domesticated species commonly used in dairy production, including cattle (*Bos taurus*), sheep (*Ovis aries*), goats (*Capra hircus*), buffalo (*Bubalus bubalis*), yak (*Bos grunniens*), donkey (*Equus asinus*), horse (*Equus caballus*), and camel (*Camelus dromedarius*).

The analysis demonstrates that cervid milks constitute a distinct cluster among mammals, with high total solids, elevated protein and fat, low lactose, and enriched casein and mineral content. Roe deer, reindeer, and moose exhibit the highest nutrient density, reflecting adaptations to ecological pressures such as infrequent suckling, rapid neonatal growth, and cold environments. Red deer and fallow deer occupy an intermediate position, producing milk richer than most domestic ruminants, while domesticated species display broader compositional variability shaped by human selection, environmental adaptation, and production requirements.

From a technological and nutritional perspective, the high protein, fat, and mineral content of cervid milks provides excellent coagulation properties and potential for specialized dairy products, although practical use is limited by small herd sizes and extensive management systems. Nevertheless, cervid milk could be exploited on small farms as a niche product, particularly in settings where conventional dairy production is not competitive. Domestic ruminant milks offer moderate energy and protein suitable for widespread consumption and established dairy processing, while equid and camel milks exhibit unique biochemical profiles adapted to their ecological niches, with potential for therapeutic and specialty applications.

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Usporedna analiza sastava i nutritivnih karakteristika mlijeka jelenskih vrsta i domesticiranih mliječnih vrsta

Sažetak

Ovaj pregledni rad usporedio je sastav i kvalitetu mlijeka pet vrsta jelena: običnog jelena (*Cervus elaphus*), soba (*Rangifer tarandus*), dame (*Dama dama*), srnjaka (*Capreolus capreolus*) i losa (*Alces alces*), s nizom udomaćenih vrsta za proizvodnju mlijeka, uključujući krave, ovce, koze, bivolice, jake, deve, magarce i kobile. Mlijeka jelenskih vrsta karakterizira visok udio ukupne suhe tvari, povišene razine proteina i mliječne masti, niska koncentracija laktoze te visoki sadržaj kazeina i minerala, što odražava ekološke prilagodbe za brz rast pomlatka, termoregulaciju i specifične roditeljske strategije. Srnjak, sob i los proizvode najkoncentriranija i nutritivno najbogatija mlijeka, dok obični jelen i dama zauzimaju srednju poziciju. U usporedbi s udomaćenim vrstama, mlijeka jelena pokazuju iznimnu energetsku gustoću i sposobnost koagulacije, što pruža potencijal za nišne, visokovrijedne mliječne proizvode na malim farmama gdje konvencionalna proizvodnja mlijeka nije konkurentna. Usporedna analiza različitih mlijeka indicira utjecaj evolucijskih, ekoloških i fizioloških čimbenika na oblikovanje sastava mlijeka te pruža uvid u moguću primjenu netradicionalnih mlijeka u specijaliziranim sustavima proizvodnje.

Ključne riječi: Cervidae; sastav mlijeka; nutritivne karakteristike; domesticirane vrste za proizvodnju mlijeka; usporedna analiza

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