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DOE MILK AS A SUSTAINABLE HIGH-VALUE DAIRY OPTION FOR SMALL-SCALE FARMS

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Review paper

Abstract: Global dairy production has undergone significant intensification, which has marginalized small-scale farms unable to compete with conventional dairy cattle systems. Therefore, the aim of this paper was to review the production potential, milk quality characteristics, organization of doe farming systems, and economic feasibility of doe milk production, with a focus on its applicability as a sustainable solution for small-scale farms. Doe milk is characterized by relatively low volume but high nutrient density, elevated protein and fat content, and functional properties, including bioactive peptides and potential hypoallergenic traits. Extensive and semi-extensive farming systems allow low-input management, efficient utilization of marginal pastures, and integration of family labour. Economic sustainability is enhanced through product diversification into cheese, fermented products, and specialty functional or cosmetic applications, compensating for limited milk yield. Despite challenges such as seasonal lactation, low milk production, and limited standardization, doe milk represents a promising alternative for small farms, offering high-value niche products and contributing to rural diversification and sustainable livestock production.

Key words: doe milk, milk quality, small-scale farms, niche dairy products, economic feasibility

Introduction

Global dairy production has undergone profound structural and organizational changes over the past several decades. These changes have been driven primarily by intensification, rapid technological development, genetic progress, and increasing specialization of production systems. As a result, milk

yields per animal and per farm have increased substantially, contributing to improved efficiency and global milk supply. However, these developments have also led to a strong concentration of production and a continuous increase in average farm size, particularly in developed dairy regions (FAO, 2020; OECD & FAO, 2023). While large-scale dairy systems have benefited from economies of scale, precision feeding, automation, and advanced herd management, including increasing levels of robotization and digital control, small-scale dairy farms have often struggled to remain competitive. Limited access to capital, rising input costs, labor shortages, and increasing regulatory demands have placed significant pressure on family-owned farms, many of which are unable to invest in modern housing systems, high-performance genetics, or advanced digital technologies (Gorton et al., 2009; Meuwissen et al., 2021; Gantner et al., 2025). Consequently, small dairy farms in many regions face economic instability, reduced profitability and, in extreme cases, abandonment, with negative implications for rural livelihoods, landscape management and regional food security. These developments have renewed broader scientific and societal debates on the role, necessity, and future direction of animal production in the 21st century, particularly in relation to sustainability, food security, and rural development (Gantner et al., 2022).

In response to these challenges, farm diversification and the development of alternative livestock production systems have gained increasing attention as strategies to enhance resilience and sustainability of small farms. Diversification into niche products, value-added processing and alternative animal species has been widely recognized as a viable pathway for maintaining farm income while reducing dependence on conventional commodity markets (van der Ploeg et al., 2019). Within this context, alternative dairy species such as goats, sheep, donkeys, mares and camels have attracted growing scientific and commercial interest due to their ability to efficiently utilize marginal land, adapt to extensive production systems and produce milk with distinctive nutritional and functional properties (Park et al., 2017; Claeys et al., 2014).

In contrast to other alternative dairy species, milk production from deer has been only marginally addressed in the scientific literature. In New Zealand in particular, deer-related research and management have largely focused on non-native populations, their impacts, and wildlife management, as well as venison production and velvet antler harvesting (Latham and Nugent, 2017). Consequently, lactation biology and milk utilization in deer have received comparatively little scientific attention. This is particularly notable given the increasing consumer interest in functional foods, natural products and novel dairy items with high nutritional value and strong product differentiation (Li et al., 2023). Doe milk, although produced in relatively small quantities, is characterized by exceptionally high concentrations of protein, fat and minerals, which confer a high nutritional

density and significant potential for value-added processing (Li et al., 2023; Park et al., 2017; Claeys et al., 2014).

From a production perspective, doe milk systems are typically associated with extensive or semi-extensive management, low external inputs and strong integration with natural ecosystems (Park et al., 2017; van der Ploeg et al., 2019). These characteristics align well with the resource base of small farms, especially those located in marginal or less-favored areas where intensive dairy cattle production is not economically viable. When combined with direct marketing, on-farm processing and short supply chains, doe milk production may offer a realistic opportunity for small farms to generate income through specialization rather than volume-based competition (van der Ploeg et al., 2019; Meuwissen et al., 2021).

Therefore, the aim of this paper was to critically review the production potential, milk quality characteristics, organization of doe farming systems, and economic feasibility of doe milk production, with particular emphasis on its possible applicability in small-scale farming systems in Europe, especially in marginal and low-input production areas.

Lactation biology and milk production characteristics in does

Climatic conditions, particularly temperature and precipitation patterns, significantly influence population dynamics and biological performance of cervid species, thereby indirectly shaping reproductive outcomes and physiological processes such as lactation (Gavran et al., 2020). Lactation in does is a biologically evolved process optimized to meet the rapid growth and high metabolic demands of fawns. In free-ranging and managed deer populations, reproductive success and offspring survival are strongly influenced by population density, climatic conditions, and habitat quality, which together shape maternal condition and resource allocation during the reproductive cycle (Gavran and Gantner, 2020). This specialization manifests in a milk profile characterized by elevated concentrations of protein, fat and total solids, which provide dense energetic and nutrient support during early life stages (Park et al., 2017; Li et al., 2023). However, this biological adaptation comes at the expense of overall milk volume, resulting in substantially lower yields per lactation compared with conventional dairy species such as dairy cattle, goats or sheep (Landete-Castillejos et al., 2000). Reported values should nevertheless be interpreted within the specific biological and production contexts from which they were obtained. For example, Landete-Castillejos et al. (2000) investigated captive Iberian red deer (Cervus elaphus hispanicus) kept under controlled experimental conditions, whereas Li et al. (2023) studied milk from farmed red deer in New Zealand collected from a commercial herd managed under pasture-based conditions with supplementary feeding.

A defining feature of doe lactation is its pronounced seasonal pattern. In wild and semi-extensive populations, lactation is closely linked to reproductive cycles and environmental cues, including photoperiodic regulation, ensuring that peak nutrient demands of offspring coincide with periods of higher forage availability (Brown, 1992; Bubenik, 2006; Scott et al., 2008; Strickland et al., 2008). Consequently, the lactation curve of does typically displays a distinct seasonal peak followed by a gradual decline, and the overall length of lactation is constrained by reproductive return intervals. This seasonality limits the feasibility of continuous milk production in the absence of controlled breeding and supplementary feeding strategies.

Quantitative data on daily milk yield in deer species remain relatively scarce, largely due to the logistical challenges of sampling and the limited number of captive production systems. Nevertheless, available studies indicate that daily milk yield in red deer does typically averages below 1 liter per day, which is markedly lower than yields observed in conventional dairy species such as goats or cows (Landete-Castillejos et al., 2000; Li et al., 2023). As shown in Table 1, does produce substantially lower milk volumes than cows or goats; however, the high concentration of protein and fat highlights their suitability for value added dairy products. Yield variability is influenced by species and subspecies genetics, maternal condition, nutrition, management system and milking protocols. For example, does with access to high-quality forage and balanced supplementation during peak lactation can sustain higher yields than those maintained on marginal pastures.

Table 1. Lactation and milk composition parameters of does (red deer) compared with conventional dairy species

Parameter	Red Deer (Does)	Dairy Cow	Dairy Goat	Notes / Comments
Lactation length, weeks	24–34[1]	40–44[2]	28–32[2]	Deer lactation is seasonal and limited by reproductive cycles
Peak daily milk yield, L/day	0.8–1.2[1]	20–30[2]	2–4[2]	Lower yield in does compensated by higher solids
Total milk solids, %	24–26[1]	12–13[2]	12–14[2]	Includes protein, fat, lactose
Protein, %	6–10[1]	3.2[2]	3.3[2]	High protein content supports fawn growth and cheese production
Fat, %	6–11[1]	3.5[2]	4.0[2]	Contributes to energy density and processing quality
Lactose, %	3–5[1]	4.8[2]	4.5[2]	Slightly lower in deer milk

[1] Li et al. (2023); Landete-Castillejos et al. (2000)
[2] Park et al. (2017)

Despite low volumetric output, the high solid content of doe milk partially offsets the volume deficit, especially in the context of value-added dairy products such as cheese, fermented milk and high protein concentrates (Li et al., 2023; Maidment et al., 2026). Elevated protein and lipid fractions contribute to desirable technological properties during processing, including curd formation and flavor development, which are critical for specialty dairy production (Haenlein, 2004; Claeys et al., 2014). From a biological standpoint, these compositional attributes are consistent with the evolutionary role of deer milk in supporting rapid early growth rather than sustained high volume yield.

Given these biological constraints, doe milk production is inherently more compatible with small-scale, specialized dairy systems rather than large-scale commercial operations. The limited supply and distinctive composition position doe milk as a premium niche product, with most commercial potential linked to product diversification and direct marketing strategies rather than bulk fluid milk sales. Integration into extensive or semi-extensive management systems, where feeding inputs and infrastructure costs are lower, further enhances the economic logic of doe dairy enterprises for small or marginal farms (van der Ploeg et al., 2019; Meuwissen et al., 2021).

The lactational biology of does reflects an evolutionary strategy prioritizing nutrient density over volume. While these limits continuous high-volume milk supply, it simultaneously creates opportunities for specialized dairy products with high nutritional and economic value when integrated into appropriate production and marketing systems.

Milk quality and nutritional characteristics

Doe milk possesses a unique chemical composition that distinguishes it from conventional dairy species and underpins its potential as a high-value niche product. Its high total solids content, including elevated levels of protein, fat, and minerals, provides a dense source of energy and nutrients suitable for both neonatal growth and human consumption (Li et al., 2023; Maidment et al., 2026). Compared with cow and goat milk, doe milk exhibits a distinct casein profile and higher proportions of whey proteins, which can influence digestibility, coagulation behavior and textural properties of processed dairy products (Haenlein, 2004; Park et al., 2017). The mineral fraction of doe milk is particularly notable, with calcium, phosphorus, and magnesium concentrations surpassing those of most conventional dairy species, offering additional nutritional advantages (Claeys et al., 2014; Li et al., 2023). From a functional standpoint, doe milk contains bioactive components with potential health-promoting effects. These include bioactive peptides generated during digestion, medium-chain fatty acids with antimicrobial and metabolic benefits, and immunoglobulins that may support gut health (Haenlein, 2004; Li et

al., 2023). Furthermore, differences in protein composition between deer milk and cow milk, particularly in the casein and whey protein fractions, suggest that deer milk may exhibit distinct allergenic properties. However, evidence regarding reduced allergenicity remains limited, and further studies are required to evaluate the potential hypoallergenic characteristics of deer milk in comparison with conventional dairy species (Claeys et al., 2014; Li et al., 2023). Such attributes render doe milk particularly attractive for functional foods and specialized dairy products targeted at health-conscious consumers. Table 2 summarizes the chemical and functional properties of doe milk compared to cow and goat milk, highlighting its high protein, fat, mineral content, and functional potential for niche dairy products.

Table 2. Chemical composition and functional properties of doe milk compared with cow and goat milk

Parameter / Property	Red Deer (Doe)	Dairy Cow	Dairy Goat	Notes / Comments
Calcium, mg/100 g	298[1]	120–130[2]	100–110[2]	Supports bone health; beneficial for cheese texture
Phosphorus, mg/100 g	190–210[1]	90–100[2]	80–95[2]	Important for metabolic and structural functions
Bioactive peptides	Present[1]	Moderate[2]	Moderate[2]	Contribute to antimicrobial, antioxidant, and gut health effects
Immunoglobulins	High[1]	Low[2]	Low[2]	Supports neonatal immunity; potential functional food applications
Hypoallergenic potential	Moderate[1]	Low[2]	Low[2]	Lower β-lactoglobulin; may reduce allergenicity
Recommended product use	Cheese, fermented milk, value-added dairy	Fluid milk, cheese, butter	Cheese, yogurt	Doe milk suited for niche and functional products

[1] Li et al. (2023); Maidment et al. (2026)
[2] Park et al. (2017); Haenlein (2004); Claeys et al. (2014)

The organoleptic qualities of doe milk also contribute to its value. Flavor and aroma profiles, while influenced by diet and lactation stage, are generally mild and pleasant, making the milk suitable for cheese, fermented products, and even direct consumption in markets seeking novel or gourmet dairy experiences (Li et al., 2023; Maidment et al., 2026). Its high solids content not only improves processing yields but also enhances the texture and creaminess of derived products, which can increase consumer acceptability and marketability.

Taken together, the chemical and functional characteristics of doe milk provide strong justification for its development as a niche dairy product. Its high

nutrient density, bioactive potential, and favorable processing properties align well with current consumer trends favoring functional, natural, and high-quality foods. Small-scale farms can leverage these qualities to produce value-added products that command premium prices, creating an economically viable alternative to conventional dairy production systems.

Organization of doe farming systems

Doe farming systems are typically based on extensive or semi-extensive management, relying on natural pastures and marginal land resources that are often unsuitable for intensive dairy cattle production. Such systems are characterized by low external inputs and strong integration with local environmental conditions, which aligns well with agro-ecological principles and sustainability-oriented small-farm strategies (Landete-Castillejos et al., 2000; Park et al., 2017; van der Ploeg et al., 2019). Does are highly adaptable animals, capable of thriving across a wide range of environmental conditions, with lactation and reproductive performance closely linked to resource availability and habitat characteristics. This ecological flexibility makes them potentially suitable for low-input and small-scale farming systems. Nevertheless, adequate shelter, basic housing conditions, and protection from adverse weather remain essential to ensure animal welfare, reproductive success, and stable milk production (Strickland et al., 2008; Scott, 2008; Park et al., 2017). Animal welfare in farmed red deer also depends on appropriate housing, stocking density, weather protection, feed and water provision, and species-adapted handling systems. Published reviews of European deer farming standards indicate that welfare requirements include minimum pen size, controlled stocking density, access to shelter, continuous provision of fresh water, and handling practices designed to minimize stress and prevent injury (Urošević et al., 2018). Because red deer are a social and stress-sensitive species, prolonged isolation and poorly designed handling facilities may compromise both welfare and production performance (Urošević et al., 2018).

Feeding strategies in doe milk production are low-input yet nutritionally sufficient, emphasizing seasonal pasture availability complemented by strategic supplementation during lactation. Pasture-based systems provide the majority of energy and fiber requirements, while small quantities of concentrate or protein-rich supplements during peak lactation enhance milk yield and support maternal condition (Li et al., 2023; Park et al., 2017). Compared with dairy cattle, feed and housing costs are significantly lower, reducing the financial barrier for small or family-run farms and increasing overall economic feasibility.

Milking does presents specific challenges linked to both anatomical and behavioral traits. Deer are highly sensitive animals, and their management during calving and lactation requires low-density systems and facilities adapted to their behavioral characteristics. In New Zealand high-country systems, breeding hinds

are typically set-stocked at low population densities in large paddocks during calving and lactation, whereas more intensive lowland systems operate at much higher stocking densities (Wall et al., 2019). Such differences in management context are important when considering the practical organization and welfare implications of doe milk production. Manual milking or small-scale adapted milking equipment is typically employed, given the relatively small udder size and lower daily milk yield. Careful attention to hygiene is paramount, as the small volume of milk must be maintained at high sanitary standards for processing into premium dairy products such as cheese, fermented milk, and specialty functional foods (Claeys et al., 2014; Maidment et al., 2026). Although labor requirements per liter of milk may be higher than in conventional dairy cattle systems, this is generally acceptable in small-scale or family-operated farms, especially when the focus is on value-added production rather than volume-based sales. Table 3 presents the key aspects of doe farming systems, highlighting low-input feeding, milking strategies, and labor requirements suitable for small-scale operations.

Table 3. Organization and management of doe farming systems (Li et al., 2023; Maidment et al., 2026; Park et al., 2017; Claeys et al., 2014)

Aspect	Doe management	Description / Notes	Advantages for Small Farms
Farming system	Extensive / semi-extensive	Utilizes natural pastures, forest edges, marginal land	Low infrastructure costs; aligns with animal welfare
Housing	Minimal shelter / simple barns	Protects from extreme weather; bedding optional	Low capital investment; easy maintenance
Feeding strategy	Pasture-based + seasonal supplementation	Concentrates or protein-rich feed during peak lactation	Low-input feeding; supports milk production and health
Water provision	Fresh, clean water	Ad libitum access required	Supports welfare and milk yield
Milking method	Manual or small-scale adapted equipment	Milking 1–2 times/day; requires careful handling	Flexible for small volumes; avoids large-scale investment
Hygiene and milk handling	Strict hygiene practices	Sanitization of equipment; proper storage at low temperatures	Ensures high-quality milk for premium products
Labor requirements	Moderate to high per unit of milk	Family-operated farms suitable; higher labor per liter compensated by product value	Feasible for small farms; focus on value-added production
Complementary activities	Agro-tourism, educational programs, forest management	Diversification of income; promotes sustainability	Enhances economic resilience; integrates well with niche products

The organization of doe farms can also integrate complementary activities, such as agro-tourism, forest management, and educational programs, which further increase income diversification and farm sustainability. Efficient herd management includes careful breeding planning, lactation monitoring, and health surveillance, all of which are critical for optimizing milk yield and maintaining high-quality milk standards (Meuwissen et al., 2021; Li et al., 2023). By combining low-input feeding, extensive grazing, and attention to welfare, small farms can establish economically viable and environmentally sustainable doe milk production systems.

Economic potential and market opportunities

Doe milk production presents a unique economic model in which profitability is driven more by product value than by production volume. At present, the most clearly documented commercial context for deer milk production is New Zealand, where a limited number of specialized farms have established milking systems based on seasonal production and once-daily milking. In these systems, deer milk is processed into niche, high-value products such as powders, cheeses, desserts, and cosmetic products, although production remains small-scale and highly specialized (Dowd, 2022). Recent research on red deer milk from New Zealand also confirms active interest in the use of deer milk as a novel ingredient in food, nutritional, and cosmetic products (Li et al., 2023). In contrast, European markets for doe milk are still largely underdeveloped, and potential commercialization is currently more likely to depend on product differentiation, short supply chains, direct sales, and integration with complementary farm activities than on standardized large-scale dairy production (van der Ploeg et al., 2019; Meuwissen et al., 2021). Production costs are relatively low, primarily due to minimal infrastructure requirements, reduced feed inputs, and lower veterinary expenses compared with conventional dairy cattle systems (Park et al., 2017; Li et al., 2023). These cost advantages are particularly pronounced in small-scale, family-operated farms, where labor is integrated within routine farm activities, and the emphasis is on value-added production rather than large-scale output. Conversely, the market value of doe milk is high, reflecting its rarity, exceptional nutritional composition, and functional properties. This premium positioning allows small farms to capture disproportionate economic returns per liter of milk or per unit of processed product (Haenlein, 2004; Maidment et al., 2026). Table 4 summarizes the key economic parameters and market opportunities for doe milk production, highlighting low costs, high product value, and the potential for diversified, value-added products suitable for small-scale farms.

Table 4. Economic potential and market opportunities of doe milk production (Park et al., 2017; Li et al., 2023; Haenlein, 2004; Maidment et al., 2026; Claeys et al., 2014; van der Ploeg et al., 2019; Meuwissen et al., 2021; Landete-Castillejos et al., 2000)

Aspect	Description	Implications for Small Farms
Production costs	Low infrastructure, low feed requirements, reduced veterinary expenses	Minimal initial investment; feasible for family-operated farms
Milk market value	High, due to rarity, nutritional quality, and functional properties	Profitability driven by value per liter rather than volume
Product diversification	Cheese, fermented products, specialty dairy items, functional foods, cosmetics	Increases added value and resilience; reduces dependence on single products
Labor requirements	Moderate to high per liter; acceptable in family-operated systems	Compatible with small-scale farms; higher labor offset by product value
Market channels	Direct marketing, farm shops, agro-tourism, niche markets	Short supply chains enhance margins; opportunity for premium pricing
Limitations	Low milk yield, seasonal production, lack of standardization, regulatory barriers	Requires strategic planning, niche marketing, and adaptation

Economic sustainability in doe milk production is strongly enhanced by product diversification. Beyond direct consumption of fresh milk, processing into cheese, fermented milk products, yogurts, and specialty dairy items significantly increases added value (Li et al., 2023). Innovative processing approaches can also yield concentrated proteins, functional beverages, and other specialty products for niche health-oriented markets. Additionally, non-food applications, such as cosmetics, skincare products, and nutraceuticals, offer further revenue streams, leveraging the unique composition of deer milk (Claeys et al., 2014). By diversifying outputs, small farms can reduce dependency on single products and improve economic resilience.

Doe milk production is particularly well-suited for small-scale farms for several reasons. Initial investment costs are modest, feeding requirements are compatible with pasture-based or semi-extensive systems, and family labor can efficiently manage small herds. Furthermore, integration with rural tourism, farm visits, and direct marketing creates additional income opportunities, while short supply chains allow farmers to capture higher margins by selling directly to consumers (van der Ploeg et al., 2019; Meuwissen et al., 2021). On-farm processing further enhances profitability and strengthens farm resilience against market fluctuations. The broader institutional context also plays an important role in shaping the economic feasibility of small-scale dairy systems. Local government strategies aimed at improving the investment climate and supporting rural entrepreneurship can facilitate the development of value-added agricultural activities in rural areas (Dokić et al., 2020).

Despite these advantages, several challenges and limitations must be considered. Doe milk yield remains low and highly seasonal, with production

peaks aligned with reproductive cycles and environmental conditions (Landete-Castillejos et al., 2000; Li et al., 2023). Lack of standardized milking technologies, processing protocols, and farm management guidelines can hinder scaling and consistency. Additionally, scientific data on long-term production economics, milk composition variability, and animal welfare in commercial deer dairy systems remain limited. Regulatory frameworks governing milk from non-conventional species are often underdeveloped or inconsistent, potentially restricting market access in some regions (Claeys et al., 2014; Park et al., 2017). Overcoming these constraints requires targeted research, technology adaptation, and supportive policy measures to fully realize the economic potential of doe milk production.

Conclusion

Doe milk production offers a viable alternative to conventional dairy systems for small-scale farms, combining low-input management with high-value niche products. Despite low and seasonal yields, doe milk's high nutrient density, distinct protein and fat profiles, and potential functional properties make it particularly suitable for specialty dairy products such as cheese, fermented foods, and functional or cosmetic applications. Extensive and semi-extensive farming systems allow efficient use of marginal lands while supporting animal welfare and family labor integration. Economic sustainability relies on product diversification, short supply chains, and value-added processing.

There are still several challenges, including limited yield, seasonal constraints, lack of standardized technologies, and regulatory barriers. Addressing these through research, optimized management, and supportive policies could expand the feasibility and profitability of doe milk production. Finally, doe milk could represent a sustainable, high-value strategy for small farms, contributing to rural diversification and the development of niche dairy markets.

Mleko košute kao održiva i visokovredna mlečna opcija za male farme

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Rezime

Globalna proizvodnja mleka doživela je značajnu intenzifikaciju, što je marginalizovalo male farme koje nisu u mogućnosti da se takmiče sa konvencionalnim sistemima uzgoja krava. Cilj ovog rada bio je da se izvrši pregled

potencijala proizvodnje, karakteristika kvaliteta mleka, organizacije sistema uzgoja košuta i ekonomske održivosti proizvodnje mleka košute, sa fokusom na primenu kao održivo rešenje za male farme. Mleko košute karakteriše relativno nizak prinos, ali visok sadržaj hranljivih materija, povišen sadržaj proteina i masti, kao i funkcionalna svojstva, uključujući bioaktivne peptide i potencijalne hipoalergene karakteristike. Ekstenzivni i poluekstenzivni sistemi uzgoja omogućavaju upravljanje sa niskim ulazima, efikasno korišćenje marginalnih pašnjaka i integraciju porodičnog rada. Ekonomska održivost se dodatno poboljšava kroz diverzifikaciju proizvoda, uključujući sireve, fermentisane proizvode i specijalne funkcionalne ili kozmetičke proizvode, čime se kompenzuje ograničen prinos mleka. Uprkos izazovima kao što su sezonska laktacija, nizak prinos i ograničena standardizacija, mleko košute predstavlja perspektivnu alternativu za male farme, nudeći visoko vredne nišne proizvode i doprinoseći ruralnoj diverzifikaciji i održivoj stočarskoj proizvodnji.

Ključne reči: mleko košute, srna, kvalitet mleka, male farme, nišni mlečni proizvodi, ekonomska održivost

Conflict of interest
The authors declare that they have no conflict of interest.

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