UNLEASHING THE POTENTIAL OF GOAT MILK IN SUSTAINABLE DAIRY SYSTEMS AMIDST HEAT STRESS CHALLENGES

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ABSTRACT

Goat milk presents a sustainable alternative to bovine milk, particularly in regions affected by climate change and heat stress. Its superior nutritional profile, higher digestibility, and lower allergenicity make it beneficial for human health. Goats are climate-resilient animals requiring fewer resources, emitting less greenhouse gases, and thriving in marginal environments. Goat-based dairy systems support food security, environmental sustainability, and rural livelihoods, especially for smallholders and women. Despite its advantages, goat milk remains underrepresented in policy and development programs. Strengthening value chains, investing in infrastructure, and integrating goat milk into public nutrition and climate-smart agriculture policies can maximize its potential.

KEYWORDS: Goat milk, sustainable dairy systems, climate resilience, heat stress

INTRODUCTION

The dairy industry plays a crucial role in ensuring global food security while sustaining millions of livelihoods, especially in developing countries. The potential benefits of goat milk to support the sustainable dairy systems is more widely acknowledged, particularly in areas where climate change and heat stress are major concerns. Its physiological, compositional, and economic benefits differentiate it from traditional cow milk and provide notable advantages for climate adaptation, food security, and rural livelihoods (Hammam *et al.,* 2022). The rising global temperature leads to heat stress, which has significant impact on animal's health, productivity and milk quality. In this context, goats are gaining attention for their adaptability to harsh environments and their milk as sustainable alternative to bovine dairy. Goats are perceived as better climate-resilient animal, especially in arid and semi-arid regions, offers a promising solution to dual challenge of maintaining milk production and safeguarding environmental sustainability. Despite the growing evidence supporting the nutritional and environmental benefits of goat milk, there remains a significant knowledge gap in understanding its full potential in sustainable dairy systems. This review explores the potential benefits of goat milk in climate-smart dairy systems, its nutritional attributes, environmental relevance and its contributions to rural livelihoods and sustainable development.

NUTRITIONAL AND FUNCTIONAL ATTRIBUTES OF GOAT MILK

Goat milk is dense in nutrients and often regarded as superior to cow milk in several aspects. It offers distinct nutritional, biochemical and functional characteristics making it promising alternative to cow milk for sustainable dairy technology and human health. It is rich in calcium, magnesium, phosphorus, and potassium and also higher levels of certain micronutrients like selenium and zinc. Some unique properties of goat's milk give it technological advantages over cow's milk. These includes smaller fat globules, which provides smooth texture for derived products, high proportion of short- and medium-chain fatty acids facilitating faster digestibility and low levels of alpha1-casein, which produce softer gel products, high water holding capacity and lower viscosity (Yadav *et al.,* 2016). The protein

profile of goat milk is notable for its lower alpha-s1 casein and higher beta-casein content. It results in reduced allergenicity, forms softer curd in stomach, better digestibility and beneficial for infants, children and individuals with cow milk allergy (López-Aliaga *et al.,* 2010). Its lipid profile helps maintain cardiovascular health and lack of agglutinin allows for uniform fat dispersion, aiding better
digestion and product formulation. Additionally, goat milk possesses therapeutic values that are increasingly supported by experimental and clinical research. The goat milk exhibits anti-inflammatory effects, helps to reduce inflammatory bowel disease symptoms. It contains prebiotic oligosaccharides that promote gut health with beneficial intestinal microflora. Goat milk proteins also contain bioactive peptides which is shown to have antihypertensive and antioxidant properties, maintains metabolism and cardiovascular health. Its high calcium and magnesium content also promotes bone mineralization and may reduce the risk of osteoporosis (Hammam *et al.,* 2022). These multifaceted advantages establish goat milk not only as a nutrient-dense food but also as a functional food with therapeutic prevalence. The key differences that makes goat milk superior to cow milk are summarized in Table 1.

Table 1: Comparative Nutritional and Therapeutic properties of goat and cow milk

Component	Goat Milk	Cow Milk
Fat (%)	4.0–4.5	3.8
Protein (%)	3.2	3.3
Lactose (%)	4.6	4.7
Calcium (mg/100g)	129.0	120.0
Magnesium (mg/100g)	20.0	12.0
Potassium (mg/100g)	180.0	150.0
Vitamin A (IU/100g)	185.0	126.0
Alpha-s1 Casein	Low (0-28%)	High (50-53.6%)
Beta-Casein	High (6-64%)	Low (37.5-39.3%)
Short- and medium-chain Fatty Acids	High	Low
Digestibility	High	Moderate
Allergenicity	Low	High
Antimicrobial Properties	Present	Present
Prebiotic Oligosaccharides	Present	Limited
Functional Peptides	Evident	Limited

Source: (Yadav *et al.,* 2016)

RESILIENCE AND SUSTAINABILITY OF GOAT-BASED DAIRY SYSTEMS

Goats are remarkably tolerant to adverse climatic conditions, including heat stress. Their efficient thermoregulation, low maintenance requirements, and browsing ability enable them to thrive in marginal environments. Their inherent adaptability makes them ideal livestock for arid and semi-arid regions where climate fluctuations challenges conventional dairy production. Although heat stress can still impact goat productivity, in terms of reduced feed intake, growth performance and altered milk composition, goats are comparatively more resilient than large ruminants like cattle. Their smaller body size, larger surface area-to-volume ratio allows better heat dissipation, which helps to sustain milk yield. However, if environmental stressors are not controlled, nevertheless they still reduce milk fat, protein, and lactose content and increase somatic cell count.

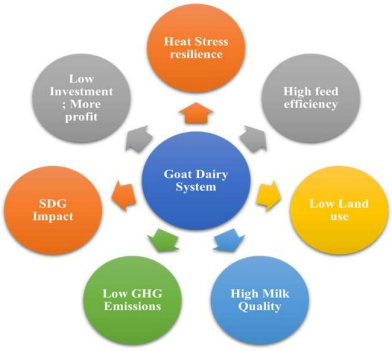

Fig. 1: Potential of Goat-based Dairy Systems under Heat stress

From an environmental sustainability perspective, goats offer significant advantages over cows. They produce lower methane emissions per unit of body weight and milk produced, lesser water footprint, and requires less feed and land compared to cows (Nair *et al.,* 2021). Moreover, their ability to thrive on thorns, shrubs, less palatable vegetation and low nutrient forages contributes to landscape management and biodiversity conservation (Godber *et al.,* 2020). These characteristics align well with the goals of sustainable dairy systems. Developing goat based dairy system helps achieve several Sustainable Development Goals (SDGs) such as SDG 2 (Zero hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), through enabling low-input animal production which promotes environmental conservation and food security.

FUNCTION IN RURAL LIVELIHOODS AND NUTRITION

Goat milk is essential for increasing food and nutrition security particularly for tribal and rural communities where bovine milk is scarce. In addition to offering a variety of goods appropriate for regional consumption and specialized markets it offers a reasonably priced source of excellent nutrition (Moran & Chamberlain, 2017). Raising goats gives smallholders especially women, a steady source of income through the sale of milk and value-added products. Communities-based dairy projects that involve the processing and marketing of goat milk have effectively increased livelihood security for cooperatives and self-help groups. Gender equity in livestock farming is improved by this inclusive decentralized model which also supports robust local economies.

IMPROVING GOAT MILK VALUE CHAINS

Targeted value chain interventions are necessary to increase the productivity and profitability of goat-based dairy products. Infrastructure for gathering and chilling standardized processing technologies, quality control systems and market connections are important steps. Spending money on branding and awareness initiatives can increase market access and help consumers get over their reluctance (Nguyen *et al.,* 2023). Public-private partnerships and producer cooperatives can be established to improve supply chain efficiency and price realization.

Despite the fact that goat milk has environmental and nutritional advantages, it is frequently left out of the mainstream dairy development policies. Future plans must include specific initiatives for goat-based dairying such as infrastructure, subsidies public nutrition program inclusion and incentives for environmentally friendly livestock management. Its socioeconomic impact can be increased by policies that support gender-inclusive goat farming and the development of marginal farmers capacities.

CONCLUSION

In the face of climate change goat milk has enormous potential to help with the problems associated with sustainable dairy production. Because of its high nutritional content, resistance to heat stress and minimal environmental impact, it is a great asset for dairy systems that are prepared for the future. Optimizing heat stress mitigation techniques, increasing milk yields through selective breeding, and expanding infrastructure for goat milk collection and processing requires more study. Its incorporation into popular sustainable agriculture models can be accelerated by investment in goat-based dairy value chains, consumer awareness campaigns, and policy support. We can create a more resilient inclusive and environmentally friendly dairy industry that benefits people and the environment by utilizing goat milk. In order to put scientific promise into practice it will be essential to fill in the knowledge gaps regarding breed-specific heat stress thresholds, infrastructure development, and market access.

FUTURE PERSPECTIVES

In order to support selective breeding programs for thermotolerance, future efforts should concentrate on expanding knowledge of the physiological and molecular responses of goats to heat stress. Goat dairy value chains can also be strengthened by the creation of region-specific dairy cooperatives, value-added product lines, and technological advancements for milk preservation in isolated locations. Goat milk's social acceptance and contribution to public health may be further enhanced by incorporating it into school feeding and nutritional supplementation programs. For

goat milk to reach its full potential in sustainable dairy systems, cooperation between researchers, policy-makers and small-scale farmers are crucial.

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