MILK: NUTRITIONAL SIGNIFICANCE, PROCESSING, AND INDIA'S DAIRY REVOLUTION - A SCIENTIFIC REVIEW

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ABSTRACT

Milk is recognized as a biologically complete food, supplying an array of essential nutrients such as calcium, high-quality proteins, lipid-soluble and water-soluble vitamins, and functional bioactive components that contribute to optimal health throughout all stages of life. This review provides a comprehensive overview of milk's biochemical composition, advancements in processing technologies, and India's significant evolution from a milk-deficient country to the leading global producer. Additionally, it explores the multifaceted role of milk in promoting economic resilience, ensuring nutritional security, and supporting sustainability goals, in the context of global observances like World Milk Day and national policy frameworks aimed at advancing the dairy sector.

KEYWORDS: Casein and whey proteins, Dairy sector in India, White Revolution, Operation Flood, Rashtriya Gokul Mission

INTRODUCTION

Milk plays an indispensable role in human nutrition from infancy through adulthood due to its rich composition of essential nutrients. It is a primary source of highly bioavailable calcium, complete proteins such as casein and whey, as well as key vitamins and minerals that support bone development, immune competence, and metabolic processes. Owing to its substantial contribution to both public health and the global economy, the Food and Agriculture Organization (FAO) designated June 1st as World Milk Day in 2001 to acknowledge and promote milk's multifaceted significance in nutrition and sustainable development (FAO, 2001).

Nutritionally, milk is considered a near-complete food, providing a balanced ratio of macronutrients and micronutrients. Scientifically, it is defined as the clean, fresh lacteal secretion obtained through the complete milking of healthy dairy animals, excluding any milk collected within 15 days before and five days after parturition. This exclusion ensures the absence of colostrum and maintains quality and safety standards. Furthermore, milk must comply with regulatory benchmarks for fat and solids-not-fat (SNF) content to ensure nutritional adequacy and consumer safety (Van et al., 2011; Harvard T.H., 2024).

NUTRITIONAL COMPOSITION AND HEALTH BENEFITS OF MILK

Cow's milk is a nutrient-rich fluid predominantly composed of approximately 87.4% water, with the remaining 12.6% consisting of milk solids that include proteins, fats, carbohydrates, vitamins, and minerals. It delivers a broad spectrum of nutrients, containing varying proportions of fat, water-soluble vitamins, minerals, trace elements, and electrolytes. Lactose is the main carbohydrate found in milk, although its concentration varies among species. In bovine milk, lactose makes up about 4.8% (roughly 12 to 12.5 grams per 240 ml serving), while human milk has a higher lactose concentration near 7%. Additionally, small amounts of other sugars such as glucose, galactose, and oligosaccharides are present.

The fat content in milk exists as a complex oil-in-water emulsion primarily composed of triacylglycerols—molecules consisting of fatty acids esterified to glycerol—with more than 400 distinct fatty acids identified to date. Other lipid classes present include phospholipids, sterols, waxes, and free fatty acids.

Regarding proteins, cow's milk contains a heterogeneous array of at least twenty different proteins. Casein proteins represent about 80% of the total protein content and exhibit considerable

heat stability. These caseins are divided into four main types: alpha-, beta-, kappa-, and gamma-caseins. The remaining 20% are whey proteins, which are more heat-sensitive and include α-lactalbumin, β-lactoglobulin, bovine serum albumin, and several minor proteins such as lactoferrin and lactoperoxidase (Taylor and Kabourek, 2003).

Milk is a complex biological fluid composed primarily of water, along with carbohydrates (mainly lactose), lipids, proteins (casein and whey), essential vitamins, and key minerals. Among the various types of animal milk, buffalo milk is distinguished by its superior nutritional content, including elevated levels of proteins, lipids, vitamins, and minerals compared to milk from other species. Notably, it also contains bioactive molecules such as gangliosides, which exhibit antioxidant and neuroprotective activities and are associated with improved bone strength, cardiovascular function, and gastrointestinal health in humans.

KEY BIO-NUTRIENTS IN MILK INCLUDE

- **Calcium**: Crucial for the development and maintenance of bones and teeth, as well as for supporting neuromuscular functions.
- **Proteins**: Milk proteins, primarily casein and whey, are of high biological value and contribute to tissue regeneration and immune response.
- **Vitamins**: Particularly rich in B-complex vitamins like B2 (riboflavin), B12 (cobalamin), and vitamin A, which play roles in metabolic processes and vision.
- **Minerals**: Important elements such as phosphorus, potassium, and magnesium are present and are vital for cellular and enzymatic functions.

The visual appearance of milk varies by species—buffalo milk is characteristically white due to its higher casein content, whereas the yellow hue in cow milk is attributed to beta-carotene, a precursor of vitamin A. Consistent consumption of milk supports normal growth, bone mineralization, and recovery following physical exertion (Garau et al., 2021).

TRANSITION FROM MILK DEFICIENCY TO GLOBAL DAIRY LEADERSHIP

India's current status as the world's largest milk producer is the result of decades of strategic planning and systemic development. In the post-independence era, the country experienced a critical deficit in dairy production, generating less than 21 million metric tonnes annually. During 1950–51, the per capita milk availability was alarmingly low, estimated at merely 124 grams per day, far below nutritional requirements.

A significant policy intervention occurred in 1965 with the formation of the National Dairy Development Board (NDDB), instituted to revitalize the dairy sector. The initiative was led by Dr. Verghese Kurien, who later became synonymous with India's White Revolution—a transformative movement aimed at dairy self-sufficiency.

This institutional foundation facilitated the launch of Operation Flood (1970–1996), one of the largest integrated dairy development programs globally. The project's objective was to enhance rural livelihoods, ensure nationwide milk distribution, and reduce dependency on imports. By the end of the program:

- More than 73,000 village-level dairy cooperatives had been successfully organized
- Approximately 700 towns and cities received a regular supply of pasteurized milk
- India achieved self-sufficiency in milk production and transitioned into a net exporter of dairy products.

Operation Flood significantly modernized India's dairy infrastructure, promoting a decentralized milk production model that empowered millions of rural farmers and established a robust cold chain and distribution network.

Current Scenario (2023–24)

- Total milk production: 239.30 million tonnes
- Global share: 25% (highest in the world)
- Per capita availability: 471 g/day (global avg. = 322 g)
- Production increase over previous year: +3.78%
- Exotic/crossbred yield: 8.12 kg/day/animal

- Indigenous/non-descript yield: 4.01 kg/day/animal
- Milk from exotic/crossbred increased by 8%
- Milk from indigenous cattle increased by 44.76%
- Milk from buffaloes declined by 16%
- Top 5 Milk Producing States: Uttar Pradesh (16.21%), Rajasthan (14.51%), Madhya Pradesh (8.91%), Gujarat (7.65%), and Maharashtra (6.71%) - together contributing 53.99% of national milk output.

ECONOMIC AND SOCIAL IMPACT OF THE DAIRY SECTOR

Dairying stands as the most significant segment within India's agricultural sector, contributing approximately 5% to the national Gross Domestic Product (GDP) (NDDB, 2024; DAHD, 2025). It serves as a critical economic activity that sustains a vast network of smallholder farmers, particularly in rural regions where alternative employment opportunities are limited.

The livestock population in India, as per the latest figures from the Department of Animal Husbandry and Dairying, comprises around 303.76 million bovines and 74.26 million goats (DAHD, 2025). These animals are not only central to the dairy value chain but also offer multiple co-benefits such as organic manure, energy sources (biogas), and traction for crop production.

Over 80 million rural households are engaged in dairy farming, with 18 million farmers affiliated with organized dairy cooperatives that facilitate structured milk procurement, quality control, veterinary support, and assured market access (NDDB, 2024). These cooperative frameworks have strengthened India's milk supply chain, contributing significantly to food security and agricultural resilience.

Importantly, the sector promotes inclusive development, with women constituting 35% of the dairy workforce. Their involvement spans from livestock care to milk handling and cooperative governance, enhancing women's economic agency, household nutrition, and social status (FAO, 2022; World Bank, 2023).

Overall, the dairy industry contributes not only to nutritional sufficiency but also to rural economic diversification and gender-balanced development, aligning closely with global development frameworks like the Sustainable Development Goals—notably SDG 2 (Zero Hunger), SDG 5 (Gender Equality), and SDG 8 (Decent Work and Economic Growth). The dairy economy ensures both nutritional security and rural livelihoods.

MILK PROCESSING AND QUALITY PRESERVATION

To ensure microbiological safety and prolong the shelf-life of milk while retaining its nutritional quality, various thermal processing methods are employed in the dairy industry. The Low-Temperature Long-Time (LTLT) pasteurization method heats milk at approximately 63°C for 30 minutes, effectively reducing pathogenic microorganisms, although it is less efficient for large-scale production due to its longer processing time (Harrigan, 2020).

The more widely used High-Temperature Short-Time (HTST) pasteurization involves heating milk to 72°C for 15 seconds, which achieves microbial safety with minimal impact on heat-sensitive nutrients such as vitamins B2 and C (Escuder et al., 2021).

Ultra-High Temperature (UHT) processing subjects' milk to temperatures between 135°C and 150°C for 2 to 4 seconds, rendering it commercially sterile and shelf-stable without refrigeration. However, this method may cause minor alterations in flavour and a slight reduction in thermolabile vitamins due to the intense heat exposure (Sood et al., 2019).

The organoleptic properties of milk are influenced by its biochemical components, with lactose imparting sweetness, volatile fatty acids contributing to sour notes, and minerals like chlorides adding slight bitterness or saltiness (Gupta & Sharma, 2018).

These processing methods facilitate the production of diverse dairy products by separating milk into fractions like skim milk and curd (coagulum), which serve as bases for items such as cheese, yogurt, butter, and ghee.

GOVERNMENT SCHEMES BOOSTING DAIRY GROWTH

India's milk production is being significantly enhanced through multiple initiatives by the Department of Animal Husbandry and Dairying, aimed at increasing milk yield, improving bovine productivity, and enhancing the profitability of dairy farming for rural communities:

- **Rashtriya Gokul Mission (2014):** This mission, with an updated budget of Rs 3400 crore for 2021–26, focuses on the conservation and development of indigenous bovine breeds. It offers free doorstep Artificial Insemination (AI) services across 605 districts, having already covered 8.87 crore animals and benefitted 5.42 crore farmers, with the objective to raise AI coverage from 30% to 70%.
- **National Programme for Dairy Development (NPDD):** Initiated in 2014 and restructured in 2021, this programme aims to enhance milk production and strengthen the dairy supply chain by developing robust infrastructure. Implementation is carried out through state cooperative federations to ensure effective grassroots reach.
- **Livestock Health & Disease Control Programme (LHDCP):** Focused on disease prevention and vaccination, this programme encompasses the National Animal Disease Control Programme (NADCP), Livestock Health & Disease Control (LH&DC), and Pashu Aushadhi initiatives.
- **National Livestock Mission (NLM):** Launched in 2014–15 and revised in 2021–22, NLM seeks to increase livestock productivity, create employment, and promote entrepreneurship. It targets enhanced production of meat, milk, eggs, and wool, with an emphasis on breed improvement, feed and fodder quality, and farmer education, supporting both domestic needs and export potential.
- **Animal Husbandry Infrastructure Development Fund (AHIDF):** Started on June 24, 2020, as part of the Atmanirbhar Bharat Abhiyan, this scheme encourages investment by individuals, private companies, MSMEs, Farmers Producers Organizations (FPOs), and Section 8 companies to establish infrastructure for dairy and meat processing, animal feed production, and breed improvement.
- **Kisan Credit Card (KCC) Scheme:** Facilitates easier access to credit for dairy farmers.

Collectively, these programmes aim to promote sustainable development and empower rural dairy farmers by improving productivity, infrastructure, and financial access.

GLOBAL AND NATIONAL CELEBRATIONS OF DAIRY

- **World Milk Day (June 1):** Launched by FAO in 2001. This annual observance emphasizes the global importance of milk in human nutrition and livelihoods.
- **National Milk Day (Nov 26):** Commemorated in memory of Dr. Verghese Kurien, the father of India's White Revolution, this day acknowledges his contributions to making India self-sufficient in milk production (NDDB, 2024).

HIGHLIGHTS OF 2023–24 MILK PRODUCTION

- India: World's largest milk producer (239.30 MT)
- GVA from milk: 82% of livestock GVA
- Global comparison:
  - USA: 11.04%,
  - Pakistan: 6.73%,
  - China: 4.34%

CONCLUSION

Milk plays a vital role in global nutrition and sustainable agriculture, with India emerging as the world's top milk producer through scientific innovation, supportive policies, and cooperative models. Initiatives like Operation Flood, Rashtriya Gokul Mission, and NPDD have driven genetic improvement, efficient breeding, and robust infrastructure. Scientific advancements such as artificial insemination, genomic selection, and modern pasteurization methods (HTST, UHT, LTLT) have enhanced productivity, product safety, and shelf-life. Emphasis on climate-resilient practices, nutritional fortification, and traceability supports public health and aligns with global sustainability goals. Empowering women and smallholder farmers ensure inclusive dairy growth, cementing milk's role in food security, rural livelihoods, and economic development.