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MILK PRODUCTION AND PROCESSING IN INDIA: A REVIEW OF TECHNOLOGIES, QUALITY STANDARDS, AND VALUE CHAIN CHALLENGES

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ABSTRACT

India has become the world's foremost producer of milk, a significant shift from its previous reliance on milk imports in the mid-20th century. This review paper examines the development of India's dairy sector, emphasising significant efforts like Operation Flood, which were essential to enhancing output and achieving milk self-sufficiency. The report analyses changes in milk production and per capita availability, assesses quality requirements and obstacles in meeting international benchmarks, and evaluates the impact of breeding procedures, veterinary care, and dairy management on improving milk quality. It also addresses the implementation of contemporary technology such as membrane filtration and automated milking systems, which have markedly enhanced processing efficiency and product quality. The structure and dynamics of the dairy value chain are analysed, highlighting the significance of organised supply chain systems, financial services, and human resource development. The report assesses the economic effects of dairy farming on rural life and the national economy while confronting ongoing obstacles such as feed shortages, sectoral disorganisation, poor productivity, and environmental sustainability concerns. Technological advancements and strategic measures are essential for maintaining development, enhancing quality, and securing the long-term sustainability of India's dairy sector. This research provides an in-depth analysis of the strengths, limitations, and prospective possibilities in the Indian dairy business.

Keywords: *- Milk Production, Modern Technology, Quality Standard, Value Chains etc.*

INTRODUCTION

India is currently the largest producer of milk globally, a position it did not always hold. In earlier decades, the country faced a significant milk shortage and relied on imports to meet its domestic demand. The country previously experienced a milk shortage, and it imported milk from neighbouring nations to accommodate its growing population. India, along with the United States, China, Pakistan, and Brazil, contributes to more than one-fifth of global milk production. During the 1950s and 1960s, India remained significantly reliant on milk imports until 1965, when the Indian government resolved to form a National Dairy Development Board to enhance the country's dairy sector. Beginning in the 1970s, the nation sought to augment milk output, resulting in the initiation of Operation Flood. By 1998, India had overtaken the United States to become the world's largest milk producer [1]. India's per capita milk availability more than quadrupled from 1991 to 2019, with output increasing at a compound annual growth rate of 4%.

Milk Production in India

In 1991, the per capita availability in India was 178 grams per day; however, in 2018, it increased to 411 grams per day. In 2018, the global per capita availability was 302 grams per day.

Table 1: Milk Production and Per Capita Milk Availability in India

Year	Production (million tonnes)	Per Capita Availability (gms/day)
2014-15	146.3	322
2015-16	155.5	337
2016-17	165.4	355
2017-18	176.3	375
2018-19	187.7	394
2019-20	198.0	411
2020-21	209.96	427
2021-22	221.06	444

India's milk output was 55.6 million tonnes in 1991 and increased to 187.7 million tonnes in 2018. The compound annual growth rate (CAGR) of Indian milk output from 1991 to 2018 was 4%. The Secretary of the Department of Animal Husbandry and Dairying under the Ministry of Fisheries, Animal Husbandry, and Dairy has described Operation Flood as the most ambitious dairy development initiative globally, serving as a catalyst for the nation's advancement in milk production [2]. This assessment evaluates the production of milk, its quality requirements, value chains, contemporary technology, and the difficulties and effects on the economy.

Quality milk production

India is the preeminent milk producer globally, accounting for over 25% of the international dairy industry. Nonetheless, its milk output frequently falls short of international standards, impacting domestic consumption and export opportunities. Efficient resource utilisation is essential to supporting sustainable farming practices and ensuring consumer safety. Quality issues must be resolved cost-effectively to enhance revenue generation.

Breeding procedures, including selective breeding techniques and modern technology such as artificial insemination and embryo transfer, can improve milk quality and quantity. Maintaining genetic variety is crucial for preventing inbreeding and ensuring herd vitality.

Dairy management techniques must prioritise feeding schedules, veterinary services, housing, and sanitation. Dairy calves must get a balanced, nutrient-dense feed, supplemented with minerals, and their water intake should be checked. Optimal nutrition enhances milk quality and promotes the health and economic viability of the herd. Acquaintance with ration-balancing applications and the dissemination of feeding information to farmers are crucial for attaining superior milk quality requirements.

Veterinary care encompasses routine assessments, vaccinations, and prompt interventions for illnesses. Preventive veterinary therapy can lessen the risk of infections that jeopardise milk production and quality. Biosecurity measures can avert epidemics of infectious diseases within the herd. Housing and sanitation are essential for dairy cattle, offering clean, pleasant, and well-

ventilated environments to mitigate stress and disease. Effective sanitation protocols, encompassing regular cleaning of milking facilities and apparatus, are essential to preserve milk purity and reduce contamination hazards [3].

Modern Dairy Technologies:

The dairy industry is perpetually in pursuit of novel and alternative processing methods to economically produce higher-quality dairy products. Aseptic membrane, microwave, radio frequency, ohmic heating, high pressure, and electrical pulse processing are among the conventional technologies that are currently being optimized; however, they require extensive testing [4].

Processing Membranes

The key to pressure-driven membrane processes is that semi-permeable membranes, which have the right physical and chemical properties, can separate molecules mainly by size, and to a lesser extent, by shape and chemical composition [5]. In order of increasing pore size, reverse osmosis, Nano filtration, ultrafiltration, and microfiltration are the primary membrane systems.

Ultrafiltration: The dairy business uses ultrafiltration for various purposes. Smaller molecules with molecular weights between 10,000 and 75,000 Dalton's can be separated using ultrafiltration membranes at operating pressures between 10 and 200 psig. Milk undergoes ultrafiltration to generate a retentate with a higher percentage of proteins, fat, and colloidal salts in proportion to the quantity of permeate removed, as well as a permeate with water, lactose, soluble minerals, non-protein nitrogen, and water-soluble vitamins. Ultrafiltration has been used in many processes, such as making milk protein standardization, removing protein from whey, separating protein types, preparing biological peptides, producing rasogolla mix powder, creating protein-rich milk, making low-lactose powder, and producing milk and whey protein concentrates [6]. Additionally, a number of fermented dairy products, including yogurt, shrimp, and other kinds of soft and semi-soft cheeses, have been produced using the ultrafiltration technique.

Reverse Osmosis: This process is basically a dewatering method. It is useful for pre-concentrating liquid feed for various applications. The molecular weight cutoff of reverse osmosis membranes is close to 100 daltons, and the pressure involved is five to ten times higher than that of ultrafiltration membranes. Potential uses for reverse osmosis technology include using pasteurized reverse osmosis concentrate in place of market milk; partially concentrating whey; partially concentrating milk and buttermilk; pre-concentrating milk for khoa production and spray drying; and bulk transporting reverse osmosis concentrated milks [7].

Nanofiltration: One method of demineralization is nanofiltration. With the nanofiltration method, acid whey can be partially stripped of minerals (around 40%), particularly the smaller ions, while also being concentrated to about 25% total solids. It separates particles with molecular weights ranging from 300 to 1000 daltons [8]. The necessary operating pressures are close to 300 psig.

In essence, microfiltration is a clarifying technique used to get rid of germs, colloidal particles, milk fat globules, suspended solids, and macromaterials. Microfiltration employs membranes with pore sizes between 0.1 and 10 microns and working pressures between 1 and 25 psig. The selective removal of microorganisms from milk is the most important use of microfiltration [9].

Value chains

The value-added supply chain confers a competitive advantage by generating and enhancing value at several stages. This process is known as the dairy value chain, with dairy producers being the fundamental component of the network. The value chain process starts with milk production and advances via aggregation, processing, manufacturing, transportation, marketing, and distribution [10]. Value chain participants comprise input suppliers, producers, processors, traders, and consumers.

Service providers, including banks, microfinance institutions, insurance firms, transporters, brokers, NGOs, government agencies, and research organizations, are essential in enabling production [11]. Their financial offerings encompass loans, pre-financing, equity holdings, factoring, and leasing agreements.

Organizational systems are crucial for managing the sequential operations of the supply chain to fulfill customer demand. Value chain development initiatives enhance the engagement of small-scale dairy producers in various chain operations. Milk producers' associations must concentrate on primary and ancillary value chain operations [12].

Core activities encompass milk production, milk collecting and incoming logistics, milk processing operations, outbound logistics, and sales and marketing. Support operations encompass the procurement of raw milk, human resource management, administration, research and development, operational infrastructure, and adherence to standard protocols [13].

Human resource management includes the recruitment of qualified individuals and the following responsibility for their growth through training, skill enhancement, and motivation. Administration encompasses corporate governance and corporate social responsibility [14]. Research and development encompass innovation and customization, new product creation, process adaptation, and the implementation of novel technologies in product manufacture. The operational infrastructure and established protocols guarantee uniformity in producing the intended final product [15].

Economic impact of dairy farming

The Indian dairy industry has undergone substantial economic expansion owing to technological advancements. Automation has enhanced milk production per cow and diminished labor and equipment expenses, thereby augmenting producers' earnings. Quality control methods have enabled farmers to satisfy international milk product standards, enhancing export opportunities and profitability. Advanced refrigeration systems have enhanced storage capacity, enabling farmers to preserve dairy products for prolonged durations without degradation [16]. This expansion has favorably influenced the economy, since the dairy industry serves as a vital economic source for millions of rural Indians and enhances the nation's trade balance. India is currently the foremost worldwide producer of milk, accounting for over 20% of total production, and it has diminished its dependence on dairy product imports [17].

The substantial transformations in the Indian dairy industry have been primarily ascribed to these technical innovations.

The Indian dairy sector has experienced substantial technological advancements, which have led to an increase in productivity and efficiency. Modern technologies, such as automated milking systems, refrigeration systems, and computerized feeding systems, have enhanced the efficacy of milk production and processing, resulting in increased profitability [18][19]. In addition, the quality of advanced dairy products has been improved through the implementation of technologies such as ultra-high-temperature treatment, membrane filtration, and aseptic packaging, which have enabled the production of high-quality dairy products with long storage lives.

Technological advancements have also reduced waste and expenses. For example, automated milking systems, computerized feeding systems, and sophisticated refrigeration systems have minimized feed and water loss, resulting in increased earnings and reduced production costs for dairy producers [20][21].

Technological advancements in transportation and logistics have increased the demand and accessibility of dairy products in a variety of regions, thereby influencing their rapid distribution and promotion. Enhanced cattle breeding methods have also been a primary focus, with artificial insemination (AI) and embryo transfer technology enabling farmers to grow superior varieties of cows that are more resistant to disease, produce more milk, and are able to adapt to local climatic conditions [22].

The Indian dairy industry has been transformed by automation in dairy operations, which has resulted in increased efficiency, reduced labor costs, and increased production. Milking appliances have improved the quality of milk and reduced the risk of contamination, thereby making it safer for consumption. Precision agriculture, which optimizes agricultural techniques such as crop rotation, fertilization, and irrigation, has been implemented to produce superior fodder for cattle, resulting in increased milk production and improved milk quality [23].

The production of a wider variety of dairy products, such as cheese, butter, and yogurt, has been

made possible by the development of advanced dairy processing methods, including ultra-high-temperature processing and aseptic packaging, which have extended the expiration life of milk and facilitated transportation and storage [24][25].

Technological innovations have facilitated the administration of the entire supply chain, from production to distribution, which is essential for the dairy industry's performance. The industry's overall profitability has been increased by the mitigation of post-harvest losses through the implementation of improved storage and transportation methods [26]. Advanced technologies, including ultra-high-temperature treatment, membrane filtering, and aseptic packaging, has resulted in substantial enhancements in the quality of products in the Indian dairy sector. These innovations have bolstered the profitability of dairy producers and expanded the availability of premium dairy products for consumers [27].

Challenges in Indian dairy industry

The Indian dairy industry encounters numerous challenges, such as inadequate quality feed and fodder, a disorganized sector, inefficient supply chains and infrastructure, insufficient milk processing capacity, restricted access to credit and insurance, low productivity and quality standards, limited product diversification, unsatisfactory returns, insufficient education and training, poor technology adoption, climate change, and environmental sustainability issues [28].

India has a deficiency of 23.4 percent in dry fodder, 11.24 percent in green fodder, and 28.9 percent in concentrates. The rising popularity of high-breed animals has generated significant demand for quality feed and fodder to satisfy the nutritional needs of milking animals. Small and marginal farmers, along with agricultural laborers involved in dairy farming, lack the financial means to acquire sufficient feed and fodder, resulting in the undernourishment of their animals. In conventional dairy production methods, feed expenses comprise up to 70% of overall expenditures, impacting the profitability of dairy farming.

The disorganized Indian dairy sector is the predominant characteristic of the Indian dairy industry, with just 18-20% of the nation's total milk output managed by the organized sector. Inefficient

supply chain management, including suboptimal logistics, insufficient cold storage facilities, and poor transportation infrastructure, leads to post-harvest losses and quality deterioration [29]. Investment in cold chain infrastructure, milk collecting centers, and transportation networks is crucial for enhancing supply chain efficiency and minimizing waste.

The milk processing sector in India is quite modest, with about 10% of the total milk processed in dairy facilities. The informal sector, comprising milkmen and sellers, manages a substantial share of milk production, resulting in inefficiencies in processing and distribution [30]. Restricted access to loans and insurance can bolster the resilience and productivity of dairy producers.

The average milk output of cows in India is less than that of their US counterparts, with an annual yield of 1,248 kilograms per cow compared to around 10,000 kilograms per year. Investing in research and development, advocating best practices, and executing quality control procedures are essential for enhancing productivity and adhering to global standards. Maintaining quality and safety standards across the dairy value chain presents challenges, including adulteration, insufficient hygiene procedures, and inadequate testing facilities, which undermine customer confidence and market competitiveness. Product diversification and value enhancement are crucial for the Indian dairy sector, given that liquid milk pre-dominates the market. Innovative and market-oriented tactics are essential for the development and commercialization of value-added dairy products [31].

Climate change presents issues to the dairy industry, including feed availability, water resources, and overall sustainability. Implementing climate-smart dairy farming techniques, advocating for resource conservation, and embracing renewable energy options may enhance the sector's enduring sustainability [32]. Advocating for environmentally sustainable ideas can guarantee enduring sustainability.

Substantial economic losses incurred by dairy producers owing to illnesses represent another critical concern. Insufficient vaccination coverage leads to economic losses due to several animal illnesses. India's farmers face direct losses exceeding 50,000 crores annually due to avoidable illnesses that vaccination could potentially alleviate.

CONCLUSION

We conclude that India's evolution from a milk-short nation in the 1950s to the world's largest milk producer is a success story of policy foresight, grassroots mobilisation, and technological progress. Led by the landmark Operation Flood and supported by government programmes, scientific breeding techniques, enhanced veterinary services, and advanced dairy technologies, the Indian dairy industry has seen a steady increase in milk production and per capita availability. India generates more than 25% of the world's milk, but problems with milk quality, infrastructure, and product diversity still prevent it from realising its full potential in overseas markets. Modern processing technologies including ultrafiltration, reverse osmosis, and nano-filtration have opened doors for better dairy shelf-life, nutritional quality, and preservation. Furthermore, the convergence of value chain models has brought discipline to the dairy system, so enabling small-scale producers to participate more actively and profitably. Economically, the dairy sector provides livelihood and nutrition security, helping rural homes spanning millions. From automated milking systems to precision agriculture, technological interventions—which range in nature—have significantly raised output while lowering running expenses and waste.

Yet, the sector is beset with its share of challenges. Chronic concerns such as shortage of feed and fodder, poor productivity, lack of integrated supply chains, and scant cold storage capacities highlight the call for more investment, learning, and building capacities. Climatic change, escalating input prices, and exposure to livestock diseases also add complexity. Overcoming these challenges using climate-smart agriculture, better animal healthcare, and improved quality assurance measures will be critical for inclusive growth. Finally, having attained self-sufficiency in milk production and having created a pioneering position in the world, now the attention needs to be given to quality improvement, value addition, and sustainability of the environment. An inter-sectoral collaboration among farmers, policymakers, technologists, and industry players is necessary to unlock the entire economic and nutritional potential of the Indian dairy industry.

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