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RECENT ADVANCES IN DAIRY PRODUCT TECHNOLOGY: A REVIEW ON PROCESSING INNOVATIONS, NUTRITIONAL ENHANCEMENTS, AND MARKET TRENDS

Dr. Shiv Shanker Katiyar
(Associate Professor)
Animal Husbandary & Dairying
R.S.M. College, Dhampur

ABSTRACT

The dairy industry has witnessed drastic reforms with the advent of processing technologies, nutritional upgrades, and shifting market pressures. Microfiltration, high-pressure processing (HPP), and crystallization are some of the technologies that have significantly enhanced the safety, quality, and stability of milk products without affecting their nutrient content. The nutritional enrichment processes have also enhanced the health benefits of milk through bioavailable micronutrients, high-quality protein, and functional fatty acids. Market trends depict rising demand for value-added goods such as A2 milk and green production methods spurred by environmental concerns and consumer demand. Indian technological advances have improved productivity and product quality and contributed substantial inputs to country employment and economic growth. In this review, recent advancements in dairy product technology are discussed in terms of novel processing technology, nutrition enhancement strategies, and economic and market significance both in the international and Indian markets.

Keywords: - *Dairy production, Innovations, Nutritional enhancements, Market trends etc.*

1. INTRODUCTION

The dairy sector is a critical component of global nutrition and rural economies, particularly in developing countries such as India. Growing demand for safe, nutritious, and shelf-stable dairy products over the years has prompted technological advancements in processing and manufacturing. The use of new technologies, like high-pressure processing, microfiltration, and membrane technology, can enhance the quality of products, ensure food safety, extend shelf life without compromising nutritional integrity, and hence trigger a trend to augment or replace current procedures. The changing consumer profile is marked by nutritional enrichment and rising market trends, specifically the requirement for A2 milk substitutes and eco-friendly methods. This article reviews recent advances in dairy product technology encompassing processing innovations, nutritional improvements, market trends, and economic impacts on the dairy industry in India.

2. PROCESSING INNOVATIONS IN DAIRY PRODUCT TECHNOLOGY

Conventional techniques have converted milk into dairy products for ages. Nonetheless, there is a continuous endeavour to investigate new technologies to improve the quality of existing items or develop new ones. Contemporary processing techniques are utilised to modify texture, improve organoleptic characteristics, ensure safety, prolong shelf life, and eventually augment the nutritional and health advantages of dairy products. Innovative methods considered substitutes for thermal treatment include pulsed electric fields, ultrasound, and high-pressure processing. HP is the most promising technique among them, as it predominantly processes the product in the 100–600 MPa range at ambient temperatures, leading to changes in many components and qualities. Moreover, the dairy sector frequently uses membrane technology for separation or fractionation, based on the size of the membrane pore and the applied pressure. Microfiltration (MF), referred to as "cold pasteurisation", is a technique capable of eliminating germs and pathogens from skim milk. This procedure entails membranes with a whole size ranging from 0.1 to 10 μm. Furthermore, we have devised contemporary analytical techniques alongside innovative technology to improve the assessment of critical attributes and processing phases in dairy product manufacturing [1].

Microfiltration (MF)

In the dairy industry, microfiltration (MF) is a widely used method for component separation, primarily for reducing bacteria, spores, and somatic cells in liquid dairy products. Extended shelf life (ESL) milk, which is thought to be "purer" and more natural than conventional heat-treated milk, can be produced by combining it with pasteurization. Membrane filtration can also be used in conjunction with ultrafiltration to process whey and to separate globular milk fat, casein, and β-lactoglobulin. The use of MF to pretreat milk in the making of cheese has also been investigated. Membranes with 1.4 μm pores are commonly used to remove bacteria from milk while keeping essential ingredients intact. To create new goods or enhance existing ones, researchers are looking at modern processing methods, including high-pressure processing, ultrasound, and pulsed electric fields. The most promising technique is high pressure (HP), which changes a number of the treated product's components and characteristics by processing the product at temperatures between 100 and 600 MPa [2].

Crystallisation

Crystallization is a process that involves the production of ice crystals by the use of atomic ordering. This occurrence has an impact on the quality of frozen meals, notably desserts that contain ice cream. The texture of the final product is determined by characteristics such as the proportions, orientation, and arrangement of these crystals. Ice crystals of a size range from 10 to 20 μm are in the best position to generate the desired texture. On the other hand, bigger crystals may result in an unpleasant texture. In terms of physicochemical properties, ice cream is a multiphase system that is differentiated by the dispersion of diverse components throughout a number of phases. The ingredients that go into making ice cream include air that is dispersed throughout a frozen liquid that is typically two-thirds water. Ice cream is made up of a solution of sucrose, lactose, carbohydrates, and mineral salts while it is in the aqueous phase. A matrix that has not been frozen, air bubbles, ice crystals, and fat globules are the four phases that make up the system. The development of ice takes place after the initial freezing process and becomes more intense in the first few hours following manufacturing. During storage, the size of ice crystals increases as a result of recrystallization. The creation of excessive crystals during storage is influenced by the total solids, initial freezing temperature, unfrozen water amount, type of stabilizer, kind of sweetener, and storage temperature [3].

High Pressure Processing (HPP)

High-pressure processing (HPP), which is often referred to as high hydrostatic pressure (HHP) or ultra-high pressure (UHP), is a cutting-edge method for the preservation of food. The processing of dairy products has become more diverse and effective as a result of the development of new techniques such as high-pressure thermal processing (HPTP) and in-bulk delivery technology [4]. Internal compression heating can elevate temperatures to 90 to 120 degrees Celsius at pressures of 600 MPa or more through the use of high pressure and low beginning temperatures. HPTP combines high pressure with low initial temperatures between 60 and 90 degrees Celsius. The process of pasteurization or sterilization may be accomplished by this method, which is often utilized for meals that are encased in high-barrier multilayer flexible polymers. In order to eliminate bacteria while maintaining the food's nutritional content and aesthetic appeal, high-pressure thermal processing (HPTP) makes use of pressure-induced heat. There are, however, obstacles that are preventing its wider implementation, such as the high cost of equipment and the extensive training of workers. The majority of systems are presently functioning at a laboratory size, which indicates that HPTP is still in its infancy [5].

3. NUTRITIONAL ENHANCEMENTS OF DAIRY PRODUCTS

Milk is frequently regarded as the "optimal nourishment" owing to the ingredients, composition, and bioavailability that milk possesses. The only species in the animal kingdom that takes the milk of other animals and continues to do so throughout their whole lives is the human species [6]. Milk is an essential daily dietary supplement for adults because it is nutritious, technically beneficial, and has pleasant sensory properties. Due to the fact that milk has a healthy proportion of carbs, lipids, and proteins, its nutritional value is directly proportional to the amount of calories it contains [7]. As a result of the components of milk working together to generate "vehicles" for essential micronutrients like calcium, phosphorus, and iron, these nutrients are easily absorbed by the body. Despite its presence in milk, iron is considered absent from the beverage [8].

Numerous studies have proven the favorable health benefits of drinking milk, particularly during the early infancy years when bone building is taking place. The calcium and phosphorus that are obtained from milk are absolutely necessary for the prevention of osteoporosis in later life. Milk and other dairy products, when incorporated into the diet of an elderly person, make it possible to successfully prevent and treat malnutrition, as well as halt the evolution of sarcopenia [9][10]. The digestive enzymes in the gut and the special enzymes in fermented foods help create bioactive peptides found in dairy products. Milk consumption on a consistent basis offers a source of water-soluble vitamins for both children and adults. It satisfies the recommended daily allowance (RDA) for vitamins B1, B2, and B12, and it also imparts a substantial quantity of vitamins A, C, and pantothenic acid [11].

Milk proteins supply a significant amount of the amino acids that are necessary for the production of raw materials. Bovine milk contains roughly 200 different amino acids, making it their primary source of amino acids. The digestibility of caseins and whey, which are the two primary types of proteins, is 91% compared to a standard reference protein [12]. Due to their high lysine content, milk proteins enhance the amino acid composition of other products. Milk fat is responsible for transporting fat-soluble vitamins (A, D, E, and K) and accounts for a sizeable percentage of the caloric energy that milk contains (9 kcal/g fat). An essential component that possesses qualities that are beneficial to one's health is conjugated linoleic acid

(CLA), which is classified as an essential fatty acid (EFA). In milk, there are a substantial number of fatty acids, and the chain lengths of these acids can range anywhere from four to more than twenty carbon atoms [13].

According to the dairy business, fat serves as a taste transporter, which allows it to enhance the flavor of milk and other dairy products. This increases the silky texture of cheeses as well as the rich flavor of various other cuisines. Extraction of fat fractions from the milk matrix, which is analogous to the extraction of protein, results in the production of important components that increase the nutritional content of food [14].

Putting a focus on the significance of individual milk components, both by the industry and by consumers, has resulted in the considerable creation of food products that are intended for consumption by the consumer themselves. The current focus on milk proteins and the differences between types (A1/A2 β-casein) helps create new products designed to meet the specific dietary needs of people with special diets [15].

4. MARKET TRENDS

Cows are the primary source of milk produced worldwide, with the European Union being the largest producer. The amount of milk produced by cows worldwide increased from 496.84 million metric tons in 2015 to 549.48 million metric tons in 2023. It is expected that this trend will continue in the years to come. However, as plant-based substitutes and even synthetic milk become more widely available, consumers' awareness and expectations about ethical and environmental production methods are growing, and there are differing views on whether buying milk is still suitable [16][17].

As an unprocessed product and as a raw material for making nutrient-dense meals and intermediate commodities, milk is an important commodity. Because of their high nutritional content and pleasant flavor, milk powders—including milk protein isolates (MPIs) and concentrates (MPCs)—have various uses and are important to businesses. Their increasing usage to improve dairy products is driven by commercial needs and technological concerns [18].

In the past, milk was produced on small farms with animals kept close to humans. Since the industrial revolution, technical developments have made it possible to continuously improve production efficiency, which has led to dairying becoming a corporate-dominated industry and increasing potential profits [19]. The increasing demand for A2 milk might have positive effects on the economy and the environment, which would change the power dynamics between larger and smaller producers. By encouraging producers and farmers to diversify their offerings, this shift helps to maintain market stability and counteract the trend of the dairy industry becoming more homogenized [20].

Since the cows from the breeds that produce A2-type milk produce somewhat less than the most common breeds now in use, the amount of milk that may be produced is limited [21]. However, A2-type milk may support greater biodiversity in local ecosystems. No hypothesis about the impact of A2-type milk on human health has been proven correct or validated. It is still uncertain if the bioactive peptides in milk that contains both A1 and A2 proteins have harmful health effects, according to the EFSA's 2009 finding [22]

Dairy milk production and consumption are shifting from the Global North to the Global South, according to an analysis of key developments in the dairy industry during the next several years [23]. Despite growing knowledge of the environmental effects of intensive dairying, there has been a notable growth in mechanized, standardized, and corporate dairy farms [24]. Dairy substitutes made from plants and synthetic materials are causing disruptions in the market. To promote harmonious growth throughout all geographic locations within this business, it is imperative to handle the challenges presented by megatrends [25].

5. ECONOMIC INFLUENCE OF TECHNICAL BREAKTHROUGHS ON THE INDIAN DAIRY SECTOR

The Indian dairy sector has experienced significant economic growth due to technological advancements. Automation has improved milk yields per cow and decreased labour and equipment expenses, resulting in increased revenue for farmers and encouraging more investment in the industry. Enhanced quality control techniques have allowed farmers to comply with worldwide milk product requirements, therefore increasing their export potential and profitability. Furthermore, enhanced storage capacity from sophisticated refrigeration systems has allowed companies to maintain substantial volumes of milk products without spoiling or deterioration [26].

The expansion of the Indian dairy sector has positively influenced the overall economy, serving as a significant source of income for millions of rural Indians. Forecasts suggest that the industry will directly employ around 8 million people and indirectly employ an additional 16 million individuals. India currently stands as the foremost global producer of milk, contributing over 20% of overall output, hence diminishing the nation's reliance on dairy product imports.

Technological innovations have significantly transformed the Indian dairy sector. Productivity and efficiency have been enhanced by the implementation of modern technologies, such as automated milking systems, automated refrigeration systems, and computerised feeding systems. These developments have enabled dairy farmers to augment milk output while reducing costs, hence improving profitability [27]. Innovations such as ultra-high-temperature (UHT) treatment, membrane filtering, and aseptic packaging have facilitated the production of high-quality dairy products with extended shelf life, therefore enhancing profitability for dairy producers and providing customers with superior dairy choices.
The use of technology in the Indian dairy industry has led to diminished waste and costs. Technologies such as automated milking systems, computerised feeding systems, and modern refrigeration systems have minimised feed and water waste, leading to decreased production costs and increased profits for dairy producers [28]. Technological advancements in transportation and logistics have facilitated improved distribution and marketing. This invention has facilitated the rapid and effective distribution of dairy products throughout several regions of the country, enhancing accessibility and therefore augmenting demand and revenue for dairy producers.

6. CONCLUSION

We conclude that an innovation in dairy food technology have revolutionized the business by offering novel processing methods, enhancing nutritional content, and adapting to market variations over the last few years. Microfiltration, crystallization, and high-pressure processing are methods that have significantly enhanced product safety, shelf life, and sensory qualities without affecting nutritional integrity. The development of alternative, cost-efficient, and environmentally friendly options, such as HPTP and membrane technology, has opened up the range of traditional milk processing. Due to their high protein, essential fatty acids, and readily available micronutrient content, dairy foods and milk continue to be an integral part of the diet of humans, even nutritionally. As A2 milk and dairy foods particularly designed according to customers' needs and health have been found out, the business is now increasingly concentrated on coming up with products to fulfil diverse needs and health preferences. From the market perspective, the global dairy industry is transforming in terms of geography, production methods, and consumer expectations. Technological advancements are enabling dairy farmers—especially in India—to produce to international levels, expand export opportunities, and enhance economic sustainability. However, the industry will also have to address challenges posed by plant-based foods, the environment, and shifting eating patterns to be competitive and inclusive. Overall, the intersection of new processing technologies, nutritional innovation, and market-responsive strategies places the dairy industry on a trajectory of long-term growth, sustainability, and consumer confidence worldwide.

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