

Utilization of Whey in Functional Dairy Beverages: Nutritional, Technological, and Industrial Perspectives

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Abstract

The dairy industry plays a vital role in global nutrition and the economy, producing a wide range of products that contribute significantly to human health. Among its by-products, whey is generated in large quantities during cheese and paneer production and has traditionally been considered a waste material, posing environmental challenges due to its high biochemical oxygen demand. However, in recent years, whey has gained considerable attention as a valuable resource owing to its rich nutritional composition, including high-quality proteins, lactose, vitamins, and minerals. Whey proteins, such as β -lactoglobulin and α -lactalbumin, are known for their excellent digestibility and bioactive properties, including antioxidant, antimicrobial, and immune-enhancing effects. This has led to the increased utilization of whey in the development of functional dairy beverages aimed at promoting health and wellness. The growing consumer demand for functional foods and beverages, driven by rising health awareness and lifestyle changes, has further accelerated the incorporation of whey into innovative drink formulations. Various technological approaches, including membrane filtration, fermentation, enzymatic modification, and fortification, have been employed to improve the functional, sensory, and shelf-life characteristics of whey-based beverages. The use of stabilizers, flavoring agents, and natural additives has also enhanced product acceptability and marketability. From an industrial perspective, the effective utilization of whey not only reduces environmental pollution but also adds economic value by converting a low-cost by-product into high-value functional products. The global market for whey-based beverages is expanding rapidly, reflecting increasing consumer preference for nutritious and convenient drink options. In the future, advancements in processing technologies and the integration of novel ingredients are expected to further enhance the scope of whey utilization, making it a key component in the sustainable development of the dairy industry.

Keywords: Beverage technology, dairy by-products, functional dairy beverages, nutraceuticals, whey proteins, whey utilization

INTRODUCTION

The dairy industry is one of the most significant sectors in the global food system, contributing substantially to nutrition, employment, and economic development. It involves the processing of milk into a wide range of products such as cheese, butter, yogurt, and paneer. During these processes, particularly cheese and paneer manufacturing, large volumes of whey are generated as a by-product. It is estimated that for every kilogram of cheese produced, approximately 8–9 liters of whey are obtained, making whey one of the most abundant by-products in the dairy industry.

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Received Date: March 23, 2026
Accepted Date: March 31, 2026
Published Date: April 01, 2026

Citation: Madhu Goswami. Utilization of Whey in Functional Dairy Beverages: Nutritional, Technological, and Industrial Perspectives. *Research & Reviews: Journal of Dairy Science & Technology*. 2026; 15(1): 18–23p.

Traditionally, whey was considered a waste product and was often discarded without proper treatment. Direct discharge into water bodies can lead to oxygen depletion, adversely affecting aquatic life and contributing to environmental

pollution. These concerns have necessitated the development of sustainable strategies for whey utilization and management [1].

In recent years, the concept of functional beverages has gained considerable attention in the food and dairy sectors. Increasing consumer awareness regarding health, fitness, and disease prevention has led to a growing demand for such products, creating new opportunities for innovation in dairy-based beverages.

Whey, due to its rich nutritional composition, has emerged as an excellent ingredient for the development of functional beverages. It contains high-quality proteins, lactose, essential amino acids, vitamins, and minerals, along with bioactive peptides that exhibit antioxidant, antimicrobial, and immune-boosting properties. The incorporation of whey into beverages not only enhances their nutritional value but also provides a cost-effective solution for utilizing dairy by-products. Moreover, advancements in food processing technologies have facilitated the development of a wide range of whey-based drinks with improved sensory and functional properties [2, 3].

WHEY: COMPOSITION AND NUTRITIONAL SIGNIFICANCE

Whey is the liquid by-product obtained during the coagulation of milk in the production of cheese, paneer, and casein. Once considered a waste material, whey is now recognized for its exceptional nutritional value and functional properties. It contains a variety of essential nutrients, making it a valuable ingredient in the formulation of functional dairy beverages [4].

Types of Whey

Whey can be classified into two main types based on the method of milk coagulation:

- *Sweet Whey*: Sweet whey is produced during the manufacture of rennet-coagulated products such as cheese. It has a relatively neutral pH (around 6.0–6.5) and contains higher levels of lactose and intact proteins, making it suitable for beverage applications.
- *Acid Whey*: Acid whey is obtained from the production of acid-coagulated products such as paneer, yogurt, and cottage cheese. It has a lower pH (around 4.5–5.0) and contains higher mineral content due to the solubilization of calcium and phosphate. Its acidic nature may require further processing before using beverages [5].

Chemical Composition

Whey is composed of approximately 93–94% water, with the remaining portion consisting of valuable nutrients:

- *Proteins (β -Lactoglobulin, α -Lactalbumin)*: Whey proteins are of high biological value and are easily digestible. β -lactoglobulin is the major protein component, while α -lactalbumin plays an important role in lactose synthesis and has nutritional significance.
- *Lactose*: Lactose is the primary carbohydrate present in whey and serves as a source of energy. It also contributes to the osmotic balance and sweetness of whey-based beverages [6].
- *Minerals*: Whey contains essential minerals, such as calcium, potassium, magnesium, and phosphorus, which are important for bone health and metabolic functions.
- *Vitamins*: It is a good source of water-soluble vitamins, particularly B-complex vitamins, such as riboflavin (vitamin B2), which contributes to its characteristic greenish–yellow color [6].

Nutritional and Health Benefits

The nutritional richness of whey makes it highly beneficial for human health and suitable for incorporation into functional beverages:

- *High Biological Value Proteins*: Whey proteins contain all essential amino acids and are rapidly absorbed by the body, making them ideal for supporting growth and tissue repair.
- *Role in Muscle Growth and Immunity*: Whey proteins are widely used in sports nutrition due to their role in muscle protein synthesis. Additionally, components, such as immunoglobulins and lactoferrin, enhance immune function [7].

- *Antioxidant and Bioactive Properties:* Whey contains bioactive peptides that exhibit antioxidant, antimicrobial, and antihypertensive properties. These compounds contribute to the prevention of oxidative stress and support overall health [7].

FUNCTIONAL DAIRY BEVERAGES

Functional dairy beverages are gaining significant attention due to their ability to provide health benefits beyond basic nutrition. The incorporation of bioactive components, probiotics, and nutrient-rich ingredients, such as whey, has led to the development of innovative beverages that support overall health and well-being [8].

Definition and Classification

Functional beverages are defined as drinks that offer additional physiological benefits apart from supplying essential nutrients. These beverages are designed to improve health, enhance performance, and reduce the risk of diseases.

Based on their composition and functionality, dairy-based functional beverages can be classified into:

- *Probiotic Beverages:* Containing beneficial microorganisms that improve gut health
- *Fortified Beverages:* Enriched with vitamins, minerals, or bioactive compounds.
- *Whey-Based Beverages:* Developed using whey as a primary ingredient for its nutritional and functional properties [9].

Types of Functional Dairy Beverages

- *Probiotic Drinks:* These beverages contain live beneficial bacteria, such as *Lactobacillus* and *Bifidobacterium*, which promote gut health, improve digestion, and enhance immunity.
- *Fortified Milk Beverages:* Milk-based drinks enriched with additional nutrients, such as calcium, vitamin D, iron, or omega-3 fatty acids, to address specific nutritional deficiencies.
- *Whey-Based Drinks:* Whey beverages are formulated using liquid whey or whey protein concentrates. They are often flavored and may include fruit juices, herbal extracts, or natural stabilizers to improve taste and functionality [10].

Health Benefits

Functional dairy beverages offer multiple health benefits, making them increasingly popular among health-conscious consumers:

- *Digestive Health:* Probiotic beverages help maintain a healthy gut microbiota, improving digestion and reducing gastrointestinal disorders.
- *Hydration and Electrolyte Balance:* Whey-based beverages are rich in electrolytes, such as potassium and sodium, to make them effective for rehydration and recovery, especially after physical activity.
- *Disease Prevention:* The presence of bioactive compounds, antioxidants, and essential nutrients helps reduce the risk of chronic diseases such as cardiovascular disorders, osteoporosis, and immune-related conditions [11].

TECHNOLOGICAL ASPECTS OF WHEY UTILIZATION

The successful incorporation of whey into functional dairy beverages depends on appropriate processing and formulation techniques that enhance its nutritional value, sensory quality, and shelf stability. Advances in dairy technology have enabled efficient utilization of whey in a variety of beverage applications.

Processing Techniques

- *Pasteurization:* Pasteurization is commonly applied to whey to eliminate pathogenic microorganisms and ensure product safety. It also helps in extending the shelf life of whey-based beverages without significantly affecting their nutritional quality.

- *Ultrafiltration and Concentration*: Membrane processing techniques, such as ultrafiltration, are used to concentrate on whey proteins and remove excess lactose and water. This improves the functional properties and nutritional density of whey, making it more suitable for beverage formulation [12].
- *Fermentation*: Fermentation using lactic acid bacteria enhances the flavor, digestibility, and probiotic value of whey beverages. It also contributes to improved shelf life and adds functional benefits such as gut health promotion.

Formulation of Whey-Based Beverages

The formulation of whey-based beverages involves the addition of various ingredients to improve taste, texture, and consumer acceptability:

- *Flavoring Agents*: Natural and artificial flavors, such as fruit extracts (mango, orange, berry), are added to enhance palatability and mask the inherent flavor of whey.
- *Sweeteners*: Sugar, honey, or low-calorie sweeteners are used to balance the taste and improve consumer appeal.
- *Stabilizers (e.g., Carrageenan)*: Stabilizers help maintain uniform consistency, prevent sedimentation, and improve mouthfeel. Natural hydrocolloids, such as carrageenan, derived from red seaweed, are widely used in dairy beverages.

Shelf-Life Enhancement

- *UHT (Ultra-High Temperature) Processing*: UHT treatment involves heating the product at very high temperatures for a short time, effectively destroying microorganisms and enzymes, thereby extending shelf life without refrigeration.
- *Packaging Technologies*: Aseptic packaging and the use of barrier materials help protect whey beverages from contamination, light, and oxygen, preserving quality and safety.
- *Preservation Methods*: The use of natural preservatives, controlled pH, and refrigeration further enhances the stability and shelf life of whey-based beverages.

INDUSTRIAL APPLICATIONS AND MARKET TRENDS

The utilization of whey in functional dairy beverages has gained significant importance in the dairy industry due to its nutritional value, economic benefits, and role in sustainable processing. Increasing consumer demand for health-oriented products has further accelerated its industrial application and market growth.

Whey Utilization in Dairy Industry

Whey, once considered a waste by-product, is now widely utilized in the dairy industry to produce value-added products. It is processed into whey protein concentrates (WPC), whey protein isolates (WPI), and whey powders, which are extensively used in beverages, nutritional supplements, and functional foods. The incorporation of whey into dairy beverages helps in reducing environmental pollution associated with its disposal while simultaneously enhancing product value. This shift from waste to resource has made whey utilization a key aspect of sustainable dairy processing [13].

Market Demand

The global demand for functional beverages has increased rapidly due to rising health awareness, changing lifestyles, and growing interest in fitness and wellness. Whey-based beverages are particularly popular among athletes, health-conscious individuals, and younger consumers due to their high protein content and nutritional benefits. The demand is also driven by the convenience of ready-to-drink products and the increasing preference for natural and nutrient-rich beverages. Innovations in flavors, formulations, and packaging have further contributed to expanding the consumer base.

Economic Importance

From an economic perspective, whey utilization offers significant advantages to the dairy industry. Converting whey into functional beverages and other products adds value to what was previously

considered a low-cost by-product. This not only increases profitability but also reduces waste management costs. Additionally, the development of whey-based products opens new market opportunities for dairy manufacturers, particularly in the functional food and nutraceutical sectors. As a result, whey utilization contributes to both economic growth and environmental sustainability within the dairy industry.

CONCLUSION

Whey, once regarded as a low-value by-product of the dairy industry, has emerged as a highly valuable resource for the development of functional dairy beverages. Its rich nutritional composition, including high-quality proteins, lactose, vitamins, and minerals, makes it an ideal ingredient for enhancing the health benefits of beverage products. The increasing demand for functional foods and drinks has further accelerated the utilization of whey in innovative formulations aimed at improving nutrition, hydration, and overall well-being. Advancements in processing technologies, such as ultrafiltration, fermentation, and UHT treatment, have significantly improved the feasibility of incorporating whey into shelf-stable and consumer-acceptable beverages. In addition, the use of flavoring agents, stabilizers, and natural additives has helped overcome sensory challenges, making whey-based drinks more appealing to a wider population. From an industrial perspective, the effective utilization of whey contributes to sustainability by reducing environmental pollution associated with its disposal and converting it into value-added products. It also provides economic benefits by opening new market opportunities in the functional beverage and nutraceutical sectors. However, challenges related to product stability, flavor acceptability, processing costs, and infrastructure still need to be addressed to maximize its potential. Continued research and innovation, along with improved processing strategies and increased consumer awareness, are essential for overcoming these limitations. Whey utilization in functional dairy beverages represents a promising and sustainable approach in the dairy industry, aligning nutritional benefits with technological advancements and environmental responsibility.

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