Whey Protein Powders: Trends in Formulation, Processing, and Health Applications

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***Abstract*—Whey protein, a highly valuable by-product of dairy processing, has gained increasing importance due to its exceptional nutritional quality, rapid digestibility, and functional versatility in modern food systems. Derived mainly as sweet or acid whey, it contains key bioactive proteins such as β lactoglobulin, α-lactalbumin, lactoferrin, and immunoglobulins, which contribute to antioxidant, antimicrobial, and metabolic benefits. Various processing steps—including coagulation, filtration, concentration, and drying—are used to produce whey protein concentrates, isolates, and hydrolysates, each offering distinct functional properties. Recent advancements in processing technologies such as high hydrostatic pressure, ultrasound, extrusion, and tribomechanical activation have further enhanced solubility, gel formation, emulsification, and stability of whey proteins, expanding their applicability in bakery goods, dairy products, beverages, snacks, and specialized nutritional formulations. Despite challenges related to off-Flavors, allergenicity, and high processing costs, emerging strategies such as encapsulation and nanotechnology offer promising solutions. Overall, whey protein continues to evolve as a sustainable, multifunctional ingredient with significant potential in the development of health-oriented and personalized food products.**

***Keywords*— Whey protein, Functional foods, Novel processing technologies, Protein solubility, Bioactive peptides, Food fortification, Dairy processing**

I. INTRODUCTION

Proteins are long chains of amino acids linked together to form structures that carry out essential functions in the body. Milk contains two major groups of proteins—casein and whey—with whey accounting for about one-fifth of the total. Compared with casein, whey proteins dissolve more easily in water and are absorbed quickly in the human digestive system. [2] Because of this, whey is often regarded as one of the highest-quality natural protein sources.

Worldwide dairy processing generates several million tons of whey each year, yet a large portion is still discarded, creating both environmental and economic challenges.[2] The portion that is recovered contains a mixture of valuable proteins such as β-lactoglobulin, α-lactalbumin, lactoferrin, and various immunoglobulins. These components contribute to a wide range of biological effects, including antioxidant activity and support for immune and metabolic health. Despite these benefits, some whey fractions—especially those that are hydrolyzed—can develop bitterness or undesirable aromas, which limits their direct incorporation into foods.[3]

Recent advances in food-processing technologies offer solutions to these limitations. Approaches such as high-pressure treatment, ultrasound processing, and extrusion have shown potential for improving the behavior of whey proteins in different food systems by enhancing their solubility, stability, and textural properties. The purpose of this review is to summarize how these developments contribute to better functional performance, improved nutritional value, and broader application of whey proteins in modern foods [2]

II. TYPES OF WHEY AND THEIR PROCESSING

Whey can be obtained from milk through different cheese-making or acidification processes, and the method used determines its characteristics. Broadly, two main forms of whey are produced.

- Acid whey results when milk is coagulated by lowering its pH, typically through the addition of food-grade acids. This process is common in products such as paneer or yogurt.[19]
- Sweet whey is formed when milk is curdled using rennet during cheese production. Because of the different mechanisms of coagulation, sweet whey tends to have a milder flavour and a

slightly higher pH than acid whey from these two types of whey, several commercial protein ingredients can be manufactured. [20]

- Whey Protein Concentrate (WPC): Contains roughly 35–80% protein. Its composition varies depending on the degree of separation and drying.
- Whey Protein Isolate (WPI): A more refined form that contains 90% or more protein, with most of the lactose and fat removed. This makes it suitable for individuals requiring low-lactose products.
- Hydrolysed Whey Protein (WPH): Produced by breaking protein chains into smaller peptides. This form digests rapidly and is generally considered hypoallergenic, making it valuable for specialized nutritional applications. These different whey products allow manufacturers to choose ingredients based on desired nutritional quality, digestibility, and functional performance in foods.[21]

III. RECOVERY AND CHARACTERISTICS OF WHEY PROTEIN

Whey protein can be obtained from the milk of several species, including cows, goats, and sheep, although cow's milk remains the primary source for large-scale industrial production. The composition of whey varies depending on the type of milk, the cheese-making process, and the extent of separation during processing.

Component	Percentage / Range	Notes
Fat	0.3 – 3.7% (Unseparated sweet whey up to ~10%)	Higher values in unseparated sweet whey
Total Protein	8.8 – 13.4%	Freeze-dried samples may reach up to 13.4%
Soluble Protein	5.4 – 12.6%	Directly related to protein solubility
Lactose	62.6 – 75.3%	Major component of whey powder
Ash	7.3 – 11.8%	Higher in acid whey
Total Acid	0 – 6.0%	Influenced by cheese type & neutralization
pH	Acid whey: 4.5 – 5.1; Sweet whey: 5.2 – 6.0	Depends on processing type
Comparison	Acid whey contains ~80% more total acid and 35% more ash	Compared with sweet whey[19,20]

These differences influence both processing behaviour and the functional performance of whey protein ingredients in foods.

IV. OBSERVATION TABLE

Sr. No.	Material / Ingredient	Purpose	Approximate Quantity	Remarks
1	Fresh milk	Primary source of whey	1000 mL	Can be obtained from cow or buffalo milk
2	Citric acid or vinegar	Promotes coagulation of milk proteins	1–2 g of citric acid or ~10 mL of vinegar	Added to separate the curd from the liquid whey
3	Distilled water	Rinsing and dilution	~100 mL	Used to wash away remaining curd particles
4	0.1 N NaOH	Adjustment of pH	As required	Helps bring whey pH to 6.0–6.5
5	Whey filtrate	Liquid containing whey proteins	~800 mL after separation	Collected following filtration
6	Gentle heating	Concentration of whey	—	Reduces volume to roughly one-third (~250 mL)

7	Spray drying or freeze drying	Removal of moisture	—	Converts concentrated whey into dry powder
8	Potassium sorbate (optional)	Prevention of microbial growth	~0.1 g	Acts as a preservative if long-term storage is needed
9	Soy lecithin (optional)	Improves solubility and dispersion	~0.5 g	Helps powder blend more easily with liquids
10	Flavoring agents (optional)	Enhances taste	~0.5 g	Typically added after drying (e.g., vanilla or cocoa)
11	Sweeteners (optional)	Provides sweetness	1–2 g	May include sugar or stevia depending on preference
12	Final whey protein powder	End product	5–10 g	Depends on protein content of milk and drying efficiency. [19,20,21]

V. PROCESSING STEPS FOR PREPARING WHEY PROTEIN POWDER:

The production of whey protein powder typically follows a sequence of separation, concentration, and drying steps designed to preserve the functional quality of the proteins.[20] The general processing flow includes whey separation, reverse osmosis or other filtration methods, evaporation, and finally spray drying at controlled temperatures.

Below is a rewritten, human-style explanation of each stage in the laboratory preparation method:

Step 1: Curdling the Milk
1. Measure one litre of fresh milk and gently warm it to about 40–45°C.
2. Dissolve 1–2 g of citric acid in warm water or use roughly 10 mL of vinegar, adding it slowly while stirring the milk.
3. As the acid mixes in, the milk will split into solid curds and a pale greenish-yellow liquid, which is the whey.
4. Pour the mixture through a muslin cloth or filter paper to separate and collect the clear whey. [20,21]

Step 2: Filtration and Clarification
1. Pass the collected whey through a filter once more to remove any small curd particles that remain.
2. If available, centrifuge the liquid at around 3000 rpm for 10 minutes to eliminate traces of fat and suspended solids.
3. Adjust the pH to a range of 6.0–6.5 using dilute NaOH (0.1 N), ensuring that the proteins remain stable during the next steps.

Step 3: Concentrating the Whey
1. Transfer the clarified whey into a clean beaker and heat it gently between 50–60°C.
2. Allow the mixture to reduce until roughly one-third of the original liquid remains (about 250 mL).
3. Care must be taken not to exceed 65°C to prevent unwanted protein denaturation.[21]

Step 4: Drying the Concentrate
Two main drying options are used:
Spray Drying: The warm concentrate is fed into a spray dryer operated at an inlet temperature of around 180°C and an outlet temperature near 80°C. The rapid dehydration forms a fine powder.
Freeze Drying: The concentrate is first frozen at −20°C overnight, then placed in a freeze dryer for one to two days until a dry, stable powder is formed. [4]

Step 5: Final Handling and Storage
1. Sieve the dried powder using a fine mesh (approximately 100-mesh) to achieve a uniform texture.
2. Optional additives—such as potassium sorbate for preservation, soy lecithin for better solubility, or flavouring and sweeteners—may be incorporated depending on the intended use.
3. Store the finished powder in an airtight container in a cool, dry location to maintain quality. [19]

Expected Yield
From one litre of milk, the typical yield of dried whey protein powder is around 5–10 grams, though this depends on the protein content of the milk and the efficiency of the drying process.[10]

Solubility and Storage Stability

- Whey protein shows high solubility in water, commonly between 91–99%.
- Solubility remains nearly unchanged in 5% ethanol solutions.
- In 5% sodium chloride, solubility decreases but generally stays within 72–98%.
- Higher levels of water-soluble protein correlate directly with improved solubility performance.
- Acid whey powders often maintain better flavor quality and resist oxidation more effectively during storage at room temperature (approximately 22°C) for several weeks. [10,12]

VI. WHEY PROTEIN AS A FUNCTIONAL INGREDIENT

Foods enriched with whey protein are often described as *functional foods* because they provide physiological benefits beyond basic nourishment. The proteins and bioactive fragments naturally present in whey contribute to several health-supportive roles. Compounds such as α-lactalbumin and β-lactoglobulin have been associated with anti-inflammatory, antimicrobial, and antihypertensive effects.[5]These proteins also participate in immune regulation and may play supportive roles in metabolic health.

Regular intake of whey protein has been linked to improvements in body composition, better management of blood glucose, and enhanced digestive and gut function. Because of these attributes, whey protein is used across different population groups, each deriving unique benefits:

Population-Specific Advantages

- Men:

Whey protein can help increase lean muscle mass, promote faster post-exercise recovery, and support metabolic health due to its rapid absorption and high essential amino acid content.

- Women:

The naturally high α-lactalbumin content in whey makes it valuable during pregnancy and lactation. It may also contribute to better blood sugar regulation and help reduce the risk of metabolic disorders.

- Children:

Whey proteins can help moderate blood glucose fluctuations and support both cognitive development and physical growth during formative years.

- OlderAdults:

As aging reduces protein absorption efficiency, whey's high digestibility is particularly beneficial. It may help maintain muscle mass, strengthen immune response, and support overall vitality.

- In summary, the versatility and biological richness of whey protein make it useful across multiple age groups and health conditions, reinforcing its role as an important functional ingredient in modern diets. [5]

VII. EFFECT OF NOVEL PROCESSING TECHNOLOGIES ON WHEY PROTEIN FUNCTIONALITY

Advances in food processing have introduced several innovative technologies that can modify the behavior and performance of whey proteins. These techniques influence the structure of the protein molecules, allowing manufacturers to tailor properties such as solubility, gel formation, foaming ability, and stability in various food applications. The following summarizes how key emerging technologies affect whey proteins:

High Hydrostatic Pressure (HHP)

HHP exposes whey proteins to extremely high pressures—typically between 200 and 800 MPa. This treatment causes partial unfolding of proteins like β-lactoglobulin, which enables them to form stronger gels and improved elastic structures. As a result, whey proteins treated with HHP often show enhanced emulsifying and foaming properties, making them suitable for products requiring stable texture and aeration. [5]

Ultrasonication

Ultrasound processing uses sound waves at frequencies around 20 kHz, usually applied for 15 to 30 minutes. These waves create microscopic cavitation bubbles that disrupt protein aggregates. The process generally increases solubility, improves the ability of whey proteins to hold water and oil, and enhances the stability of emulsions. This makes ultrasonication particularly helpful when formulating beverages or semi-liquid foods. [6]

Extrusion

Extrusion combines heat and mechanical shear to reshape the protein structure. When whey proteins undergo extrusion, their tertiary structure is altered, which can increase viscosity and promote polymerization. This transformation can lead to improved textural properties, making whey proteins more functional in snacks, cereals, and other structured foods. [14]

Tribomechanical Activation (TA)
TA involves the application of intense mechanical forces that reduce particle size and create more reactive surfaces. For whey proteins, this technique can enhance foaming, support gel formation, and increase viscosity. These changes broaden the potential uses of whey proteins in foods requiring both aeration and stability. [8]

Together, these technologies demonstrate how structural modification of whey proteins can lead to improved performance and expanded use across a variety of food formulations.

VIII. WHEY PROTEIN–FORTIFIED FOOD PRODUCTS

The incorporation of whey protein into various food categories has been widely explored, as it can enhance both nutritional value and functional characteristics. Research across multiple product groups shows that whey protein affects texture, sensory attributes, and overall acceptability in different ways depending on the concentration used and the type of food. [13]

Bakery Products

Bread
Adding whey protein to bread formulas—sometimes up to 30% of the flour base—can noticeably increase the protein and mineral content. However, higher levels may reduce loaf volume and alter crumb structure, meaning that careful formulation is required to maintain desirable texture.

Biscuits and Cookies
At moderate inclusion levels (around 4–10%), whey protein can raise the protein and fat content of cookies and biscuits. Although nutritional value improves, these products may become firmer or slightly harder if whey levels are too high.

Cakes and Muffins
Lower amounts of whey protein (approximately 5–7%) generally enrich cakes and muffins without negatively affecting quality. Excessive use, however, can lead to dryness or introduce off-flavors, which reduces consumer preference.

Snacks, Pasta, and Noodle Products
Whey protein can enhance the nutritional profile and textural quality of items such as extruded snacks, noodles, and pasta. Levels ranging from about 5–20% have been shown to improve protein content and sensory attributes. In many cases, consumer acceptance is highest when whey protein is added at around 10%. Additionally, products tend to exhibit a lower glycaemic response when whey is incorporated.

Dairy Products
Whey protein is widely used in yogurt, cheese, ice cream, and milk-based beverages. Typical addition rates range between 1–7%, enhancing viscosity, water-holding capacity, and antioxidant activity. However, formulations containing more than about 2% may experience slight reductions in flavour appeal.

Iron-fortified whey protein concentrates have also been developed, offering improved mineral absorption without creating metallic or unpleasant Flavors.

Beverages
Fortifying beverages—such as fruit-based drinks, probiotic blends, and energy beverages—with whey protein can improve both nutritional value and functional performance. These fortified drinks often show better antioxidant capacity and may also support muscle recovery and gut health. Sensory evaluations generally report good consumer acceptance.

Other Food Applications
Whey protein has been used successfully in a variety of other foods, including traditional dishes like idli, emulsified products such as mayonnaise, mashed potatoes, and even meat items like frankfurters. In these products, whey protein contributes to enhanced texture, increased protein content, and improved overall quality.

Through these diverse applications, whey protein demonstrates remarkable versatility, making it a valuable ingredient across different food processing sectors.[13]

IX. CHALLENGES AND FUTURE PROSPECTS

Although whey protein has become an important component in the development of functional foods, several issues continue to limit its broader application. One of the main challenges is the tendency of certain whey-derived peptides—especially those formed during hydrolysis—to develop bitterness or other off-Flavors.[9]These sensory drawbacks can make product formulation difficult. In addition, whey proteins can trigger allergic reactions in sensitive individuals, and their structural instability under certain processing conditions may lead to inconsistencies in texture or reduced functional performance.

Another limitation is the cost associated with advanced processing technologies. Techniques such as high-pressure treatment, extrusion, and ultrasonic processing offer clear functional advantages but often require specialized equipment and significant energy input, which may restrict their adoption in small- to medium-scale manufacturing.

Looking ahead, several promising directions may help overcome these challenges. Nanotechnology is expected to play a larger role in improving the targeted delivery of whey-derived bioactive peptides within the body. Encapsulation methods are also being explored to mask unwanted flavors, improve nutrient protection, and enhance stability during storage. Furthermore, as personalized nutrition continues to grow, whey proteins—especially in peptide form—may be tailored for specific health needs or incorporated into new categories of functional beverages.

Overall, ongoing technological and scientific advancements are likely to expand the potential applications of whey protein and further integrate it into next-generation food systems. [9]

X. CONCLUSION

Whey protein continues to gain importance as a versatile and sustainable ingredient for the development of modern functional foods. Its naturally high nutritional quality, rapid digestibility, and rich profile of essential amino acids make it suitable for a wide range of dietary needs. Emerging processing technologies—such as high-pressure treatment, ultrasound, extrusion, and tribomechanical activation—have further improved its performance by enhancing solubility, stability, and texture in various formulations. These innovations provide new ways to overcome challenges related to flavor, structural changes, and processing limitations.

The growing interest in personalized nutrition and health-focused food products is expected to create even more opportunities for whey proteins and their bioactive components. By optimizing processing conditions and refining formulation strategies, manufacturers can broaden the applications of whey protein across beverages, bakery goods, dairy products, and specialized nutritional items.

Overall, whey protein stands out as a reliable, high-quality ingredient capable of supporting muscle development, metabolic health, immune function, and recovery across all age groups. Its adaptability and scientifically supported benefits position it as a key protein source in both current and future food systems.

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