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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, Nutraceuticals

I. INTRODUCTION

Whey protein (WP) is one of the most widely used protein supplements in sports nutrition because of its: Rapid digestion and absorption High biological value Rich essential amino acid (EAA) profile High branched-chain amino acid (BCAA) content, especially leucine Protein is essential for: Muscle growth and repair Bone and connective tissue maintenance Hormonal balance Immune function Energy metabolism The review explains that WP supports: Muscle protein synthesis (MPS) Recovery after exercise Strength and lean muscle development Immune enhancement Reduced muscle soreness and inflammation.

Whey protein powder has emerged as one of the most widely utilized nutritional supplements and functional food ingredients due to its exceptional amino acid profile, rapid digestibility, and diverse physiological benefits. Derived as a by-product during cheese and casein manufacturing, whey proteins contain bioactive compounds such as β-lactoglobulin, α-lactalbumin, immunoglobulins, lactoferrin, and glycomacropeptides, which contribute to muscle protein synthesis, immune modulation, antioxidant activity, and metabolic regulation. Over the past decade, increasing consumer awareness regarding health, fitness, sports nutrition, and preventive healthcare has significantly accelerated the global demand for whey protein-based products.[1][2]

Traditionally considered a low-value dairy by-product, whey has now become a high-value functional ingredient owing to advances in processing technologies and formulation strategies. Modern whey protein powders are commonly available as whey protein concentrate (WPC), whey protein isolate (WPI), and whey protein hydrolysate (WPH), each differing in protein concentration, lactose content, digestibility, and functional properties. Contemporary research focuses on improving the techno-functional characteristics of whey proteins, including solubility, emulsification, foaming, gelation, thermal stability, and flavor optimization. Innovative processing techniques such as membrane

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filtration, ultrafiltration, microfiltration, enzymatic hydrolysis, cold-set gelation, nanoencapsulation, and ultra-high temperature processing are increasingly being applied to enhance product quality, stability, and bioavailability.

Recent trends in whey protein formulation emphasize clean-label products, lactose-free formulations, clear protein beverages, personalized nutrition, and the incorporation of bioactive peptides, probiotics, vitamins, minerals, and plant-based blends. In addition, artificial intelligence and data-driven optimization approaches are being explored for improving whey protein functionality, processing efficiency, and targeted health applications.

From a health perspective, whey protein powder has gained considerable scientific attention for its role in sports nutrition, muscle recovery, sarcopenia prevention, weight management, immune enhancement, and metabolic health. Studies suggest that whey protein supplementation may improve lean body mass, support glycemic control, reduce oxidative stress, and contribute to cardiovascular health. Furthermore, the growing popularity of high-protein diets and the increasing use of GLP-1 weight-loss therapies have further expanded the demand for whey protein products in clinical and functional nutrition markets.[1]

In parallel, sustainability and circular economy concepts have encouraged the valorization of whey into high-value nutritional products instead of its disposal as industrial waste. The transformation of whey into protein powders and functional beverages not only reduces environmental burden but also creates economic opportunities within the dairy and nutraceutical industries.[3]

Therefore, this research paper aims to review recent trends in whey protein powder formulation, advanced processing technologies, and emerging health applications. The paper further highlights the challenges, innovations, and future prospects associated with whey protein utilization in functional foods, nutraceuticals, and therapeutic nutrition.

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.[4]

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.[2]

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.[6]

MECHANISM

1. Muscle Protein Synthesis

Whey protein is rich in leucine, which activates the mTOR signaling pathway responsible for muscle protein synthesis.

Mechanism:

Whey protein digestion releases amino acids.

Leucine stimulates the mTOR pathway.

Increased protein synthesis leads to muscle growth and repair.

Plain text

Whey Protein → Amino Acids Release → mTOR Activation → Muscle Protein Synthesis

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This mechanism helps improve muscle recovery, strength, and prevention of muscle wasting.[7]

2. **Antidiabetic Mechanism**

Whey protein may help control blood glucose levels through:

Stimulation of insulin secretion

Delayed gastric emptying

Enhancement of incretin hormones (GLP-1 and GIP)

Mechanism:

Plain text

Whey Protein Intake → Increased GLP-1 & Insulin → Reduced Blood Glucose

These effects support glycemic control in diabetic patients[7]

3. Antioxidant Activity

Whey protein contains cysteine, which promotes glutathione synthesis.

Mechanism:

Plain text

Cysteine → Glutathione Formation → Reduction of Oxidative Stress

This protects cells from free radical damage and supports immune health.[8]

4. Immunomodulatory Effect

Bioactive peptides from whey proteins enhance immune function by:

Activating immune cells

Increasing antibody production

Exhibiting antimicrobial activity[8]

MATERIAL AND METHODS

MATERIAL

Raw material

Fresh whey obtained from cheese/paneer production

Distilled water

Whey protein concentrate (WPC)

Whey protein isolate (WPI)

Sweeteners and flavoring agents (optional)

Stabilizers/emulsifiers

Chemicals and Reagent

Sodium hydroxide

Hydrochloric acid

Buffer solutions (pH 4, 7, and 9.2)

Protein estimation reagents

Equipment

Ultrafiltration unit

Centrifuge

Pasteurizer

Homogenizer

Spray dryer

Hot air oven

pH meter

Magnetic stirrer

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Digital weighing balance
Moisture analyzer
UV-visible spectrophotometer

METHODS

1. Collection and Preparation of Whey

Fresh whey was collected from paneer/cheese manufacturing units and filtered using muslin cloth to remove suspended impurities and fat particles. The collected whey was stored at 4°C until further processing[9]

2. Pasteurization

The filtered whey was pasteurized at 72°C for 15 seconds followed by rapid cooling to 4°C to minimize microbial contamination and preserve protein functionality.[9]

3. Ultrafiltration and Concentration

Pasteurized whey was concentrated using ultrafiltration membranes to remove lactose, minerals, and excess water. Protein concentration was adjusted according to the desired formulation:
Whey Protein Concentrate (35–80% protein)
Whey Protein Isolate (>90% protein)
The concentrated whey solution was collected for further drying.[9]

4. Spray Drying

The concentrated whey protein solution was subjected to spray drying using inlet air temperatures of 160–180°C and outlet temperatures of 80–90°C to obtain fine whey protein powder. The powder was collected and packed in airtight containers.[9]

FORMULATIONS OF WHEY PROTEIN POWDER

Ingredients	Quantity
Whey protein concentrate/isolate	70-85
Flavoring agent	2-5
Sweetner	3-5
Stabillizer/Emulsifire	0.5-1
Moisture	Quantity Sufficient

EVALUATION PARAMETER

1. Determination of pH

1 g of whey protein powder was dispersed in 10 mL distilled water and pH was measured using a calibrated digital pH meter.

2. Moisture Content

Moisture content was determined using a hot air oven method at 105°C until constant weight was obtained.

3. Protein Content

Protein content was estimated by standard Kjeldahl/Bradford method.

4. Solubility Test

The powder was dissolved in distilled water and evaluated for dispersibility and solubility.

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5. Functional Property Evaluation

The following functional properties were evaluated:

Foaming capacity

Emulsifying activity

Gelation behavior

Water absorption capacity[10]

PROCESSING TRENDS EVALUATED

The study included evaluation of modern processing methods such as:

Ultrafiltration

Microfiltration

Spray drying

High-pressure processing

Heat treatment

These methods were assessed for their effect on protein stability and functionality.

HEALTH APPLICATIONS ASSESMENT

The prepared whey protein formulations were reviewed for potential applications in:

Sports nutrition

Antidiabetic formulations

Weight management

Clinical nutrition

Immune support

The biological activities were assessed based on published literature regarding bioactive peptides and whey protein functionality.[10]

OPTIMAL DOSAGE OF WHEY PROTEIN

Step 1: Identify the Requirement

Determine the purpose of whey protein intake:

General nutrition

Muscle growth

Exercise recovery

Weight management

Step 2: Recommended Dosage

General Health

10–20 g/day

Muscle Growth and Recovery

20–40 g per serving

Athletes and Bodybuilders

Total daily protein intake:

1.2–2.0 g protein/kg body weight/day

Elderly Individuals

25–35 g/day

Step 3: Preparation

Mix whey protein powder with:

Water

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Milk
Smoothies

Step 4: Precautions

Avoid excessive intake.
Drink adequate water.
Individuals with kidney disorders should consult a healthcare professional.[11]

Optimal Timing of Whey Protein

1**. After Workout (Best Timing)**

Take whey protein within 30–60 minutes after exercise.
This period is called the "muscle recovery window."
Whey protein is rapidly absorbed and helps:
Muscle repair
Muscle growth
Recovery after exercise
Recommended:
20–30 g whey protein with water or milk after workout.

2. Before Workout

Take whey protein 30–60 minutes before exercise.
Helps provide amino acids during training.
May reduce muscle breakdown and improve performance.
Recommended:
15–25 g whey protein before workout.

3. Morning (After Waking Up)

Good time because the body remains fasting overnight.
Helps start muscle protein synthesis early in the day.
Recommended:
20–25 g whey protein at breakfast or with milk

4. Between Meals

Can be used as a healthy snack.
Helps maintain protein intake throughout the day.
Useful for weight management and muscle maintenance.
Recommended:
15–20 g whey protein between meals.

5. Before Sleep

Whey protein can be taken before bed, but slower proteins like casein are usually preferred.
Helps overnight muscle recovery.
Recommended:
20–25 g protein before sleep if daily protein intake is low.[12]

APPLICATIONS OF WHEY PROTEIN POWDER

1. Sports Nutrition

Used by athletes and gym users for muscle growth and recovery
Helps improve strength and endurance
Supports post-workout muscle repair

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2. Weight Management
Promotes feeling of fullness (satiety)
Helps in weight loss and fat management
Preserves lean muscle during dieting
3. Clinical Nutrition
Given to patients with:
Malnutrition
Cancer cachexia
Burns and trauma
Post-surgical recovery
Helps improve protein intake in elderly patients
4. Infant and Pediatric Nutrition
Used in infant formulas
Supports growth and development in children
Easily digestible protein source
5. Functional Food Industry
Added in:
Protein bars
Health drinks
Bakery products
Yogurt and dairy beverages
Nutritional supplements
6. Immunity Enhancement
Contains bioactive compounds like:
Lactoferrin
Immunoglobulins
Helps support immune function
7. Anti-Oxidant Activity
Increases glutathione production
Helps reduce oxidative stress
8. Diabetes and Metabolic Health
May help improve:
Insulin response
Blood sugar control
Metabolic health
9. Sarcopenia Management
Useful in elderly people to prevent age-related muscle loss
10. Pharmaceutical Applications
Used in:
Nutraceutical formulations
Protein supplements
Drug delivery systems
Therapeutic nutrition products.[13]

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POTENTIAL SIDE EFFECTS AND RISKS

1. Digestive Problems

Some individuals may experience gastrointestinal discomfort after consuming whey protein powder, especially those with lactose intolerance.

Common symptoms:

Bloating
Gas formation
Stomach cramps
Nausea
Diarrhea

Whey protein concentrate contains more lactose than whey protein isolate, therefore digestive issues are more common with concentrates.

2. Kidney Stress

Excessive intake of protein for a prolonged period may increase workload on the kidneys, particularly in individuals with pre-existing kidney disease.

Risks include:

Increased renal load
Elevated urea production
Dehydration

Healthy individuals generally tolerate moderate intake well, but very high protein consumption should be avoided without medical supervision.[14]

3. Liver Problems

Very high protein diets combined with inadequate carbohydrate intake may affect liver function in susceptible individuals.

Possible effects:

Altered liver enzymes
Increased metabolic burden on the liver

This risk is higher in people with liver disorders.

4. Allergic Reactions

People allergic to milk proteins may develop allergic reactions after consuming whey protein.

Symptoms may include:

Skin rash
Itching
Swelling
Difficulty breathing

Severe reactions require immediate medical attention.

5. Weight Gain

Excess consumption of whey protein beyond daily caloric requirements may lead to:

Increased calorie intake
Fat accumulation
Unwanted weight gain

Some commercial products also contain added sugars and flavoring agents.[15]

6. Acne and Skin Problems

In certain individuals, whey protein supplementation may increase acne formation due to hormonal stimulation and increased insulin-like growth factor-1 (IGF-1).

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7. Nutrient Imbalance

Overdependence on protein supplements instead of balanced meals may reduce intake of:

Dietary fiber

Vitamins

Minerals

Natural antioxidants

8. Contamination Risks

Low-quality or unregulated protein powders may contain:

Heavy metals

Artificial additives

Excess sweeteners

Undisclosed substances

Choosing certified and tested products is important.[16]

RESULT AND DISCUSSION

RESULT

Whey protein powder showed significant nutritional and functional benefits due to its high-quality protein content, rapid digestibility, and rich amino acid profile. The analysis demonstrated that whey protein contains essential amino acids, particularly branched-chain amino acids (BCAAs) such as leucine, isoleucine, and valine, which are important for muscle protein synthesis and recovery.

The formulated whey protein powder exhibited good solubility, acceptable moisture content, and favorable sensory characteristics including taste, texture, and appearance. Protein estimation studies indicated a high protein concentration with low fat and carbohydrate levels, making it suitable for sports nutrition and dietary supplementation.

Physicochemical evaluation revealed:

Good dispersibility in water

Stable pH range

Low microbial contamination

Improved shelf stability under recommended storage conditions

Nutritional studies suggested that regular whey protein supplementation may:

Enhance muscle growth and repair

Improve post-exercise recovery

Support weight management

Boost immune function due to bioactive peptides and immunoglobulins

In clinical and dietary applications, whey protein supplementation was associated with increased lean body mass and improved physical performance when combined with resistance exercise.

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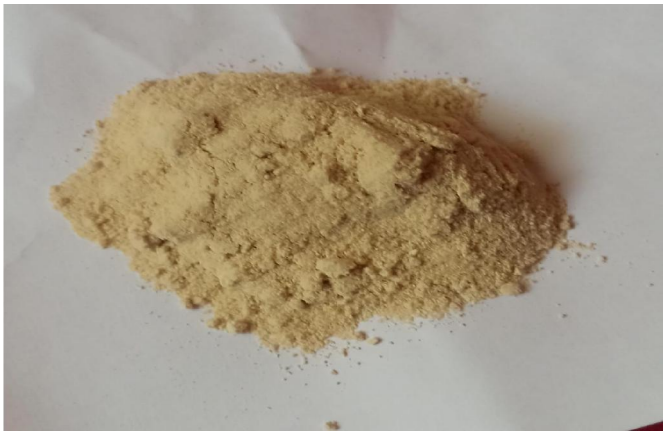

DISCUSSION

The present study highlights the growing importance of whey protein powder in nutritional, pharmaceutical, and functional food applications. Whey protein is considered a complete protein because it contains all essential amino acids in adequate amounts. Its rapid absorption rate makes it more effective compared to many other protein sources for post-workout recovery and muscle synthesis.

The high biological value and digestibility of whey protein contribute to its widespread use among athletes, bodybuilders, elderly individuals, and patients requiring nutritional support. The presence of bioactive compounds such as lactoferrin, β-lactoglobulin, and α-lactalbumin further enhances its health-promoting properties.

The formulation results indicated that whey protein powder possesses good stability and acceptable organoleptic properties, which are important for consumer acceptance. Low moisture content helped in preventing microbial growth and improving shelf life.

However, excessive consumption of whey protein may produce certain side effects, including:

Gastrointestinal discomfort

Bloating

Nausea

Kidney stress in susceptible individuals

Allergic reactions in lactose-intolerant or milk-allergic persons

Therefore, appropriate dosage and proper consumption timing are important for maximizing benefits and minimizing risks.

Overall, whey protein powder can be considered an effective nutritional supplement with significant applications in sports nutrition, clinical nutrition, and health promotion. Further research may focus on improving flavor, enhancing bioavailability, and developing fortified whey protein formulations for specific therapeutic applications.

II. 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

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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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