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Plant-Based Functional Foods: Emerging Ingredients, Processing Strategies and Health-Promoting Potential

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Abstract

Plant-based functional foods have emerged as an important component of modern nutrition because of their ability to provide essential nutrients together with biologically active compounds that may support human health. Increasing consumer awareness of diet-related disorders, sustainability, and preventive healthcare has stimulated interest in functional ingredients derived from fruits, vegetables, cereals, pulses, legumes, seeds, algae, and medicinal plants. These foods contain diverse phytochemicals, including polyphenols, carotenoids, flavonoids, dietary fibres, phytosterols, peptides, and other bioactive constituents. However, processing can substantially influence their nutritional composition, bioavailability, sensory characteristics, and functional properties. Contemporary approaches such as germination, fermentation, extrusion, high-pressure processing, drying, encapsulation, and controlled formulation are therefore being investigated to improve the stability and bioavailability of plant-derived bioactives. This short review highlights emerging plant-based functional ingredients, major processing strategies, their potential health-promoting effects, and future opportunities for developing sustainable and scientifically supported functional foods.

Keywords: *Plant-based foods, Bioactive components, functional foods, phytochemicals, dietary fibre, polyphenols, fermentation, health promotion.*

1. Introduction

The relationship between diet and human health has received increasing scientific attention as the prevalence of obesity, cardiovascular disorders, type 2 diabetes, and other chronic diseases continues to increase. In this context, functional foods have gained considerable importance because they can provide physiological benefits beyond basic nutritional requirements [1]. Plant-based foods are particularly promising functional food sources because plants contain numerous naturally occurring compounds with antioxidant, anti-inflammatory, antimicrobial, hypolipidemic, and metabolic regulatory properties. Fruits, vegetables, whole grains, pulses, legumes, nuts, seeds, herbs, spices, and edible algae contain complex mixtures of nutrients and bioactive compounds. Dietary fibre, polyphenols, carotenoids, flavonoids, phytosterols, resistant starch, vitamins, minerals, and plant proteins are among the major components responsible for their functional potential [2]. Regular consumption of diets rich in plant foods has been associated with improved metabolic health and reduced risk of several chronic diseases.

The growing demand for healthier and more sustainable diets has also encouraged the food industry to explore innovative plant-derived ingredients. Protein concentrates, plant-based peptides, prebiotic fibres, fruit and vegetable powders, seed-derived oils, polyphenol-rich extracts, and fermented plant ingredients are increasingly incorporated into functional food formulations. Nevertheless, the biological activity of these compounds depends not only on their concentration but also on their chemical form, stability, digestion, absorption, and interaction with the food matrix.

2. Emerging Plant-Based Functional Ingredients

2.1 Fruits and Vegetables

Fruits and vegetables represent major sources of vitamins, minerals, dietary fibre, polyphenols, flavonoids, anthocyanins, and carotenoids. Berries, grapes, pomegranate, citrus fruits, tomatoes, carrots, leafy vegetables, and cruciferous vegetables have attracted particular interest because of their high concentrations of bioactive compounds. Anthocyanins from berries and purple-coloured vegetables, for example, have demonstrated antioxidant and potential anti-inflammatory properties, while carotenoids such as lycopene and β-carotene are associated with cellular protection and metabolic benefits [3]. Fruit and vegetable processing by-products are also emerging as valuable functional ingredients.

Peels, seeds, pomace, and pulp residues can contain substantial quantities of dietary fibre and phytochemicals. Their incorporation into bakery products, beverages, snacks, and nutraceutical formulations may simultaneously increase nutritional value and reduce food waste.

2.2 Whole Grains and Pseudocereals

Whole grains such as oats, wheat, barley, rice, and maize provide dietary fibre, minerals, vitamins, phenolic compounds, and bioactive peptides. Oats are particularly recognized for their β-glucan content, which has been associated with cholesterol-lowering effects and improved glycaemic regulation [4]. Pseudocereals such as quinoa, amaranth, and buckwheat have also gained attention because they provide high-quality proteins, minerals, dietary fibre, and diverse phytochemicals. Their gluten-free characteristics further increase their potential for specialized food formulations.

2.3 Pulses, Legumes, Nuts and Seeds

Pulses and legumes, including chickpea, lentil, pea, soybean, and common bean, are important sources of plant proteins, complex carbohydrates, dietary fibre, and bioactive compounds. Protein hydrolysates and peptides generated from plant proteins have demonstrated antioxidant, antihypertensive, and metabolic regulatory potential [5].

Nuts and seeds provide unsaturated fatty acids, phytosterols, tocopherols, minerals, and phenolic compounds. Flaxseed, chia, sesame, pumpkin, and sunflower seeds are increasingly used in functional foods because of their nutritional density and potential cardiovascular benefits.

2.4 Plant Proteins and Bioactive Peptides

The transition toward plant-based diets has accelerated research into alternative protein sources. Soy, pea, chickpea, lentil, faba bean, and cereal proteins can be processed into concentrates, isolates, textured proteins, beverages, and meat alternatives. During enzymatic hydrolysis or gastrointestinal digestion, some proteins can release peptides with biological activities, including antioxidant and angiotensin-converting enzyme inhibitory effects [5].

The future development of plant proteins will depend not only on nutritional quality but also on improving flavour, texture, digestibility, and consumer acceptance.

3. Processing Strategies for Functional Food Development

Food processing can either enhance or reduce the functional properties of plant ingredients. Consequently, appropriate processing technologies are essential for preserving bioactive compounds while improving food safety, stability, digestibility, and sensory quality.

3.1 Germination

Germination is a relatively simple biological process that can improve the nutritional and functional characteristics of cereals, pulses, and seeds. Germination activates endogenous enzymes and can increase the availability of certain phenolic compounds, vitamins, peptides, and minerals while reducing some antinutritional factors [6]. Germinated grains and legumes can therefore serve as ingredients for functional beverages, bakery products, breakfast foods, and nutritional supplements.

3.2 Fermentation

Fermentation represents one of the oldest and most effective methods for improving plant foods. Lactic acid bacteria, yeasts, and other microorganisms can modify food matrices, improve digestibility, generate bioactive metabolites, and reduce selected antinutritional compounds. Fermentation may also enhance the bioavailability of phenolic compounds and produce potentially beneficial postbiotic metabolites [7].

Fermented plant-based beverages, cereals, legumes, and vegetable products are consequently receiving considerable attention in functional food research.

3.3 Extrusion and Thermal Processing

Extrusion is widely used to manufacture cereals, snacks, breakfast foods, and plant-based meat products. It can improve texture, digestibility, and product stability while allowing the incorporation of different plant ingredients. However, excessive temperature and processing time may cause degradation of heat-sensitive vitamins and phytochemicals. Optimization of processing conditions is therefore essential.

Thermal treatments can also improve the bioavailability of certain compounds. For example, cooking may disrupt plant cell structures and facilitate the release of some carotenoids. Thus, the effect of processing is compound-specific and depends on temperature, duration, food composition, and processing method.

3.4 Encapsulation and Advanced Processing

Encapsulation technologies provide opportunities to protect sensitive plant bioactives from oxidation, light, heat, and gastrointestinal degradation. Polyphenols, carotenoids, essential oils, and other functional compounds can be incorporated into suitable carrier systems to improve their stability and controlled delivery [8]. Non-thermal technologies such as high-pressure processing, pulsed electric fields, ultrasound, and cold plasma are also being investigated for the production of minimally processed functional foods. These approaches may help preserve nutritional quality while maintaining microbiological safety.

4. Health-Promoting Potential

The health effects of plant-based functional foods are largely associated with their combined content of fibre, phytochemicals, unsaturated fatty acids, vitamins, minerals, and bioactive peptides. Dietary fibre can support gastrointestinal function and influence glucose and lipid metabolism. Soluble fibres such as β-glucan have received particular attention for their potential role in maintaining healthy blood cholesterol concentrations [4].

Polyphenols and other phytochemicals can interact with cellular signalling pathways associated with oxidative stress and inflammation. Their antioxidant properties may contribute to cellular protection, although the biological effects of individual compounds can vary substantially according to their bioavailability and metabolism [3]. Plant-based diets rich in minimally processed foods have also been associated with favourable cardiovascular and metabolic outcomes. However, it is important to distinguish between whole plant foods and highly processed plant-based products. A product may be plant-derived but still contain substantial amounts of sodium, refined carbohydrates, saturated fats, or other ingredients that reduce its overall nutritional quality. The gut microbiota represents another important pathway through which functional plant foods may influence health. Dietary fibres and certain phytochemicals can serve as substrates for intestinal microorganisms, resulting in the formation of metabolites such as short-chain fatty acids. These interactions may influence intestinal barrier function, immune regulation, and metabolic processes [9].

5. Conclusion

Plant-based functional foods represent an important intersection between nutrition, food technology, sustainability, and preventive health. Fruits, vegetables, grains, pulses, seeds, nuts, and plant proteins provide diverse bioactive compounds with potential antioxidant, metabolic, cardiovascular, and gastrointestinal benefits. Emerging processing technologies such as germination, fermentation, extrusion, encapsulation, and non-thermal processing can improve the nutritional and functional characteristics of these ingredients when appropriately optimized. Nevertheless, greater emphasis is required on bioavailability, clinical validation, product quality, and consumer acceptance. Future development of plant-based functional foods should integrate nutritional science with advanced food processing and sustainable production approaches to deliver safe, effective, and scientifically substantiated health-promoting products.

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