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Emerging Plant-Based Ingredients for Functional Food Formulation: Nutritional, Technological and Health Perspectives

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Abstract

The growing demand for healthier, sustainable, and minimally processed foods has accelerated the development of plant-based ingredients for functional food formulation. Beyond conventional cereals, legumes, fruits, and vegetables, emerging ingredients such as pseudocereals, plant proteins, seed flours, fruit by-products, edible leaves, microalgae, plant fibres, and botanical extracts are receiving increasing attention. These ingredients provide proteins, dietary fibre, polyphenols, carotenoids, minerals, vitamins, and other bioactive compounds that can improve the nutritional and functional characteristics of food products. Advances in extraction, fermentation, germination, enzymatic treatment, extrusion, encapsulation, and drying technologies have expanded their applications in beverages, bakery products, snacks, meat alternatives, and nutraceutical foods. Nevertheless, challenges related to bioavailability, sensory properties, processing stability, allergenicity, standardization, and consumer acceptance remain.

Keywords: *Plant-based ingredients, functional foods, plant proteins, dietary fibre, bioactive compounds, food formulation, sustainable nutrition.*

1. Introduction

Functional food development is increasingly influenced by consumer demand for products that provide nutritional benefits beyond basic energy and macronutrient supply. At the same time, concerns regarding environmental sustainability and the resource requirements of conventional food production have stimulated interest in plant-derived ingredients [1]. Plant-based ingredients offer considerable diversity in nutritional composition and technological functionality. Cereals, pulses, pseudocereals, fruits, vegetables, seeds, leaves, algae, and agricultural by-products can provide proteins, fibres, vitamins, minerals, polyphenols, carotenoids, flavonoids, and other bioactive substances. Recent research has moved beyond the simple addition of plant powders to foods. Modern approaches seek to isolate, concentrate, stabilize, and structurally modify plant components so that they can perform specific technological and nutritional functions. This transition is supporting the development of next-generation functional foods with improved nutritional density, sensory quality, and sustainability.

2. Emerging Plant-Based Ingredients

Several categories of plant-derived ingredients have attracted particular attention because of their nutritional density and processing potential. Pseudocereals such as amaranth, buckwheat, and quinoa provide proteins, dietary fibre, minerals, and phytochemicals. Their protein quality and gluten-free characteristics make them useful in bakery and specialized foods [2].

Legume-derived ingredients, including pea, chickpea, lentil, mung bean, and faba bean proteins, are increasingly used as sources of plant protein. They can be incorporated into meat alternatives, beverages, bakery products, and nutritional formulations. Seeds such as flaxseed, chia, sesame, sunflower, and pumpkin provide proteins, fibre, minerals, polyunsaturated fatty acids, and phytochemicals. Fruit and vegetable processing by-products are another important emerging source of dietary fibre and bioactive compounds.

Table 1. Emerging plant-based ingredients and their potential applications

Ingredient category	Major components	Potential applications
Pseudocereals	Protein, fibre, minerals, polyphenols	Bakery products, beverages
Legume proteins	Protein, peptides, fibre	Meat alternatives, protein foods
Chia and flaxseed	Fibre, omega-3 fatty acids, lignans	Functional bakery and beverages
Pumpkin and sunflower seeds	Protein, minerals, healthy lipids	Snacks and protein formulations
Fruit peels and pomace	Fibre, polyphenols, carotenoids	Bakery foods, beverages
Moringa and leafy powders	Minerals, carotenoids, polyphenols	Nutritional foods and drinks
Microalgae	Protein, pigments, bioactive compounds	Functional foods and supplements
Plant extracts	Polyphenols, flavonoids, other phytochemicals	Functional formulations

3. Nutritional Perspectives

Plant-based ingredients can improve the nutritional density of foods by supplying nutrients that may be limited in conventional formulations. Plant proteins are particularly important because of increasing demand for protein-rich foods and alternatives to animal-derived ingredients. Dietary fibre represents another major functional component. Soluble and insoluble fibres can influence gastrointestinal function, satiety, carbohydrate digestion, and lipid metabolism. Fibre-rich ingredients derived from fruits, vegetables, cereals, and seeds can therefore serve both nutritional and technological roles [3]. Plant foods also provide diverse phytochemicals. Polyphenols, flavonoids, carotenoids, glucosinolates, and other compounds have been investigated for antioxidant, anti-inflammatory, and metabolic effects. However, the physiological activity of these compounds depends on their chemical form, concentration, bioaccessibility, metabolism, and interaction with the food matrix.

4. Technological Functionality

The usefulness of a plant ingredient depends not only on its nutrient composition but also on its technological properties. Plant proteins can contribute to emulsification, water binding, gel formation, and texture development. Fibres can improve viscosity, moisture retention, and structural properties.

Seed-derived ingredients can contribute healthy lipids and improve the nutritional profile of bakery and snack products. However, oxidation of unsaturated fatty acids can reduce shelf stability and produce undesirable flavours. Fruit and vegetable by-products are particularly attractive because they can provide fibre and bioactive compounds while reducing food-processing waste. Their incorporation into food products represents a circular-economy approach that can increase the value of agricultural resources [4].

5. Processing Technologies

Processing is essential for improving the functionality and bioavailability of plant ingredients. Germination can activate endogenous enzymes and modify proteins, carbohydrates, and phytochemicals. Fermentation can improve digestibility, reduce selected antinutritional factors, and transform bioactive compounds [5]. Extrusion is widely used for plant protein products and snacks. It can produce desirable textures and improve convenience while allowing the incorporation of multiple plant ingredients. Encapsulation is increasingly important for protecting sensitive compounds such as polyphenols, carotenoids, essential fatty acids, and plant extracts. Encapsulation can improve stability against oxygen, light, moisture, and temperature and may also influence controlled release during digestion. Green extraction technologies, including ultrasound-assisted, microwave-assisted, enzyme-assisted, and pressurized-liquid extraction, provide opportunities for recovering bioactive compounds with reduced solvent use and improved process efficiency.

6. Health Perspectives

The health potential of emerging plant-based ingredients is largely associated with their proteins, dietary fibre, healthy lipids, micronutrients, and phytochemicals. Fibre-rich ingredients can contribute to intestinal health and may influence glycaemic and lipid responses. Plant proteins can provide essential amino acids, although their nutritional quality varies according to amino-acid composition and digestibility. Combining complementary plant protein sources can improve the overall amino-acid profile. Polyphenols and carotenoids have attracted considerable attention because of their antioxidant and other biological activities. Some plant compounds may also interact with the gut microbiota, resulting in the formation of metabolites with physiological effects [6]. Nevertheless, functional claims should be based on appropriate evidence. Results obtained from chemical assays or laboratory models cannot by themselves establish clinical benefits in humans.

7. Challenges in Functional Food Formulation

Despite their potential, emerging plant-based ingredients present several formulation challenges. Plant proteins may have characteristic beany or bitter flavours, while some plant fibres can produce undesirable texture. Phenolic-rich ingredients may contribute bitterness or astringency. Antinutritional factors such as phytates, tannins, oxalates, and protease inhibitors can reduce nutrient bioavailability. Appropriate processing can reduce these compounds, but excessive processing may simultaneously affect desirable nutrients. Allergenicity is another consideration for selected plant ingredients. Ingredient safety, standardization, contaminant control, and accurate labelling are therefore essential for commercialization.

Consumer acceptance remains equally important. A nutritionally superior food product will have limited commercial value if its taste, appearance, texture, or price is unacceptable to consumers.

Table 2. Major challenges and potential solutions

Challenge	Possible consequence	Potential solution
Beany or bitter flavour	Low consumer acceptance	Fermentation and flavour optimization
Poor protein functionality	Weak texture or stability	Protein modification and blending
Antinutritional factors	Reduced nutrient availability	Germination and fermentation
Bioactive instability	Loss during processing/storage	Encapsulation
Oxidative deterioration	Off-flavour and reduced shelf life	Antioxidant protection and packaging
Variable raw materials	Inconsistent product quality	Standardization and quality control
High ingredient cost	Limited commercialization	Local sourcing and process optimization

8. Future Opportunities

Future functional food development is likely to focus on multifunctional plant ingredients capable of simultaneously providing nutrition, texture, stability, and health-related functionality. Blending different plant sources may enable complementary nutritional and technological properties. Precision fermentation and advanced biotechnology may provide new opportunities for improving plant protein functionality and reducing undesirable flavour compounds. Improved extraction and encapsulation technologies can facilitate the incorporation of highly sensitive bioactive compounds. The utilization of agricultural and food-processing by-products is particularly promising from a sustainability perspective. Fruit peels, seeds, pomace, bran, and other fractions can be converted into fibre-rich or phytochemical-rich ingredients rather than discarded. Future research should increasingly evaluate bioaccessibility, gastrointestinal digestion, microbiome interactions, and human health outcomes. Such evidence will be essential for translating promising laboratory findings into scientifically supported functional food claims.

9. Conclusion

Emerging plant-based ingredients provide significant opportunities for developing nutritious, functional, and sustainable foods. Pseudocereals, legumes, seeds, plant fibres, leafy materials, microalgae, and fruit-processing by-products can supply proteins, dietary fibre, minerals, healthy lipids, and diverse bioactive compounds. Advances in fermentation, germination, extrusion, green extraction, enzymatic processing, and encapsulation are improving their technological functionality and bioavailability. However, challenges related to sensory quality, antinutritional factors, allergenicity, stability, standardization, and consumer acceptance must be addressed. Future functional food innovation should combine complementary plant ingredients with advanced processing and robust nutritional evidence. Such approaches can support the development of next-generation foods that contribute simultaneously to human health, resource efficiency, and sustainable food systems.

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