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Underutilized Legumes as Future Functional Foods: Nutritional Quality, Processing Technologies, Bioactive Compounds and Health Potential

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Abstract

Underutilized legumes represent an important but relatively neglected group of food crops with considerable potential for improving dietary diversity, food security, and sustainable nutrition. Legumes such as bambara groundnut, horse gram, moth bean, cowpea, winged bean, black gram, and lima bean provide proteins, dietary fibre, minerals, vitamins, phenolic compounds, flavonoids, and other bioactive constituents. Their ability to tolerate diverse environmental conditions further increases their relevance for resilient food systems. Traditional processing methods including soaking, germination, cooking, fermentation, and roasting can improve digestibility, reduce antinutritional factors, and modify bioactive compounds. Modern technologies such as extrusion, enzymatic treatment, protein fractionation, and encapsulation provide additional opportunities for developing functional ingredients and value-added foods. Underutilized legumes can be incorporated into bakery products, snacks, beverages, plant-based protein foods, and gluten-free formulations. This highlights their nutritional quality, bioactive potential, processing technologies, health-related properties, and opportunities for their development as future functional food ingredients.

Keywords: *Underutilized legumes, functional foods, plant proteins, dietary fibre, bioactive compounds, food processing, sustainable nutrition.*

1. Introduction

Legumes are among the most important plant sources of protein and have traditionally contributed to food security in many regions. However, agricultural and commercial systems remain heavily dependent on a limited number of major pulse crops. Numerous locally adapted legumes remain underutilized despite their nutritional and agronomic potential [1]. Bambara groundnut, horse gram, moth bean, cowpea, winged bean, hyacinth bean, lima bean, and other minor legumes provide substantial amounts of proteins, carbohydrates, dietary fibre, minerals, and phytochemicals. Many of these crops are also adapted to drought, heat, poor soils, and other environmental stresses, making them attractive for climate-resilient agriculture [2]. Greater utilization of these legumes could simultaneously improve dietary diversity, support local farming systems, and provide new raw materials for functional food development.

2. Nutritional Quality of Underutilized Legumes

The major nutritional advantage of legumes is their protein content. Legume proteins provide essential amino acids and can complement cereal proteins in mixed diets. Combining legumes with cereals can therefore improve overall protein quality. Underutilized legumes are also valuable sources of dietary fibre, resistant starch, minerals such as iron, calcium, magnesium, zinc, and potassium, and several B-group vitamins. Their fibre and slowly digestible carbohydrate fractions may contribute to improved nutritional quality and satiety. The nutritional composition varies substantially among species and cultivars. Environmental conditions, maturity, storage, and processing can further influence nutrient concentrations and bioavailability.

Table 1. Selected underutilized legumes and their functional food potential

Legume	Important nutritional/bioactive components	Key processing approaches	Potential food applications
Bambara groundnut	Protein, fibre, minerals, phenolics	Germination, fermentation, roasting	Flour, beverages, snacks
Horse gram	Protein, fibre, polyphenols	Soaking, germination, cooking	Bakery foods, soups, functional flour
Moth bean	Protein, fibre, minerals	Germination, fermentation	Snacks, sprouts, flour
Cowpea	Protein, fibre, phenolics	Soaking, cooking, fermentation	Protein foods, bakery products
Winged bean	Protein, lipids, minerals	Cooking, fermentation, fractionation	Protein ingredients, foods
Lima bean	Protein, fibre, phenolics	Soaking, cooking, germination	Flour, soups, snacks
Hyacinth bean	Protein, fibre, minerals	Cooking, fermentation	Traditional and functional foods

3. Bioactive Compounds

Underutilized legumes contain diverse phytochemicals, including phenolic acids, flavonoids, tannins, saponins, phytosterols, and other compounds. These constituents contribute to the antioxidant properties of many legumes [3]. Phenolic compounds can occur in free, conjugated, or bound forms. Processing may modify their chemical structure and accessibility. Some phenolic-rich fractions have demonstrated antioxidant and other biological activities in experimental models. Legumes also contain bioactive peptides that can be released through enzymatic hydrolysis or fermentation. Such peptides have been investigated for potential antioxidant, antihypertensive, antimicrobial, and metabolic activities [4]. However, the health effects of individual phytochemicals or peptides depend on their bioavailability and physiological concentrations. Therefore, laboratory evidence should be distinguished from clinically established effects.

4. Processing Technologies

Processing is essential for improving the nutritional and functional quality of underutilized legumes. Conventional methods such as soaking, cooking, roasting, germination, and fermentation can reduce antinutritional factors and improve digestibility. Soaking can reduce soluble antinutritional compounds and facilitate cooking. Germination activates endogenous enzymes and may increase the availability of selected nutrients and bioactive compounds. Fermentation can further improve digestibility and modify phenolic compounds through microbial metabolism [5]. Modern technologies provide additional opportunities. Extrusion can produce convenient snacks, breakfast products, and plant-protein foods while modifying starch and protein functionality. Enzymatic treatment can improve protein solubility and release bioactive peptides. Dry fractionation and wet extraction can produce protein-rich and fibre-rich ingredients. These fractions can subsequently be incorporated into foods with specific nutritional or technological requirements.

5. Antinutritional Factors and Their Management

A major limitation of many underutilized legumes is the presence of antinutritional factors. Phytates can bind minerals, while tannins and other compounds may interfere with protein and mineral utilization. Some legumes also contain protease inhibitors and other compounds that affect digestion. Appropriate processing can substantially reduce these factors. Cooking, soaking, germination, fermentation, and roasting are particularly useful approaches. Nevertheless, excessive processing may cause nutrient losses or reduce desirable bioactive compounds. An optimized processing strategy should therefore reduce undesirable components while retaining nutritional and functional constituents.

6. Functional Food Applications

Underutilized legumes can be converted into flours and incorporated into bakery products, crackers, snacks, noodles, porridges, and other cereal-based foods. Their protein and fibre contents can improve the nutritional profile of these products. Legume-based beverages and protein formulations represent another growing opportunity. Protein concentrates and isolates can be used in plant-based beverages and meat alternatives, although flavour and functional properties must be carefully managed. Fermented legume foods are particularly promising because fermentation can simultaneously improve sensory properties, digestibility, and bioactive characteristics. Germinated legume powders can also be incorporated into functional beverages and breakfast foods. Combining underutilized legumes with cereals, millets, seeds, and vegetables may provide complementary nutritional profiles and improve product acceptability.

7. Health Potential

The health-related potential of underutilized legumes is associated with their proteins, fibre, resistant starch, minerals, and phytochemicals. Dietary fibre can support gastrointestinal function and influence the gut microbiota. Fermentation of fibre by intestinal microorganisms produces short-chain fatty acids that participate in metabolic and intestinal processes [6]. Legume proteins may contribute to satiety and maintenance of muscle protein intake. Certain peptides generated during digestion or processing have shown potential biological activities in experimental systems. Phenolic compounds and other phytochemicals may contribute to antioxidant and anti-inflammatory responses. Some legume-based foods have also been investigated for their potential effects on glycaemic regulation and cardiovascular risk factors. Nevertheless, greater human evidence is required before specific disease-prevention claims can be made. Health outcomes depend on the complete food matrix, dietary pattern, quantity consumed, and individual metabolic characteristics.

8. Sustainability and Future Opportunities

Underutilized legumes can contribute to agricultural diversification and sustainable food systems. Many species are adapted to marginal environments and may require fewer external inputs than some conventional crops. Legumes can also contribute biologically fixed nitrogen to agricultural systems, potentially reducing dependence on synthetic nitrogen fertilizers when appropriately integrated into cropping systems [7]. Future development should focus on improved cultivars, standardized processing, modern ingredient fractionation, and consumer-oriented product design. Greater investment in local processing infrastructure could create value chains around traditionally neglected crops. Research should also investigate the bio accessibility of legume bio actives, protein digestibility, gut microbiome interactions, and long-term health outcomes. Life-cycle assessment and techno-economic studies will be useful for determining the sustainability and commercial feasibility of new products.

9. Conclusion

Underutilized legumes represent promising resources for developing future functional foods while supporting agricultural diversification and sustainable nutrition. Their proteins, dietary fibre, minerals, phenolic compounds, flavonoids, and bioactive peptides provide a strong nutritional foundation for value-added food products. Traditional processing methods such as soaking, germination, fermentation, roasting, and cooking can improve digestibility and reduce antinutritional factors, while modern technologies can generate specialized protein and fibre ingredients. Bakery products, beverages, snacks, fermented foods, and plant-based protein products offer important opportunities for utilization. Greater attention to sensory quality, standardization, bioavailability, safety, and consumer acceptance is required. Integrating traditional knowledge with modern food processing and nutritional research could transform underutilized legumes into commercially relevant ingredients for sustainable and health-oriented food systems.

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