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Pulses in Human Nutrition: Nutrient Composition, Bioavailability, and Emergency Applications - A Review

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ABSTRACT
Pulses are increasingly recognized as strategic foods for advancing global nutrition, reducing micronutrient deficiencies, and strengthening emergency food systems. This review synthesizes evidence on the nutrient composition, bioavailability, and functional properties of major pulses including lentils, chickpeas, common beans, pigeon pea, and mung bean and examines their relevance for both routine diets and crisis conditions. Pulses provide high-quality plant protein, complex carbohydrates, dietary fiber, iron, zinc, folate, and diverse bioactive compounds with antioxidant, metabolic, and immunomodulatory effects. Despite their nutritional richness, mineral bioavailability is often constrained by phytates, tannins, and protease inhibitors; however, soaking, thermal processing, germination, fermentation, and emerging technologies such as pulsed electric field treatment significantly improve nutrient accessibility. The review further evaluates the role of pulses in humanitarian food assistance, emphasizing their long shelf life, cultural acceptability, logistical ease, and suitability for fortified and biofortified interventions. Evidence from emergency settings highlights the importance of pre-processed pulse products, nutrient-dense pulse, cereal blends, and climate-resilient varieties for supporting vulnerable populations. Critical research gaps are identified across bioavailability assessment, processing scalability, breeding for nutrient density under climate stress, and integration into public-sector nutrition programs. Collectively, the findings underscore the multifaceted value of pulses and support their expanded use in nutrition policy, health programming, and emergency food system design.

Keywords: Pulses, Nutrient Bioavailability, Emergency Nutrition, Micronutrient Deficiencies

Introduction

Micronutrient deficiencies, collectively referred to as "hidden hunger," remain one of the most persistent global nutrition challenges, affecting over two billion people worldwide and disproportionately impacting low- and middle-income countries. These deficiencies particularly in iron, zinc, and folate persist even when caloric needs are met and contribute to impaired immunity, reduced cognitive development, adverse pregnancy outcomes, and increased vulnerability to infectious diseases.

Humanitarian crises amplify these nutritional risks. Climate-related disasters, protracted conflict, displacement, and disruptions in food supply chains often force emergency food systems to prioritize calorie delivery over nutrient adequacy [1]. Standard emergency rations typically rely on cereals or fortified blended flours, which may meet energy requirements but often fail to provide sufficient amounts of bioavailable protein, iron, zinc, and other essential micronutrients needed by children, pregnant women, and other high-risk groups. This gap highlights a systemic limitation within current emergency food strategies, which frequently ensure food security but not comprehensive nutrition security.

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Pulses including lentils, chickpeas, common beans, pigeon pea, mung bean, and cowpea offer a highly strategic solution for addressing these deficiencies. Pulses are nutrient-dense sources of plant protein, lysine, iron, zinc, folate, and dietary fiber, and they contain diverse bioactive compounds with established health benefits [2]. Their long shelf life, low moisture content, affordability, and cultural acceptability across many regions make them particularly well suited for crisis preparedness and emergency food distribution. Furthermore, advances in pulse biofortification have demonstrated improvements in iron and zinc levels without altering consumer acceptability, offering a scalable and sustainable food-based approach to reducing hidden hunger in resource-constrained settings.

Despite extensive research on pulse nutrition, bioavailability, health outcomes, and agronomic benefits, these domains are often examined in isolation. There is limited integrative analysis that positions pulses within the broader context of emergency food systems and disaster-resilient nutrition planning.

- Therefore, this narrative review aims to synthesize multidisciplinary evidence to: Summarize the nutrient composition and bioactive properties of major pulses; Examine determinants of nutrient bioavailability, especially under low-resource and emergency conditions;
- Review clinical and epidemiological evidence on the health effects of pulse consumption;
- Evaluate the suitability of pulses for emergency food assistance and ready-to-use formulations; and
- Discuss agronomic resilience, biofortification, and sustainability factors relevant to crisis-affected food systems.
- By integrating evidence across nutrition science, public health, agronomy, and humanitarian logistics, this review provides a comprehensive framework for incorporating pulses into both long-term nutrition strategies and emergency food responses.

Method

This review employed a narrative, integrative review methodology to synthesize multidisciplinary evidence on the nutrient composition, bioavailability, health impacts, and emergency-food applications of pulses. A narrative approach was selected because the research questions span diverse fields including nutrition science, public health, food technology, agronomy, and humanitarian logistics where study designs, outcomes, and reporting standards vary widely, making systematic aggregation neither feasible nor appropriate.

Literature Search Strategy

A comprehensive literature search was conducted between January and March 2025 across major scientific databases, including PubMed, Scopus, Web of Science, Google Scholar, and the FAO and WHO document repositories. The search combined controlled vocabulary (MeSH terms) and free-text terms. Key search strings included:

- "Pulses" OR "legumes"
- "Nutrient composition" OR "micronutrients" OR "bioactive compounds"
- "bioavailability" OR "antinutrients" OR "iron absorption" OR "zinc absorption"
- "Emergency food" OR "humanitarian food assistance" OR "disaster nutrition"
- "undernutrition" OR "micronutrient deficiency" OR "hidden hunger"
- "Pulse biofortification" OR "climate-resilient crops"
- Reference lists of relevant articles and reviews were screened manually to identify additional publications.

Inclusion and Exclusion Criteria

Inclusion Criteria

Studies were included if they:

- Reported primary or secondary data on nutrient composition, bioavailability, antinutritional factors, or health effects of edible pulses;
- Described the use of pulses in emergency or humanitarian food systems;
- Discussed agronomic traits, biofortification outcomes, or sustainability relevant to nutrition security;
- Were published in English between 2000 and 2025 in peer-reviewed journals, institutional reports, or academic books.

Exclusion Criteria

Studies were excluded if they

- Focused exclusively on oilseed legumes (e.g., soybean oilcake) unless used for nutritional comparison;
- Reported data irrelevant to human nutrition (e.g., industrial applications);
- Lacked methodological transparency;
- Were non–peer-reviewed web articles or unpublished theses;
- Did not provide extractable data on pulses or nutrient outcomes.

Data Synthesis and Evaluation

Given the heterogeneity of study designs ranging from biochemical analyses and clinical trials to food-technology studies and humanitarian program reports findings were synthesized qualitatively. Evidence was grouped into four thematic domains:

- Nutrient composition and bioactive compounds.
- Nutrient bioavailability and antinutritional factors.
- Health effects relevant to undernutrition and micronutrient deficiencies.
- Emergency food applications, biofortification, and agronomic resilience.

Where conflicting results were identified (e.g., variations in iron bioavailability or impacts of processing techniques), the review prioritized:

- Studies with larger sample sizes,
- More rigorous analytical methods, and
- Findings consistently reproduced across multiple contexts.

Limitations of the Review Method

As a narrative review, this work does not employ systematic review protocols such as PRISMA, nor does it conduct meta-analysis. Publication bias, variability in analytical methods across studies, and limited availability of high-quality data from humanitarian settings may influence conclusions. Nevertheless, the narrative approach is justified due to the multidisciplinary nature of the topic and provides a comprehensive synthesis needed to inform policy, practice, and future research.

Nutrient Composition of Pulses

Pulses including lentils, chickpeas, dry beans, peas, green gram, black gram, and horse gram are characterized by a dense nutritional profile that contributes substantially to global dietary quality. Their composition reflects a unique balance of macronutrients, micronutrients, and bioactive compounds, positioning pulses as key contributors to both everyday nutrition and emergency food strategies [3]. The following subsections summarize the major nutritional attributes of pulses with emphasis on components most relevant to nutrition security, public health, and food system resilience.

Macronutrient Composition

Pulses provide a nutritionally advantageous macronutrient profile composed primarily of complex carbohydrates, plant-based proteins, and dietary fiber, while remaining naturally low in fat [4]. This combination supports their widespread use in plant-based diets and food assistance programs.

Carbohydrates

Carbohydrates constitute approximately 50–65% of the dry weight of most pulses, predominately in the form of starch. Unlike rapidly digestible starches found in refined grains, pulse starch contains high proportions of: slowly digestible starch (SDS) resistant starch (RS) and non-digestible oligosaccharides

These components contribute to low postprandial glycemic responses, improved glucose regulation, and enhanced colonic fermentation, making pulses particularly valuable for populations with high burdens of diabetes or metabolic risk.

Protein and Amino Acid Profile

Pulses contain 20–25% protein, placing them among the richest plant sources of dietary protein. The protein fraction is characterized by: high lysine content, balancing lysine-deficient cereal-based diets and lower levels of sulfur amino acids (methionine and cysteine).

This amino acid complementarity forms the biochemical foundation for traditional cereal and pulse combinations (e.g., rice–lentils, maize–beans), which collectively achieve a more complete amino acid profile. Pulse proteins also generate bioactive peptides during digestion and processing, which exhibit antioxidant, antihypertensive, and lipid-modulating activities.

Dietary Fiber

Pulses provide 10–15% total dietary fiber, comprising both soluble and insoluble fractions. This fiber supports: enhanced satiety and weight regulation, improved gastrointestinal function, reduced serum cholesterol and improved glycemic control.

Given the persistent global fiber gap, dietary pulses represent one of the most efficient strategies to increase fiber intake in both developed and developing settings [3].

Fat Content

Most pulses contain 1–2% lipid, predominantly unsaturated fatty acids. Their naturally low fat and absence of cholesterol contribute to cardioprotective dietary patterns and suitability for populations requiring low-fat therapeutic diets.

Influence of Processing

Processing such as boiling, pressure cooking, roasting, germination, and fermentation modifies macronutrient accessibility and digestibility. Heat treatment alters starch fractions, increases soluble fiber availability, and improves overall nutrient bioaccessibility, while germination and fermentation further enhance functional properties.

Micronutrient Composition

Pulses are notable for their high concentrations of minerals and B vitamins, many of which are limiting in cereal-based or resource-constrained diets.

Iron

Pulses provide 4–7 mg iron per 100 g dry weight, although the proportion absorbed depends on the presence of phytates and polyphenols. Iron from pulses is particularly important in LMICs, where dietary diversification is limited and anemia remains highly prevalent [5]. Biofortified bean and lentil varieties have demonstrated increased iron concentrations and measurable improvements in iron status in target populations.

Zinc

Zinc content in pulses ranges between 2–4 mg per 100 g, contributing to immune function, growth, and reproductive health. Although zinc absorption may be constrained by phytic acid, traditional processing techniques can significantly improve bioavailability.

Folate and B Vitamins

Pulses are among the richest plant sources of folate (vitamin B9), typically providing 180–300 µg per 100 g dry weight. Folate is essential for DNA synthesis, neurological development, and prevention of neural tube defects. Pulses also supply thiamine, riboflavin, niacin, and vitamin B6 at levels meaningful for metabolic and cognitive function.

Magnesium, Potassium, and Calcium

Pulses supply significant quantities of essential macro-minerals:

- Magnesium: 120–150 mg/100 g
- Potassium: 700–900 mg/100 g
- Calcium: 40–120 mg/100 g

These nutrients contribute to cardiovascular health, neuromuscular function, and bone integrity.

Selenium and Trace Minerals

Selenium concentrations average around 160 ng/g, a considerable contribution in regions with selenium-deficient soils. Pulses also contain copper, manganese, and molybdenum, supporting antioxidant pathways and enzymatic processes.

Effects of Biofortification

Modern breeding and agronomic biofortification strategies have successfully enhanced iron, zinc, and selenium levels in several pulse crops. These interventions strengthen the ability of pulses to address hidden hunger and are increasingly integrated into agricultural policy and public health programs.

Bioactive Compounds

Pulses contain a diverse array of bioactive compounds that contribute to their functional health benefits and complement their nutrient profile.

Phenolic Compounds

Phenolic acids, flavonoids, and tannins provide antioxidant activity that supports cellular protection, reduces oxidative stress, and may lower the risk of chronic diseases such as cardiovascular disorders and certain cancers [6].

Saponins

Saponins contribute to cholesterol-lowering effects, modulation of immune responses, and potential anti-carcinogenic activities. Their amphiphilic structure facilitates interactions with bile acids and cholesterol.

Phytates (Phytic Acid)

Phytic acid acts as both an anti-nutritional factor (by binding minerals) and a bioactive compound with antioxidant and anti-inflammatory properties. Its negative effects on mineral absorption are substantially reduced by soaking, germination, and fermentation, which activate phytase enzymes [7].

Resistant Starch and Oligosaccharides

Resistant starch and non-digestible oligosaccharides function as prebiotics, stimulating beneficial gut bacteria such as Bifidobacterium and Lactobacillus. Their fermentation yields short-chain fatty acids (SCFAs) that support metabolic regulation, colonic health, and immune function [8].

Influence of Processing on Bioactive Compounds

Processing techniques particularly germination, fermentation, and emerging methods such as pulsed electric field treatment can enhance the bioactive potential of pulses while reducing anti-nutritional factors. Fermentation has been shown to increase antioxidant capacity and improve digestibility in multiple legume species.

Pulses in Emergency Food Security

Pulses play a critical role in emergency food security due to their nutrient density, long shelf life, cultural acceptability, and logistical suitability for large-scale humanitarian operations. These attributes make pulses essential components of rations distributed during natural disasters, conflict-related displacement, and protracted food insecurity.

Shelf Stability and Storage Advantages

A defining advantage of pulses in emergency contexts is their exceptional shelf stability. Dried pulses can be stored for extended periods without refrigeration and with minimal nutrient degradation, making them dependable during supply-chain disruption, unreliable electricity access, and limited food storage infrastructure. Their low moisture content reduces microbial spoilage, enabling stockpiling and pre-positioning in disaster-prone regions.

Nutrient Density and Relevance for Malnutrition

Pulses provide concentrated sources of protein, complex carbohydrates, dietary fiber, iron, zinc, potassium, and folate nutrients frequently deficient in crisis-affected populations. Their protein content (approximately 20–25% dry weight) supports recovery from acute and chronic undernutrition, while their micronutrient profile helps address widespread deficiencies in iron and zinc. In settings where diet diversity is limited, inclusion of pulses in emergency rations contributes to improved nutrient adequacy and supports immune function, growth, and maternal and child health.

Biofortified varieties offer additional benefits. Conventional breeding and genetic interventions have enhanced the iron, zinc, and selenium content of several pulse species, improving their effectiveness in food-insecure environments.

Logistical Advantages in Humanitarian Response

Pulses are well suited to large-scale humanitarian supply chains due to their low weight relative to nutrient density, transportability, and reduced risk of spoilage. Their dry form enables bulk transport and cost-efficient distribution to remote or physically inaccessible regions. Because pulses are widely consumed across cultural and religious groups, their integration into emergency rations minimizes food rejection and ensures high acceptability among diverse populations.

Integration into Humanitarian and Social Protection Programs

Pulses are integral components of general food distributions, targeted supplementary feeding programs, school feeding initiatives, and community-based management of acute malnutrition. In refugee camps across Africa and Asia, pulses form part of staple rations due to their reliability and nutritional adequacy. Their inclusion in school meal programs supports nutritional recovery in children while maintaining educational continuity in crisis settings.

Pulse-based ready-to-cook and ready-to-eat products are increasingly used for rapid response during natural disasters, offering immediate sources of protein and energy when households lose cooking facilities.

Processing and Value-Chain Factors Affecting Emergency Use

Optimizing pulses for emergency distribution requires attention to processing technologies and supply-chain resilience. Low-cost processing techniques such as soaking, pressure cooking, fermentation, and germination improve digestibility, reduce anti-nutritional factors, and enhance mineral bioavailability. Germination combined with pulsed electric field treatment has demonstrated improvements in in vitro protein digestibility and reduction of anti-nutritional compounds in faba beans [3].

Value-chain resilience is equally critical. Consistent availability of high-quality pulses relies on efficient production networks, robust storage facilities, and reliable transport systems [9]. Post-harvest fortification and packaging innovations can further enhance nutrient retention during extended storage and distribution.

Pulses serve as a cornerstone of emergency food security due to their nutrient density, stability under adverse conditions, logistical advantages, and wide cultural acceptance. Strengthening pulse value chains, expanding biofortification programs, and promoting accessible processing technologies can significantly enhance their impact in humanitarian response and contribute to improved nutrition outcomes among crisis-affected populations.

Bioavailability and Factors Affecting Absorption in Pulses

Pulses are nutrient-dense foods that provide protein, complex carbohydrates, dietary fiber, and key micronutrients such as iron, zinc, folate, magnesium, and potassium. However, the nutritional value of pulses is determined not only by their compositional profile but also by the bioavailability of these nutrients the proportion that is released from the food matrix, absorbed, and utilized by the human body. Bioavailability is influenced by several intrinsic factors, including anti-nutritional compounds naturally present in legumes, and extrinsic factors such as processing techniques, preparation methods, and emerging food technologies. Understanding these interactions is essential for maximizing the nutritional benefits of pulses, particularly in populations dependent on legume-based diets and in settings where micronutrient deficiencies are widespread [5,7].

Iron and Zinc Bioavailability

Pulses contribute meaningfully to dietary iron and zinc intake, yet the bioavailability of these minerals is often limited. Iron in pulses is present predominantly as non-heme iron, which has lower absorption efficiency than heme iron found in animal-source foods. Zinc is also present in plant-bound forms that are less readily absorbed. The primary inhibitor of absorption for both minerals is phytic acid (myo-inositol hexaphosphate), which chelates iron, zinc, calcium, and magnesium to form insoluble complexes that remain unabsorbed in the gastrointestinal tract [7].

Despite this inhibitory effect, pulses remain critical sources of dietary minerals in low- and middle-income countries (LMICs), where animal-source foods are scarce or unaffordable. Iron and zinc deficiencies are highly prevalent in such regions, and increased pulse consumption supported by appropriate processing can improve intake substantially. Interventions that reduce phytic acid content or degrade it into lower inositol phosphates enhance the bioavailability of iron and zinc and strengthen the nutritional impact of pulses [12-15].

Folate Bioavailability

Pulses are among the richest natural sources of folate (vitamin B9), supplying 180–300 µg per 100 g dry weight. Folate supports DNA synthesis, methylation pathways, fetal development, and red blood cell formation. Unlike iron and zinc, folate bioavailability is less significantly affected by phytic acid or other anti-nutritional factors. Instead, the major challenge is thermal degradation, as folate is heat-sensitive and can be lost during prolonged cooking or boiling [7].

However, some traditional methods such as germination and fermentation can increase folate levels through microbial synthesis or endogenous metabolic changes. Therefore, selection of appropriate preparation and processing strategies is essential to preserve folate in legume-based diets [16-20].

Anti-Nutritional Factors in Pulses

Pulses contain several compounds classified as anti-nutritional factors (ANFs), which can interfere with nutrient digestion and absorption. Although they serve protective roles in plants, ANFs may reduce nutrient utilization in humans when pulses are consumed without adequate processing. Major ANFs include phytates, tannins, saponins, protease inhibitors, lectins, and oxalates [7].

Phytates (Phytic Acid)

Phytic acid is the most widely studied ANF in pulses. It forms insoluble complexes with iron, zinc, calcium, and magnesium, substantially reducing their absorption (Singh & Kaur, 2023). This effect is particularly concerning in regions where pulses constitute a dietary staple and micronutrient deficiencies are endemic. However, phytic acid also possesses beneficial properties, functioning as an antioxidant and exerting potential anti-carcinogenic and glycemic-regulating effects [7].

Tannins

Tannins, a class of polyphenols, bind to proteins and digestive enzymes, impair protein digestibility, and inhibit mineral absorption [7]. Nonetheless, tannins contribute antioxidant and antimicrobial activities and may have beneficial metabolic effects at moderate levels [21-25].

Saponins

Saponins are bioactive glycosides known for their foaming characteristics and bitter taste. In high concentrations, saponins may disrupt cell membranes and impair nutrient absorption. Yet they also offer hypocholesterolemic, immunomodulatory, and anti-carcinogenic properties, making them a dual-impact component similar to phytic acid [7].

Protease Inhibitors

Protease inhibitors including trypsin and chymotrypsin inhibitors reduce protein digestibility by blocking digestive enzymes in the gastrointestinal tract. Long-term consumption of inadequately processed legumes high in protease inhibitors can impair nitrogen balance and growth [7]. These compounds are effectively inactivated by heat [26-29].

Lectins

Lectins (or hemagglutinins) are carbohydrate-binding proteins that can adhere to intestinal mucosa, reducing nutrient absorption and causing gastrointestinal irritation. Certain legumes, such as kidney beans, contain high levels of lectins that require thorough cooking to prevent toxicity [30].

Oxalates

Oxalates chelate calcium to form insoluble calcium-oxalate complexes, reducing calcium bioavailability and potentially contributing to kidney stone formation in susceptible individuals [7].

Processing Techniques for Improving Bioavailability

Processing methods are central to enhancing nutrient absorption and reducing the impact of anti-nutritional factors in pulses. Traditional techniques including soaking, cooking, germination, fermentation, and roasting remain widely used and accessible. Newer methods such as pulsed electric field treatment offer additional potential for improving bioavailability [31,32].

Soaking

Soaking pulses in water for several hours leaches out water-soluble ANFs such as phytates, tannins, and oligosaccharides. It also activates endogenous phytases, enzymes that hydrolyze phytic acid into more absorbable lower inositol phosphates [7].

Thermal Processing: Boiling, Steaming, and Pressure Cooking

Thermal treatments dramatically reduce protease inhibitors and lectins, improving safety and digestibility. Boiling and pressure cooking soften cell walls, enhance protein digestibility, and reduce resistant starch levels. However, heat-sensitive nutrients such as folate must be managed carefully to limit losses [34-39].

Germination (Sprouting)

Germination is among the most effective methods for improving bioavailability. Sprouting activates endogenous enzymes, reduces phytic acid and tannin content, increases vitamin levels (including folate and vitamin C), and enhances protein and starch digestibility. Germination is low-cost, scalable, and suitable for household, community, and institutional use [40-42].

Fermentation

Fermentation improves nutritional quality through microbial breakdown of phytates and tannins, synthesis of vitamins, and enhancement of antioxidant activity. Fermentation processes using Rhizopus oligosporus or Pleurotus ostreatus have shown substantial reductions in ANFs in chickpeas, pigeon pea, and soybean [7].

Roasting

Roasting provides moderate reductions in certain ANFs and improves flavor and palatability. However, it is less effective than wet-heat methods for lectin reduction [7].

Novel Processing Technologies

Pulsed Electric Field (PEF) Treatment

Low-intensity pulsed electric field technology is emerging as a promising method for improving nutrient accessibility in pulses. PEF disrupts cell membranes, increases hydration, enhances enzymatic reactions, and improves protein and starch hydrolysis. When combined with germination, PEF significantly improves in vitro digestibility and accelerates phytate breakdown in legumes such as faba beans [43-45].

Biofortification

Biofortification improves the intrinsic micronutrient content of pulses through plant breeding, genetic engineering, or agronomic interventions. High-iron and high-zinc varieties of chickpea, lentil, common bean, and pigeon pea developed through ICRISAT, ICAR, and Harvest Plus initiatives contribute directly to improved mineral intake among populations with limited dietary diversity [5]. Biofortification complements traditional processing by addressing deficiencies at the source [46-50].

The bioavailability of micronutrients in pulses is determined by complex interactions between mineral-binding compounds, physicochemical properties of the legume matrix, and the effects of processing. While anti-nutritional factors such as phytates, tannins, protease inhibitors, and lectins can reduce nutrient absorption, a variety of traditional and emerging processing techniques significantly mitigate these effects. Soaking, cooking, germination, fermentation, and roasting remain accessible and effective methods for enhancing bioavailability in resource-limited settings. Novel technologies such as pulsed electric field treatment and biofortification offer additional pathways for improving nutrient uptake. Together, these strategies maximize the nutritional potential of pulses and strengthen their role in supporting micronutrient adequacy and public health [50-53].

Pulses in Emergency Food Systems

Humanitarian emergencies whether triggered by climate-related disasters, armed conflict, epidemics, or economic instability disrupt food supply chains and severely compromise dietary quality. Emergency food systems are often forced to prioritize caloric sufficiency over nutrient density, resulting in monotonous rations dominated by refined cereals and starches. This leaves vulnerable populations at high risk of protein-energy malnutrition, micronutrient deficiencies, and immune impairment. Pulses represent a strategically valuable class of foods that can help close this nutritional gap owing to their long shelf life, high nutrient density, cultural acceptability, and cost-effectiveness. This section synthesizes the evidence supporting pulses as an essential component of emergency food systems and evaluates practical considerations for their integration into humanitarian supply chains.

Nutritional Rationale for Using Pulses in Emergencies

Compared with staple cereals typically distributed in food aid (e.g., rice, maize, wheat), pulses offer superior concentrations of key nutrients required for survival and recovery. They provide 19–26% protein and 60–63% complex carbohydrates per dry weight, along with substantial amounts of iron, zinc, potassium, magnesium, and folate. These nutrients are essential for immune function, hematopoiesis, and metabolic resilience, which are often compromised in crisis-affected populations.

The high dietary fiber content of pulses supports gastrointestinal integrity, a crucial factor during emergencies where diarrheal diseases and gastrointestinal infections are common. Their low glycemic index ensures stable energy release, making them suitable for populations facing prolonged food insecurity and erratic meal timing.

Biofortified varieties of lentil, bean, chickpea, and pigeon pea with higher iron and zinc densities further increase their value as emergency nutrition commodities [5]. Human feeding trials have shown improved hemoglobin concentrations and reductions in iron deficiency when biofortified pulses are consumed consistently within household diets [5].

Shelf-Stability and Suitability for Crisis Conditions

Pulses are among the few nutrient-dense foods that tolerate long-term storage without significant spoilage or nutrient degradation. Their naturally low moisture content (typically

10–12%) minimizes microbial growth and oxidation, enabling storage for years under ambient conditions.

This durability is particularly important in settings where: refrigeration is unavailable, supply routes are disrupted by conflict or flooding, aid must be pre-positioned for rapid deployment and storage environments are unstable

Dry pulses do not require specialized packaging or temperature control, making them cost-effective to procure, transport, and stockpile. For agencies operating under budgetary and logistical constraints, this resilience represents a major operational advantage.

Cultural Acceptability and Consumption Patterns

Pulses are staple foods in South Asia, the Middle East, Latin America, and Sub-Saharan Africa, providing cultural familiarity that increases acceptance in emergency rations. Unlike unfamiliar fortified blends or specialized supplements, pulses integrate easily into traditional cooking methods and recipes.

This is critical because food rejection is a persistent challenge in humanitarian contexts. Distribution of nutritionally adequate but culturally unfamiliar foods often results in low consumption, sharing, or resale within camps. In contrast, pulses exhibit high acceptability across diverse ethnic and cultural populations, improving the likelihood that vulnerable individuals consume the food intended for them.

Role in Humanitarian Food Assistance Programs

Pulses have long been incorporated into humanitarian feeding strategies. They are routinely included in- general food distributions by WFP and UNHCR, targeted food assistance for pregnant women and young children, school feeding programs, supplementary feeding in refugee and displacement camps and post-disaster relief packages.

Field reports from refugee camps in the Middle East, South Asia, and Sub-Saharan Africa have documented that chickpeas, lentils, cowpeas, and mung beans provide essential protein and micronutrients in diets otherwise dominated by rice and wheat flour.

During acute emergencies such as earthquakes and floods, pre-packaged pulse-based meals (e.g., instant lentil soups, ready-to-cook legume blends) have been deployed as rapid nutritional support due to their low cost and ease of preparation.

6.5 Processing Requirements and Barriers in Emergency Settings

While pulses are nutritionally valuable, some varieties require long cooking times, substantial water, and fuel all of which may be scarce in crisis contexts. Additionally, anti-nutritional factors (ANFs), such as phytates, tannins, and lectins, can hinder mineral absorption if pulses are inadequately processed [7].

To address these challenges, several processing strategies are used in humanitarian food design:

Pre-processing to Reduce Cooking Time

- Pre-boiled and dehydrated pulses
- Roasted or parboiled pulses
- Micronized or instant pulse flours

These forms require minimal water and heat, reducing energy demands for displaced households.

Reduction of Anti-Nutritional Factors

Traditional methods such as soaking, cooking, germination, and fermentation significantly reduce ANFs and improve digestibility. Germination activates phytases that degrade phytates, while boiling denatures lectins and protease inhibitors.

Low-intensity pulsed electric field (PEF) processing combined with germination further accelerates protein and starch hydrolysis, improving nutrient accessibility. Although not yet widely used in humanitarian supply chains, these technologies have potential for scalable implementation in centralized processing facilities.

Development of Pulse-Based Emergency Foods

Recent Innovations Include

- Ready-to-use pulse porridges
- Fortified pulse–cereal blends
- High-energy pulse biscuits
- Instant rehydration lentil meals

These products deliver protein, micronutrients, and prebiotic fiber with minimal preparation.

Value Chain Resilience and Logistical Considerations

For pulses to be effective in emergency systems, the surrounding value chain must remain functional. This includes seed production, farmer access, procurement channels, storage, transportation, and distribution networks. Disruptions at any stage can limit availability during crises.

Evidence from LMICs shows that local pulse markets are often more resilient than perishable food markets during climate shocks. However, supply reliability still depends on- adequate buffer stocks, stable import policies, functioning market infrastructure, farmer incentives for pulse cultivation and access to affordable storage technologies

Investment in local procurement, rather than reliance on imported commodities, can strengthen regional food security and reduce transportation time and cost.

Fortification and Biofortification Strategies

Micronutrient malnutrition especially iron, zinc, and folate deficiency often intensifies during emergencies. Fortification and biofortification of pulses offer scalable solutions.

Case Studies from Global Humanitarian Operations

Refugee Camps in Sub-Saharan Africa- Cowpea and common bean distributions significantly improved protein intake and reduced reported hunger scores among displaced families.

Post-earthquake response in Nepal- Instant lentil soups were incorporated into relief packages to provide rapidly absorbable nutrients and reduce cooking time requirements.

Flood-affected regions of Pakistan- Chickpeas and lentils supplied by WFP served as primary protein sources within relief rations and were preferred due to local familiarity and ease of preparation.

Strategic Importance for Climate-Resilient Emergency Nutrition Pulses also contribute to long-term food system resilience. Their nitrogen-fixing ability reduces fertilizer dependence, and many varieties demonstrate drought tolerance, making them critical crops as climate shocks intensify. Integrating pulses into community-level agriculture strengthens recovery and reduces dependency on external aid.

Pulses offer unmatched advantages for emergency food systems, combining nutrient density, long shelf life, cultural acceptability, and logistical feasibility. Their integration strengthens the nutritional quality of humanitarian rations, supports recovery from protein-energy and micronutrient malnutrition, and enhances resilience of food systems in crisis-prone regions. Future emergency nutrition strategies should prioritize investment in pre-processed pulses, fortified and biofortified varieties, and resilient value-chain structures to fully leverage their humanitarian potential.

Critical Gaps, Limitations, and Future Research Directions

Despite substantial evidence supporting the nutritional, functional, and environmental value of pulses, several critical gaps and limitations persist across biological, agricultural, processing, and policy domains. Addressing these issues is essential to fully harness the potential of pulses in improving human nutrition, public health, and food system resilience.

Biological Gaps

Although numerous observational studies and mechanistic investigations highlight the health benefits of pulses, high-quality randomized controlled trials (RCTs) demonstrating direct clinical outcomes remain limited. Most available evidence focuses on associations rather than causality, restricting the ability to establish definitive conclusions regarding pulse consumption and health improvement.

Furthermore, isotopic tracer studies, which provide precise measurements of iron, zinc, and folate absorption, are markedly underrepresented. Current estimates of mineral bioavailability rely largely on in vitro digestion models or indirect biomarkers, both of which lack the accuracy required to inform dietary recommendations.

Mechanistic understanding of pulse-derived bioactive compounds, including polyphenols, flavonoids, saponins, and oligosaccharides, is also incomplete. Emerging evidence shows that legume flavonoids regulate lipid metabolism through AMPK-mediated suppression of lipogenesis and enhancement of lipolysis and thermogenesis, yet the breadth of metabolic pathways involved and their interaction with different dietary patterns remains to be fully elucidated [6].

Agricultural Gaps

Agricultural limitations significantly constrain the nutritional potential of pulses. The genetic base controlling micronutrient traits (iron, zinc, folate) is narrow in many species, reducing the efficiency of conventional breeding programs [5]. Although biofortification initiatives are underway, the development and dissemination of climate-resilient, nutrient-dense varieties remain limited. Additionally, the slow adoption of improved cultivars by smallholder farmers is linked to inadequate seed delivery systems, low farmer awareness, and insufficient policy support. Expanding genetic diversity, integrating multi-trait selection (nutrient density + climate resilience), and strengthening seed systems are essential for sustainable impact.

Processing and Value-Chain Gaps

Efficient processing technologies are required to reduce anti-nutritional factors (ANFs) and improve nutrient bioavailability. Traditional household-level methods such as soaking, boiling, germination, and fermentation are effective but often not scalable for industrial or humanitarian applications [7].

Advanced processing methods such as germination combined with low-intensity pulsed electric field (PEF) treatment have shown promising results, including enhanced protein and starch digestibility and reduced phytate content (Johnston et al., 2024). However, deployment of these technologies remains limited due to cost, infrastructure constraints, and lack of commercial-scale research.

Folate degradation is another persistent issue: folate is highly heat-sensitive, and substantial losses occur during storage, milling, and cooking unless optimized processing and protective packaging strategies are employed.

Value-chain inefficiencies including poor storage facilities, post-harvest losses, and limited aggregation networks further reduce the availability, affordability, and nutritional quality of pulses from production to consumption.

Policy and Implementation Gaps

Despite their affordability and nutritional richness, pulses remain underrepresented in public nutrition programs, including school meals, hospital diets, child supplementation programs, and welfare feeding schemes. This underutilization is partly due to weak policy prioritization, inconsistent procurement strategies, and limited awareness of the benefits of pulses among decision-makers.

Moreover, fragmented value chains undermine farmer incentives, reducing production and limiting the availability of nutrient-dense varieties in local markets. Effective integration of pulses into national dietary guidelines, procurement policies, and social protection programs requires coordinated action across agriculture, health, and education sectors [55,56].

Future Research Directions

Addressing these gaps requires a coordinated, interdisciplinary research agenda that integrates nutrition science, agriculture, food technology, and public policy.

- Use Integrative Metabolomics to Map Bioactive Functions- Metabolomics and multi-omics approaches should be used to elucidate the metabolic pathways underpinning

the health benefits of pulse-derived polyphenols and flavonoids, including interactions with gut microbiota and host metabolism [6].
- Expand Dual-Trait Breeding for Nutrition and Climate Resilience- Breeding programs must prioritize simultaneous improvement in nutrient density and stress tolerance to ensure pulses remain productive under climate variability [5].
- Develop Nutrient-Dense, Pulse-Based Fortified Products- Research should focus on germinated, fermented, or micronutrient-fortified pulse products for infants, pregnant women, and other vulnerable populations.
- Develop Low-Cost Fermentation and Processing Technologies- Research should evaluate scalable fermentation strategies to enhance digestibility, micronutrient bioavailability, and shelf-life. Fermented pulse products have demonstrated antioxidant, antihypercholesterolemic, and anti-diabetic properties that merit deeper investigation.

Conclusions

Pulses are uniquely positioned at the intersection of nutrition, health, food security, and environmental sustainability. Their rich nutrient profile including high-quality plant protein, dietary fiber, essential minerals, folate, and diverse bioactive compounds makes them indispensable for addressing micronutrient deficiencies, protein-energy malnutrition, and diet-related chronic diseases. Extensive evidence supports the roles of pulses in improving glycemic control, reducing cardiovascular risk, supporting gut microbiome health, and contributing to immune resilience. Their low glycemic index, high soluble and insoluble fibers, and beneficial phytochemicals collectively underpin these health benefits. Emerging mechanistic studies further highlight complex metabolic pathways modulated by legume-derived polyphenols, although causality requires validation through robust clinical trials. Beyond human health, pulses serve as a cornerstone of emergency food systems due to their shelf-stability, nutrient density, affordability, and cultural acceptability. These characteristics make them highly suitable for disaster relief, humanitarian programs, and nutrition interventions targeting vulnerable populations. However, several limitations persist across biological, agricultural, processing, and policy domains. Gaps in bioavailability data, limited adoption of nutrient-dense varieties, inadequate scalable processing technologies, and weak value chains restrict the full realization of their benefits. Addressing these issues requires coordinated efforts involving advanced breeding, scalable processing innovations, clinical research, and strengthened policy frameworks.

Overall, pulses represent a highly strategic food group capable of improving public health, advancing food and nutrition security, and supporting environmental sustainability. Leveraging their full potential demands an interdisciplinary approach integrating nutrition science, agriculture, food technology, and policy to translate existing evidence into impactful, population-level outcomes.

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Declaration of Generative AI

During the preparation of this manuscript, the author used AI solely to enhance language clarity. The final content was reviewed and edited by the author, who takes full responsibility for the accuracy and integrity of the publication.

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