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REVIEW ARTICLE

Integrating plant proteins into sustainable food systems: a narrative review of challenges and opportunities

Integración de proteínas vegetales en sistemas alimentarios sostenibles: una revisión narrativa de desafíos y oportunidades

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Abstract The projected growth of the global population toward 2050 will significantly increase protein demand, intensifying the environmental pressure associated with animal-based sources. In this context, plant-based proteins emerge as a sustainable alternative with strong potential to reduce the environmental impact of food systems. However, their large-scale adoption faces technological, economic, cultural, and regulatory challenges, mainly related to techno-functional limitations, processing costs, and consumer acceptance. Technological advances, public policy support, cost-reduction strategies, and consumer education are identified as key elements to overcome these barriers, highlighting the need for a systemic and multidisciplinary approach to strengthen food security and promote more sustainable food systems.

Keywords plant-based proteins, alternative proteins, food systems, technological barriers, consumer acceptance, sustainable protein transition.

Resumen El crecimiento proyectado de la población mundial hacia 2050 incrementará significativamente la demanda de proteínas, intensificando la presión ambiental asociada a las fuentes de origen animal. En este contexto, las proteínas vegetales emergen como una alternativa sostenible con alto potencial para reducir el impacto ambiental de los sistemas alimentarios. No obstante, su adopción a gran escala enfrenta desafíos tecnológicos, económicos, culturales y regulatorios, relacionados principalmente con limitaciones tecno-funcionales, costos de procesamiento y aceptación del consumidor. Los avances tecnológicos, el apoyo de políticas públicas, la reducción de costos y la educación del consumidor se identifican como elementos clave para superar estas barreras, destacándose la necesidad de un enfoque sistémico y multidisciplinario para fortalecer la seguridad alimentaria y promover sistemas alimentarios más sostenibles.

Palabras clave proteínas de origen vegetal, proteínas alternativas, sistemas alimentarios, barreras tecnológicas, aceptación del consumidor, transición proteica sostenible.

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PUBLIS EDITORIAL

Introduction

The global population is projected to reach 9.8 billion by 2050 (UN, 2019). This growth is associated with an increased demand for food, both for human consumption and animal feed. The question of whether the world will be able to provide safe, sufficient, and nutritious food to all at all times has recently gained significant attention. The supply of sufficient and quality proteins, in particular, is a critical concern (Malila et al., 2024). The demand for animal-based protein is also projected to double by 2050 (Henchion et al., 2017). Such increased demand is expected to intensify pressure on land due to the need to produce more animal feed and water.

The overall result is increased greenhouse gas (GHG) emissions and ultimately global warming (Tilman & Clark, 2014). Moreover, conversion of forests, wetlands, and natural grasslands into agricultural lands is anticipated, and this is threatening our environment and climate (Xu et al., 2021). In light of the global protein demands and the impact of animal-based proteins on the environment, alternative proteins (APs) have emerged as promising solutions for achieving food security and environmental sustainability (Aiking, 2011).

There are four (4) main groups of APs based on their origin: insect-based, plant-based, microbe-derived, and cultured meat and seafood (Malila et al., 2024). Among these sources, plant proteins are the most accepted protein sources by consumers, followed by cultured meat, microbe meat, and insect-based meat as the least preferred (Circus & Robison, 2019; Grasso et al., 2019). According to Su et al. (2024), the market for APs is projected to increase exponentially to USD 26.5 billion by 2030, up from USD 15.3 billion in 2023.

In addition, Bryant (2022) highlighted that due to their environmental and economic benefits, plant proteins hold immense potential for addressing food security and sustainability. Similarly, Mejia et al. (2016) found that plant proteins have the potential to reduce GHG emissions, as their overall life cycle carbon dioxide (CO_2) emissions are 54 times lower than those of animal-based meat. Furthermore, plant-based proteins offer advantages in terms of land use, water use, and energy use over animal proteins (Ferrari et al., 2022).

Despite the increasing global interest in plant-based proteins as sustainable alternatives to animal-derived proteins, their large-scale integration into mainstream food systems remains constrained by a complex interplay of technological, economic, cultural, and policy-related barriers (de Moraes et al., 2023; Newton et al., 2024). Although numerous studies have explored individual aspects of these challenges, a coherent synthesis linking these factors within the broader sustainability transition remains limited.

Therefore, the objective of this narrative review is to critically evaluate existing literature on plant-based proteins with a focus on: (1) identifying and analyzing the key technological, economic, cultural, environmental, and policy-related constraints affecting their adoption in sustainable food systems; (2) examining current and emerging strategies for overcoming these barriers; and (3) highlighting future directions necessary to strengthen the contribution of plant-based proteins to global food security and environmental sustainability. The scope of this review covers peer-reviewed literature on major plant protein sources, their functional and nutritional attributes, processing challenges, consumer acceptance, and regulatory considerations within the context of sustainable food system transformation

Methodology

This study was conducted as a narrative literature review to synthesize existing knowledge on plant-based proteins and their role in sustainable food systems. A structured search of peer-reviewed scientific literature was carried out using major academic databases and scholarly search engines, including Google Scholar, Scopus, Web of Science, and PubMed. The search mainly focused on publications released between 2010 and 2025 to capture recent scientific advancements and current debates in the field.

The literature search was performed using combinations of the following keywords: "plant proteins", "plant-based proteins", "animal proteins", "animal-based proteins", "alternative proteins", "vegetable proteins", "sustainable food systems", "meat analogues", "protein functionality", and "consumer acceptance". Boolean operators such as AND/OR were used to refine searches and improve relevance.

Only peer-reviewed journal articles and authoritative review papers published in English were considered eligible for inclusion. Conference abstracts, non-peer-reviewed reports, editorials, and unrelated studies were excluded. The selected articles were screened based on title and abstract relevance, followed by full-text evaluation. Information extracted from the selected literature included plant protein sources, processing and functional characteristics, technological challenges, economic constraints, cultural acceptance, and policy-related issues. The collected data were then thematically analyzed and qualitatively synthesized under major thematic areas, namely: sources of plant-based proteins, technological barriers, socio-cultural acceptance, economic challenges, policy constraints, and comparative advantages over animal-based proteins.

Results and discussion

Sources of plant-based proteins

There are various widely studied plant protein sources, including legumes, cereals and pseudocereals, seeds, and nuts

(Figure 1). Legumes include pea, cowpea, soybean, lupin, bean, and chickpea (Coda et al., 2017). Cereals include maize, millet, rice, wheat, sorghum, soya beans, and barley, while pseudocereals include amaranth, buckwheat, and quinoa (López et al., 2018). Seeds consist of sunflower, chia, pumpkin, flaxseed, and sesame (Mattila et al., 2018). Nuts include almond, peanut, and cashew nut (de Oliveira Sousa, 2011). Other sources include major fruits and vegetables (Boyle et al., 2024) and tubers such as potato, yam, cocoyam, and cassava (Petrusán et al., 2016). These protein sources differ not only in protein content but also in amino acid composition, techno-functional properties, digestibility, and suitability for different food applications, which strongly influence their use in sustainable food system transitions.

Cereals

Cereals include barley, wheat, corn, and rice. They are staple foods all around the world (Amagliani et al., 2017). Rice is among the most consumed cereals in almost all countries in the world. Like other cereals, rice is rich in asparagine and glutamine amino acids. The rice endosperm contains 80% glutelin and 20-25% prolamin, while the outer layers are rich in albumin and globulins. Interestingly, glutelin contains the highest amount of lysine of any other protein found in rice (Hoogenkamp et al., 2017). Wheat is also another cereal with protein content ranging from 7-22% (Shewry, 2009). Millet, a cereal with 7-12% protein content and rich in amino acids like lysine, has been suggested by scientists for the mitigation of hidden hunger due to its readily available nutrients (Yousaf et al., 2021). From a functional perspective, cereal proteins generally exhibit poor emulsifying and gelling properties when compared to legume proteins, mainly due to their lower solubility and limited surface activity. However, wheat gluten is a notable exception, as its gliadin and glutenin fractions provide unique viscoelastic and texturizing properties. These properties make wheat gluten highly valuable in the formulation of meat analogues, where it contributes to fibrous structure and chewiness. Thus, cereals serve not only as protein sources but also as structural enhancers in plant-based food formulations, particularly in hybrid protein systems.

Pseudocereals

Pseudocereals are edible dicotyledon seeds that have starch content and a physical appearance similar to cereals. For that reason, they are referred to as false cereals and in-

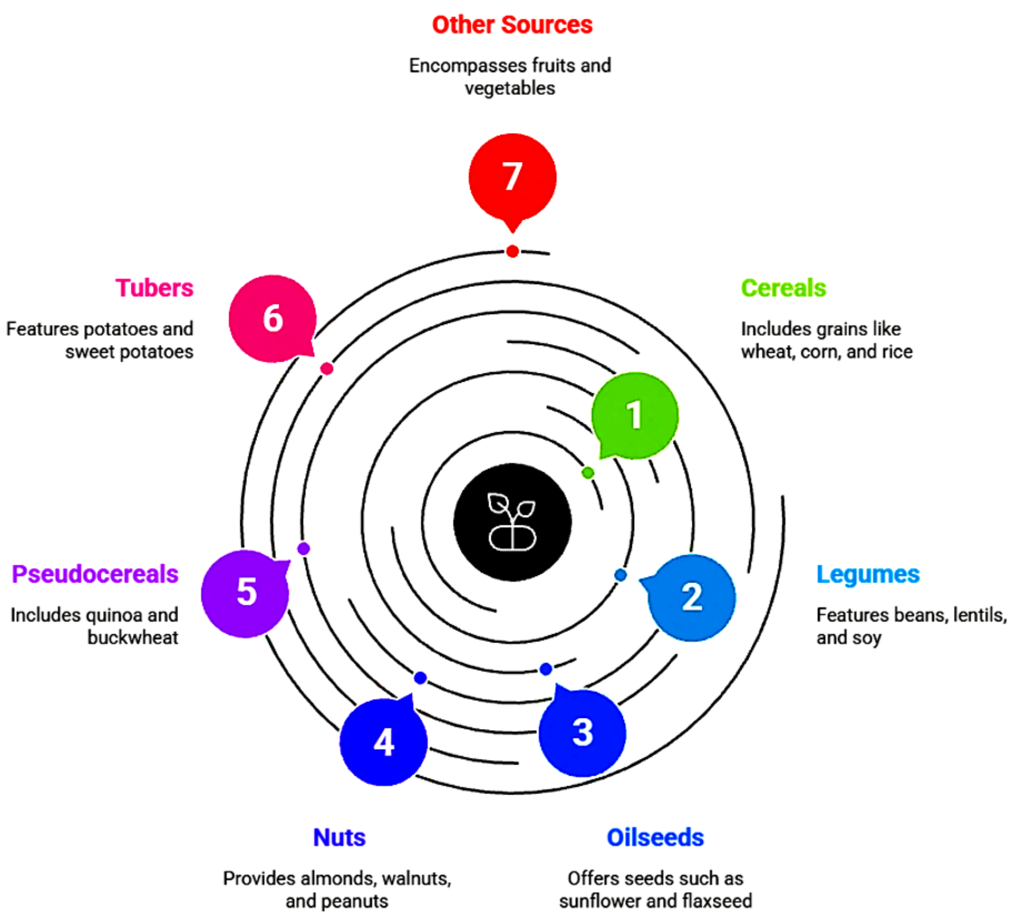

Figure 1. Sources of plant-based proteins (Langyan et al., 2022; Kovačević et al., 2024).

clude quinoa, buckwheat, and amaranth (Alvarez-Jubete et al., 2010). Due to their richness in protein and other constituents (fiber, minerals, vitamins, and unsaturated fatty acids), pseudocereals have been reported to replace animal-based proteins and develop novel foods, for instance, for gluten intolerance (López et al., 2018; Malik & Singh, 2022).

In addition to their favorable nutritional profile, pseudocereal proteins exhibit relatively balanced amino acid composition, particularly with higher lysine content than most cereals. This improves their biological value and complements the amino acid limitations of cereal-based diets. Their functional properties, including water-holding and emulsifying capacity, also support their application in bakery products, snacks, and meat analogues. Pseudocereals can therefore be considered among the quality plant-based protein sources for future sustainable diets.

Seeds

Seeds have been reported to be excellent sources of quality nutrients (Amagliani et al., 2017). For example, flaxseeds, which have low lysine content (Olivos-Lugo et al., 2010), are, however, full of nutritious protein, essential amino acids, phenolic compounds, and fiber (Anaya et al., 2015). Sunflower seeds are good sources of nutrients: proteins, minerals, fats, carbohydrates, and vitamins (Muhammad et al., 2012). Watermelon seeds are rich in amino acids, leucine, and arginine (Lakshmi & Kaul, 2011). In addition, Chen and Luo (2024) reported that chia seeds contain up to twenty percent (20%) protein content with 18 essential amino acids except lysine.

From a techno-functional standpoint, seed proteins often exhibit good emulsifying and foaming capacities due to their surface-active properties. However, their high lipid content may require defatting during processing, increasing production cost. Additionally, the presence of anti-nutritional factors and phenolic compounds can influence protein digestibility and sensory quality. Despite these challenges, seed proteins remain promising alternative proteins for vegans, as well as for gluten- and soy-intolerant consumers, particularly in beverage and bakery applications.

Nuts

The United States Department of Agriculture Nutrient Database (Rhodes et al., 2020) reported nuts as rich sources of proteins, with peanuts and almonds doing the best. However, chestnuts have been reported to have poor-quality proteins (Chung et al., 2013). The composition of protein in nuts is dominated by both essential and non-essential amino acids. The non-essential amino acids include glutamic acid, which predominates in almonds, as well as arginine and aspartic acids in peanuts. Lysine, phenylalanine, and valine are the essential amino acids predominant in most nuts (Venkatachalam & Sathe, 2006). Major proteins found in nuts have, however, been reported to be responsible for nut allergies (Amir et al., 2023), which represents a significant safety and regulatory challenge in food product development. Hence, labeling should be clearly indicated when these proteins are used in food products to inform consumer choices. Although the amino acid composition may vary across nut species, nuts remain valuable protein-rich ingredients with additional health benefits derived from unsaturated fatty acids, making them useful in plant-based spreads, snacks, and beverage formulations.

Legumes

Legumes have been one of the edible seeds since prehistoric times in human civilization. They are known for their nitrogen fixation capabilities across centuries. Through nitrogen fixation by their symbiotic nodules, they produce amino acids, which are building blocks for endogenous proteins (Bennetau-Pelissero, 2018). For many sub-Saharan countries, cowpeas are a good source of protein, and their protein quality is improved when combined with cereals (Fatokun et al., 2002). Different legumes have different predominance of proteins, with globulins dominating in most legumes (Figure 2). For example, glycinin and β-conglycinin are abundant in soybeans (41% of total grain weight), and α-conglutin in lupine seeds (35-37% of total grain weight). From a functional standpoint, legume proteins exhibit superior emulsifying, foaming, and gelling properties compared to most cereal proteins, making them highly suitable for meat analogues, dairy alternatives, and protein beverages. However, their application is sometimes limited by the presence of anti-nutritional factors, beany flavor, and allergenicity, particularly in soy-based products. Nevertheless, legumes remain the most technologically and nutritionally important plant protein sources for large-scale substitution of animal proteins.

Challenges with plant-based proteins and recommendations

Challenges limiting the integration of plant-based proteins into sustainable food systems can be classified into technological, cultural and social, economic, as well as policy-related. These barriers are not isolated; rather, they interact in complex ways to influence production feasibility, product quality, market competitiveness, and consumer adoption. Understanding these interconnections is essential for identifying effective leverage points for accelerating the transition toward sustainable protein systems.

Technological barriers

Despite the potential benefits offered by plant-based proteins, developing alternative products such as meat, burgers, and milk with sensory and nutritional profiles comparable to their conventional counterparts remains a major technological challenge (Malila et al., 2024). One of the technological barriers that accounts for the failure of plant-based proteins' integration into food systems is the structural nature of the legume proteins. Legume proteins, for example, are predominantly stored in globular forms within seeds and tubers, which exhibit poor water-holding capacity, limited gelling properties, weak foaming ability, and lack the fibrous, elastic structure characteristic of animal muscle proteins such as myosin and actin (Figure 2).

To overcome these limitations, plant proteins must undergo extensive processing such as thermal extrusion, shear alignment, enzymatic modification, and protein blending to impart the desired textural and functional characteristics (Sim et al., 2021). These processes take more time, resources, and significant production costs.

Soy and pea proteins (mainly composed of globulins and albumins) are commonly used in formulating meat analogs due to their availability and cost-effectiveness (Sha & Xiong, 2020). Interestingly, wheat gluten (abundant in gliadins and glutenins), which is particularly valued due to its extensibility and elasticity, has been reported to contribute to the chewiness and other functional characteristics of meat analogues (Chiang et al., 2019; Nanta et al., 2021). More recently, rice and mung proteins have been reported to possess properties similar to wheat gluten and can be used in combination with primary proteins to enhance nutritional benefits missing in other plant proteins (Tarahi, 2024). However, the reliance on multiple protein sources and complex processing routes further increases formulation complexity and production cost.

Hence, advancements in protein extraction, fractionation, fermentation, and extrusion technologies are required to improve yield, reduce energy consumption, and enhance techno-functional performance. Blending complementary proteins and applying mild modification techniques can reduce the need for extreme processing while improving texture, digestibility, and sensory quality. These innovations are central to improving both product quality and economic feasibility.

Figure 2. Appearance of animal and plant-based proteins (Ismail et al., 2020).

Cultural and social acceptance barriers

Cultural and social acceptance represents a critical barrier to the adoption of plant-based proteins, particularly in those societies where these proteins are not part of their traditional cuisine (Niva et al., 2017). Food Fussiness (FF), is a condition where one becomes highly selective on the type of food they are willing to eat due to its attributes such as taste, texture, and flavor, and Food Neophobia (FN), a condition closely related to fussiness but referring to rejection or aversion to unfamiliar foods, have limited the acceptance of plant-based proteins (Godfray, 2019; Grasso et al., 2019).

Cultural beliefs are also at the core of the market growth for these proteins. A study conducted by Eckert et al. (2024), on public perceptions of plant-based proteins from social media comments in Canada, observed that some people do not consume soy proteins because of their association with femininity, while some believe that the consumption of plant-based meat is contrary to human nature and the evolution of man. Gender and age have been reported to positively affect public attitudes toward plant-based proteins. A study by Takeda et al. (2023) indicated that females and elders rate plant-based proteins higher than males and young people. Similar findings have been reported in Europe (Grasso et al., 2019; Dupont & Fiebelkorn, 2020). However, evidence from Africa and other parts of America remains limited, highlighting a regional research gap.

Education has been consistently identified as a key driver of sustainable dietary shifts. It has been found that education level greatly influences the shift toward more sustainable protein sources, with higher-educated consumers leading the way (De Boer & Aiking, 2011). A study by Van et al. (2017) highlighted that consumers who are concerned about the health benefits of plant-based proteins are those who are educated compared to those who are not. Although Takeda et al. (2023) indicate that consumers' decisions are primarily influenced by their scientific interests rather than their educational background, education remains a powerful tool for shaping food choices.

Therefore, public awareness, nutrition education programs, and transparent communication on health, environmental, and safety benefits are critical for reducing misconceptions and increasing social acceptance. Improving sensory quality through technological innovation is equally important, as taste and texture remain dominant drivers of consumer choice.

Scaling up costs and economic challenges

Plant-based proteins in their raw ingredient form are relatively cheaper than animal-based proteins (Ismail et al., 2020). Their small-scale processing is also considered cheaper than their animal counterparts. However, the production and processing of these proteins on a large scale is challenging (Sha & Xiong, 2020). Because they exist in globular form, plant proteins like pea proteins demand large investments for extraction equipment and subsequent processes such as purification and texturization (Geijer & Gammoudy, 2020).

For example, in Italy, soy drink production costs have been reported to be higher than those of cow milk (Coluccia et al., 2022). In Canada, according to the research done by Dalhousie University's Agri-Food Analytics Lab, plant-based meats are at thirty-eight percent (38%) higher than meat-based versions, while chicken nuggets are at 104% higher than animal counterparts (Rogers, 2023). In Southeast Asia, despite higher prices of plant-based proteins, consumers are willing to pay for the products due to the associated health benefits. On the other side, higher prices make it difficult for low-income families in those countries to opt for plant-based proteins (Rogers, 2023). A recent survey evaluating Europeans' attitudes towards plant-based eating showed that 38% of respondents cited high price as the primary limiting factor to purchasing plant-based proteins, while 30% cited taste (Proveg International, 2024). It was noted that more than twenty-six percent (26%) of those who eat plant-based proteins regularly in the United States were influenced by affordability (Wall, 2025). Similar economic limitations have been reported in South Africa, particularly for legume production and consumption (Gerrano et al., 2022).

Therefore, reducing production costs through improved process efficiency, scaling up infrastructure, local sourcing of raw materials, and technological optimization is essential for improving affordability. Policy incentives such as tax relief, subsidies, and support for agri-food innovation can further enhance competitiveness. Retailers should also reframe plant-based proteins as high-quality yet affordable products rather than niche premium items. These measures are consistent with the views of Newton et al. (2024) and Schenk et al. (2018), who emphasize cost reduction as a critical driver of consumer adoption.

Policy constraints

The successful integration of plant-based proteins into sustainable food systems is strongly dependent on public policy support (Swain, 2024). Effective policy can empower consumers to make informed choices that prioritize environmental sustainability (Capacci et al., 2012). The implementation of robust nutrition policies is essential for securing a sustainable future for humanity (Sabaté & Soret, 2014). However, many countries still lack harmonized standards for plant-based protein processing, labeling, and safety evaluation, which undermines public trust in these products (Shah et al., 2024).

International trade barriers have stymied the development of favorable taxation schemes for sustainable food products (Fellmann et al., 2018). Consequently, it is often conscious consumers who shape niche markets, prepared to pay premium prices for products that align with their values (Akaichi et al., 2019), rather than by widespread mainstream adoption.

The United States has implemented supportive policies at both national and local levels are paving the way for a shift toward plant-based diets by incentivizing their production and consumption. Government-run schools are also taking the initiative by incorporating various programs that emphasize plant-based proteins in their menus (Espinosa-Marrón et al., 2022). Despite these initiatives, existing global policy frameworks remain insufficient to address the challenge of feeding nearly ten billion people by 2050 (Sweet, 2019).

There is an urgent need to establish supportive and harmonized standards for plant-based proteins that will enhance consumer confidence in their safety and quality. There is also a pressing need for tax reforms, such as tax incentives and subsidies, to make sustainable foods more accessible to everyday consumers. Furthermore, global initiatives mirroring those in the United States, where schools actively promote plant-based diets, should be adopted worldwide to accelerate the transition toward sustainable food systems. These efforts could significantly accelerate dietary transitions toward sustainability.

Integrated systems perspective

Technological limitations increase processing intensity, which raises production costs and retail prices, thereby reducing affordability and slowing consumer adoption. Low adoption, in turn, reduces political motivation for policy reform, reinforcing a negative feedback loop that constrains large-scale transition. Conversely, technological innovation, cost reduction, consumer education, and supportive policies can create a positive reinforcement cycle that accelerates the integration of plant-based proteins into sustainable food systems. Addressing these challenges, therefore, requires a coordinated, multidisciplinary, and systems-based strategy.

Advantages of plant-based protein over animal protein

Plant-based proteins have several advantages over animal proteins, making them increasingly important in the global transition toward sustainable food systems. These advantages extend beyond individual health benefits to broader implications for climate change mitigation, natural resource conservation, and food system resilience.

Health and nutritional advantages

Plant-based proteins are generally associated with lower levels of saturated fats and cholesterol and higher contents of dietary fiber, vitamins, minerals, and bioactive compounds compared to animal proteins (Hu, 2021). Regular consumption of plant-based protein sources such as legumes, whole grains, nuts, and seeds has been linked to a reduced risk of cardiovascular diseases, type 2 diabetes, obesity, and some types of cancer (Satija et al., 2016; Godfray et al., 2018).

Unlike many animal-based proteins, which are often accompanied by high levels of saturated fat and heme iron that may increase disease risk when consumed excessively, plant proteins provide essential amino acids alongside phytochemicals with antioxidant, anti-inflammatory, and metabolic regulatory functions. Although some plant proteins are limited in one or more essential amino acids, complementary protein combinations (e.g., cereals and legumes) can effectively achieve balanced amino acid profiles (Young & Pellett, 1994).

From a public health standpoint, the shift from animal to plant protein consumption represents not only a nutritional substitution but also a preventative strategy against non-communicable diseases (NCDs), particularly in urbanizing and aging populations.

Environmental sustainability advantages

One of the most significant advantages of plant-based proteins over animal proteins is their substantially lower environmental footprint. Livestock production is responsible for a large share of global greenhouse gas emissions, land degradation, water pollution, and biodiversity loss (Gerber et al., 2013). In contrast, plant protein production requires less land, water, and energy per unit of protein produced (Poore & Nemecek, 2018).

For example, beef production generates up to 20–60 kg CO_2-equivalent per kilogram of protein, whereas most plant proteins generate less than 5 kg CO_2-equivalent per kilogram (Poore & Nemecek, 2018). Similarly, animal agriculture consumes significantly larger volumes of freshwater and contributes disproportionately to nitrogen and phosphorus pollution compared to plant-based systems.

These environmental efficiencies position plant-based proteins as a central pillar in climate-smart agriculture and low-carbon food system transitions, particularly under global commitments to greenhouse gas reduction and sustainable resource management.

Food security and resource-use efficiency

Plant-based proteins contribute more efficiently to global food security due to their superior feed-to-food conversion efficiency. Animal protein production is inherently inefficient because large quantities of plant biomass are required to produce relatively small amounts of edible animal protein (Smil, 2014). Direct human consumption of plant proteins, therefore, allows greater caloric and protein availability per unit of land and water.

Legumes such as soybean, cowpea, lentil, and chickpea also contribute to soil fertility through biological nitrogen fixation, reducing dependence on synthetic fertilizers and improving long-term agricultural sustainability. This dual role as both protein sources and soil enhancers strengthens the resilience of smallholder farming systems, particularly in low- and middle-income countries.

Economic and market advantages

From an economic standpoint, plant-based proteins offer opportunities for value chain diversification, agro-industrial development, and income generation. Compared to livestock systems, plant protein production generally requires lower capital investment, shorter production cycles, and reduced exposure to animal disease risks. This makes plant-based protein value chains particularly attractive for small- and medium-scale producers.

The rapid growth of the global plant-based food market has created new opportunities for product innovation, employment, and export-oriented agribusiness development. Furthermore, plant-based protein industries can be more geographically distributed than livestock systems, enhancing regional food system resilience.

Public health and food safety advantages

Animal-based protein systems are frequently associated with zoonotic disease risks, antimicrobial resistance, and food safety hazards arising from intensive production systems (WHO, 2017). Plant-based protein systems, by contrast, carry a substantially lower risk of zoonotic pathogen transmission and eliminate the need for routine antibiotic use. Reduced dependence on intensive animal agriculture supports not only environmental sustainability but also global health security by lowering the probability of future foodborne and zoonotic disease outbreaks.

Despite their many advantages, plant-based proteins are not without limitations. Challenges related to protein digestibility, antinutritional factors, sensory quality, and consumer acceptance remain significant as discussed above. Additionally, some ultra-processed plant-based products may contain high levels of sodium, additives, or refined fats, which can offset some of their health benefits.

Therefore, the sustainability advantage of plant-based proteins is maximized when they are minimally processed, nutritionally balanced, culturally acceptable, and produced through environmentally responsible agricultural systems.

Overall, plant-based proteins provide clear advantages over animal proteins in terms of human health, environmental sustainability, food security, economic inclusivity, and public health safety. Their integration into sustainable food systems is not merely a dietary trend but a structural transformation aligned with global climate goals, nutrition security strategies, and sustainable development frameworks.

Conclusions

Plant-based proteins constitute a central element in the transition toward sustainable, resilient, and nutritionally secure food systems, offering clear environmental and health advantages over animal-derived proteins, including lower greenhouse gas emissions, reduced land and water use, and benefits for cardiovascular and metabolic health. Nevertheless, their large-scale integration remains constrained by interrelated technological limitations in texture, flavor, and functionality, high processing costs, socio-cultural resistance, and insufficient regulatory and policy support. Addressing these challenges requires continued technological innovation, harmonized regulatory frameworks, targeted public policies, and effective consumer education. Despite the narrative nature of the review and data limitations across regions, the evidence underscores that, with coordinated scientific, policy, and societal efforts, plant-based proteins can play a decisive role in enhancing global food security and advancing sustainable food systems.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

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Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Statement on the use of AI

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