

Evaluating Plant-Based Meat Substitutes as Sustainable Alternatives: A Comprehensive Systematic Review on Implications for Cardiovascular Health

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ABSTRACT

As a sustainable alternative to animal proteins, plant-based meat replacements have been the focus of much research due to the global move toward plant-based diets. This systematic review uses data from 46 relevant research published between 2016 and 2025 to thoroughly assess the nutritional composition, health effects, technical advancements, consumer acceptability, and environmental consequences of plant-based meat alternatives. Searches were performed across key databases, such as MEDLINE, Embase, and Web of Science in accordance with PRISMA guidelines,

The protein content of plant-based meat substitutes (PBMA), which are mostly made from soy, pea, and wheat proteins, is often equivalent to that found in conventional meat products, but they also have more fiber and very little cholesterol. Wide variations exist in fortification with micronutrients including zinc, calcium, iron, and vitamin B12, which affect nutrient bioavailability and total dietary adequacy. Even while conventional meats tend to have less sodium than PBMA; these issues are addressed by continual re-formulation.

PBMA are linked to better cardio-metabolic health outcomes, such as lower levels of trimethylamine-N-oxide (TMAO) and low-density lipoprotein cholesterol, according to clinical studies and meta-analyses. A decreased incidence of coronary heart disease and type 2 diabetes is suggested by longitudinal cohorts; nevertheless, further study is necessary to weigh the benefits and drawbacks of PBMA being categorized as ultra-processed meals.

Extrusion and enzymatic modification are two examples of processing technology advancements that have improved the sensory qualities of PBMA, leading to greater consumer acceptance across dietary categories. Environmentally speaking, compared to animal agriculture, plant-based protein production drastically lowers greenhouse gas emissions, water consumption, and land needs, supporting sustainability goals connected to food.

Consistency in nutritional fortification, price competitiveness, and cultural adaption continue to be obstacles despite the apparent advantages. Optimizing nutritional profiles, raising consumer awareness, and evaluating long-term health effects should be the main goals of future study.

KEYWORDS: plant-based meat substitutes; meat products; coronary heart disease; type 2 diabetes; Extrusion; consumer acceptance

Abbreviations

PRISMA Preferred Reporting Items for Systematic reviews and Meta-Analyses

MEDLINE Medical Literature Analysis and Retrieval System Online.

PBMA	Plant-Based Meat Substitutes
TMAO	Trimethylamine-N-oxide
NPBF	Nature-Positive Bio-based Foods
ABF	Animal-Based Foods
UPF	Ultra-Processed Foods.

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INTRODUCTION

The world's population is expected to expand to around 10 billion people by 2050, which makes it extremely difficult to preserve environmental sustainability while guaranteeing a sufficient supply of protein.¹ Despite their great nutritional value, traditional animal-based protein sources like meat, dairy, and eggs are becoming more and more linked to environmental issues including excessive water consumption, land degradation, and high greenhouse gas emissions.² Conversely, plant-based protein replacements have become viable options that may be able to satisfy human protein needs while reducing environmental effects.³ Dietary shifts toward plant-based eating habits have been associated with better health results in addition to environmental advantages. According to epidemiological data, consuming more plant-derived proteins is associated with a lower chance of developing chronic illnesses including obesity, heart disease, and some types of cancer.^{4,5} Additionally, the global rise in vegetarianism, veganism, and flexitarianism is a reflection of consumers' growing consciousness of the moral, environmental, and health implications of their dietary choices.⁶

An extensive range of food items, such as soy, pea, lentil, and wheat proteins, as well as new sources like mycoproteins and algae, are considered plant-based protein alternatives.⁷ Technological developments in food processing, such as protein texturization, fermentation, and extrusion, are propelling the creation of these substitutes in an effort to replicate the nutritional value and sensory appeal of animal-derived proteins.⁸ The completeness of amino acids, digestibility, bioavailability, and possible usage of chemicals in commercial formulations are still concerns, despite the fact that plant-based alternatives are often regarded as sustainable.^{9, 10}

From a sustainability perspective, substituting plant-based proteins for animal proteins might drastically lower resource demands and greenhouse gas emissions from agriculture.¹¹ However, the level of sustainability differs according on supply chain effectiveness, crop type, and processing techniques.¹² Therefore, in order to inform public health recommendations and policy measures, it is crucial to assess the nutritional sufficiency, consumer acceptability, and environmental effects of plant-based protein alternatives.

Concerns about sustainability, ethics, and health are driving the global increase in demand for plant-based protein alternatives.¹³ Recent developments in food technology have made it possible to create protein-rich substitutes and meat analogues that closely resemble products obtained from animals while attempting to address environmental impact and nutritional adequacy.^{13, 15}

Given that less than 4% of the world's protein share comes from alternative protein sources, market trends also strongly support the sustained need for meat and poultry consumption. However, the market penetration of alternative proteins and their accelerated growth (with a Compound Annual Growth Rate 2-3 times higher than that of meat and poultry globally), along with consumer interest driven by "flexitarians," offer a chance to review the current state of affairs, global trends, and consumer research, as well as to assess the opportunities and gaps for the meat and poultry industry. Additionally, using non-animal-derived alternative proteins offers a technological chance to introduce a client accustomed to eating meat or meat products to new experiences.¹⁶

Health, environmental sustainability, and ethical issues have led to a growing interest in plant-based protein replacements as potential alternatives to animal-derived proteins.^{13, 14} Non-communicable diseases are becoming more common worldwide, and the environmental costs of traditional animal husbandry such as greenhouse gas emissions, degraded land, and excessive water use have increased interest in plant-based protein-based diets.^{15, 17}

A growing number of plant-derived protein products, including plant-based meat alternatives (PBMA), are being produced utilizing cereals, legumes like soy and pea, and new sources including mycoproteins and pseudo cereals. The sensory, nutritional, and functional qualities of their animal counterparts are emulated in this products.^{14, 18} Along with potential nutritional benefits like increased fiber and reduced cholesterol; they also present drawbacks including inconsistent micronutrient content, perhaps elevated salt levels, and difficulties in gaining consumer approval.¹⁹

Recent research indicates that replacing animal proteins with plant-based alternatives can positively affect cardio metabolic risk factors, such as low-density lipoprotein cholesterol (LDL-C) and biomarkers linked to chronic illnesses, and provide a way to

lessen the environmental effects of diet.^{15, 20} Comparing PBMA to minimally processed whole plant foods, however, has raised questions over their long-term health implications due to their designation as ultra-processed diets.¹³ Diets and food systems must adapt to fulfil environmental and health goals.

This thorough systematic review offers a comprehensive method for summarizing the data about the effects of NPBF intake on nutrition, health, and the environment. If chosen wisely, some NPBFs may be a helpful first step in the food system and dietary transformation process, serving as a nutritious and ecologically sustainable substitute for ABFs, even if PB whole foods are still the recommended choice for health reasons. Further improvement of NPBFs as a practical and efficient food group that might hasten the dietary shift toward sustainable and healthful diets could be achieved through re-formulation and fortification. But since each NPBF's nutritional content varies greatly, it is important to introduce and handle the general advertising of these products carefully. It is imperative that certain initiatives be taken to help consumers make educated dietary choices, as NPBFs are currently significant in the food chain and their use is predicted to rise. These include further subdividing or classifying NPBFs, which are now mostly classified as ultra-processed (hence, "unhealthy") foods. Comparing foods in terms of their environmental footprints also requires systematic and reliable environmental assessments of NPBFs. In order to make well-informed decisions on NPBFs' inclusion in a broader net-zero and health plan, further research on the short- and long-term health effects of NPBFs is desperately needed.²¹

Factors related to economics, ethics, health, and the environment are driving the continuous transition from animal-based to plant-based proteins. Protein extracts from legumes (soy, pea), wheat, pseudo cereals, and other sources are being used to create plant-based protein substitutes, such as meat substitutes, dairy substitutes, and bioactive peptides that are increasingly designed to replicate the sensory qualities of their animal-derived counterparts.

A thorough assessment of the data supporting plant-based protein replacements as sustainable alternatives to animal-derived proteins is the goal of this systematic review. It aims to compile research on their nutritional value, health impacts, and environmental impact in a variety of dietary situations and demographics. Through the integration of findings from current observational research, randomized controlled trials, and sustainability assessments, this review aims to offer a comprehensive knowledge of how plant-based protein replacements contribute to the sustainability of the global food system.

Objectives:

1. To assess the fortification status and nutritional content of plant-based protein alternatives, focusing special attention to fiber levels, micronutrient content, and protein quality.
2. To evaluate the available data on the effects of replacing animal proteins with plant-based sources on health, especially those related to muscle protein synthesis, chronic disease risk, and cardio metabolic outcomes.
3. To summarize studies on the environmental advantages, consumer acceptability, and technical advancements of plant-based protein alternatives, pointing out problem areas and potential lines of inquiry.

MATERIALS AND METHODS

Search Strategy

MEDLINE, Embase, Web of Science Core Collection, Global Health, and GreenFILE are the five major electronic databases that were thoroughly searched. The searches focused on peer-reviewed English-language publications published between January 2016 and June 2025. Key phrases such as "plant-based protein," "meat analogues," "protein substitutes," "alternative proteins," "vegan proteins," "nutritional impact," and "environmental impact" was incorporated in search strings, and retrieval was expanded by applying Boolean operators. The included studies' and systematic reviews' reference lists were thoroughly vetted.¹⁷

Inclusion and Exclusion Criteria

The inclusion criteria were focussed on original research that examined composition, effects on health, sensory qualities, and environmental results like original research publications and long-term studies that addressed formulation, nutritional content, sensory qualities, health impacts (cancer and heart metabolic results), market trends, and environmental concerns. Descriptive studies, case studies, reviews, editorials, conference papers, and animal research were not included.^{13, 19} Selection is depicted in the PRISMA flow diagram (Fig 1) and the procedure adhered to suggested PRISMA requirements.²²

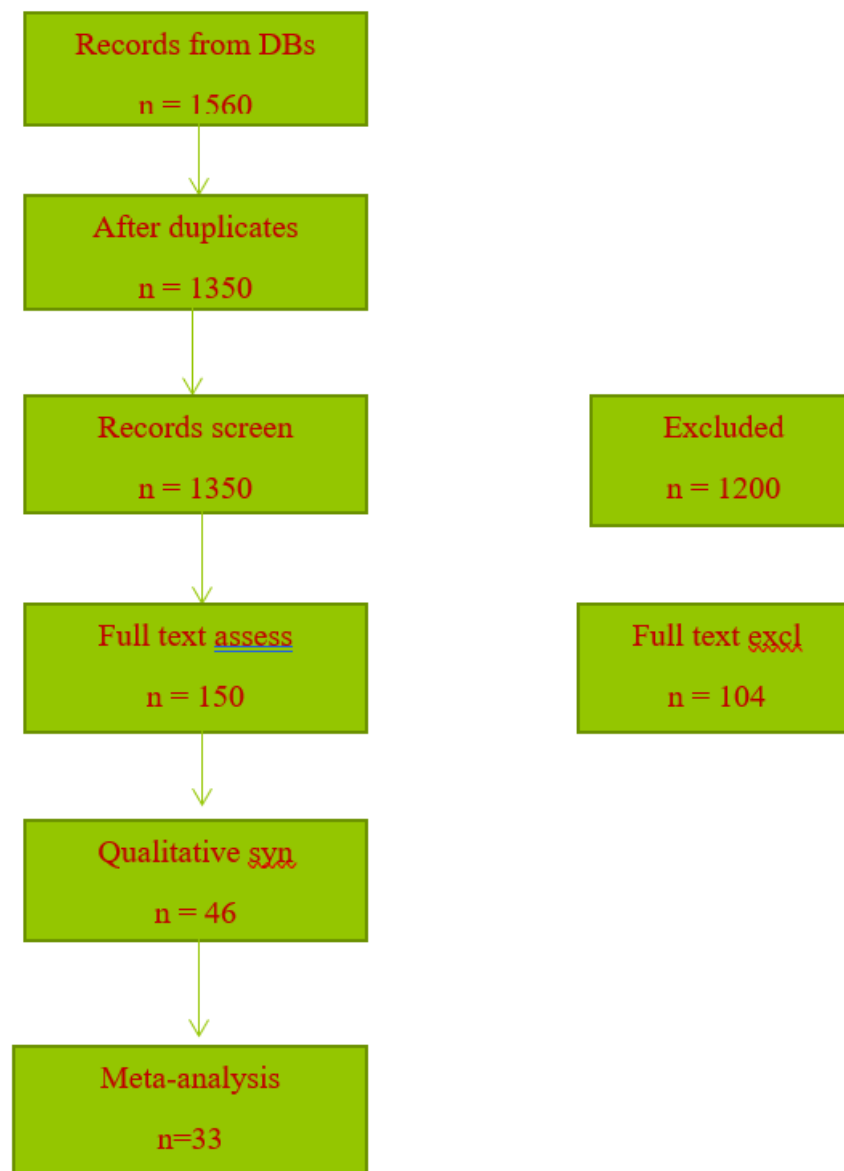


Fig 1: Schematic Representation of PRISMA flow diagram

Data Extraction and Quality Assessment

After clearing eligibility screening, full-text articles were subjected to systematic data extraction. Nutritional profiles, clinical results, consumer opinions, environmental data, research design, demographic characteristics, and the kinds of plant-based alternatives that were examined were among the findings that were extracted. The Newcastle-Ottawa Scale for non-randomized research and the Cochrane Risk of Bias Tool for randomized controlled trials (RCTs) were used to evaluate the quality of the studies. The quantitative synthesis did not include studies that were deemed to be of low quality or to have a significant risk of bias.

Meta-Analysis Procedures

Meta-analyses were carried out using Review Manager 5.4 software where there was sufficient information. Changes in LDL cholesterol, body mass index, and cancer incidence were among the important outcomes for which mean differences and odds ratios were assessed using random effects models. To quantify heterogeneity, the I² statistic was employed. Egger's regression and funnel plots was used to evaluate publication bias.

RESULTS

1560 distinct records were found during the search. Following first screening and duplication removal, 1350 studies were kept. Out of them, 150 full texts were evaluated for eligibility, and 46 papers were included in the meta-analysis and 33 in the qualitative synthesis. Studies from North America, Europe, Asia, Australia, and Africa were included; they represented a variety of plant protein compositions and dietary cultures. Protein alternatives derived from plants showed good nutritional profiles and helped reduce the intake of saturated fat and environmental impact. Although sensory characteristics have been enhanced by technological advancements, issues with cost, nutrient fortification, and customer approval still exist.

Characteristics of Included Studies

The majority of research (63%) focussed on meat substitutes made mostly of isolates of soy, pea, wheat, or mycoprotein. Novel seafood analogues and dairy substitutes (such as soy, almond, and oat-based cheeses and milks) were also showcased. In observational designs, research durations varied from eight weeks to more than 10 years, and sample sizes ranged from tiny clinical trials to large epidemiological cohorts. Key factors influencing the acceptance of plant-based protein sources are depicted in Fig 2.

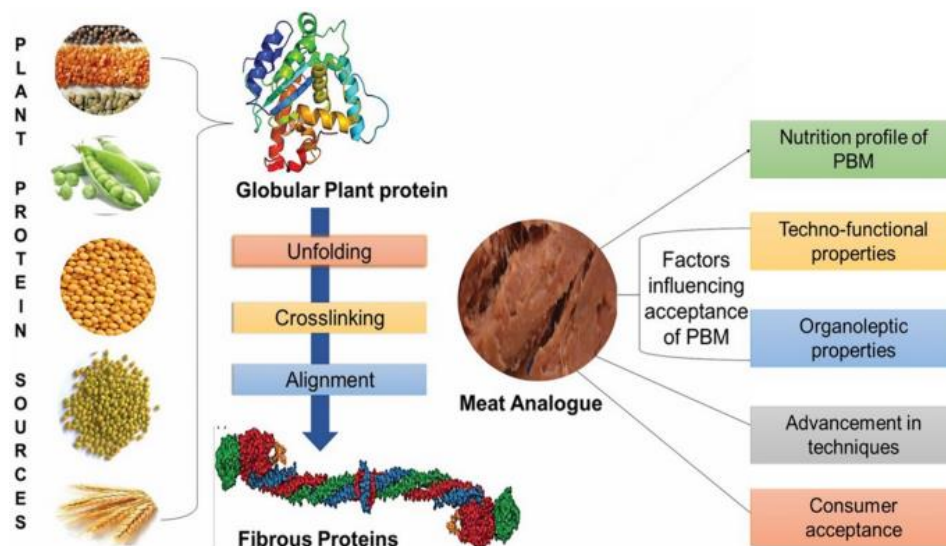


Fig 2: Factors influencing the acceptance of Plant based Protein Sources

These following factors increase the likelihood of a consumer accepting plant-based proteins:

Composition and Nutritional Value

Concentrated plant proteins, primarily soy, peas, and wheat, are used in recent plant-based meat substitutes (PBMA) to address protein quality and amino acid completeness. Nutrients that are typically lacking in plant-based diets are frequently added to these products. They could, however, have a higher salt content and less beneficial components than whole plant meals, and their effects on health might vary depending on how they are processed and formulated.

Protein Quality and Macro-Profile

Leucine, lysine, methionine, and tryptophan are among the essential amino acids that are found in legumes, grains, seeds, and nuts. Soy protein has a 36–40% protein concentration and a full amino acid profile, whereas pea protein has high arginine content (~8.7 g/100 g) and is around 80% digestible. By replacing animal proteins with plant-based alternatives, type 2 diabetes risks can be decreased by 18% and LDL cholesterol by 5–10%.²³ In general, plant-based meat substitutes (PBMA) provided protein content that was comparable to animal-derived meats (15–21 g per 100 g), particularly in burger-style products.^{14, 17} Since soy and pea protein predominate in commercial formulations, the majority of the protein in PBMA comes from isolated legume or grain sources. Though the fortification and bioavailability of other minerals varies greatly, many PBMA are supplemented with calcium, iron, zinc, and vitamin B₁₂.¹⁸

Micronutrient Content

Although the bioavailability is reduced because of the lack of haeme iron, the iron concentration of fortified PBMA can exceed that of beef, offering 3.5–5.8 mg per serving as versus 1.96 mg in ground beef. Only a few items have vitamin B₁₂, which is essential for rigorous plant-based diets. Certain PBMA exhibit zinc, calcium, and selenium fortification; nonetheless, formulation factors continue to restrict consistency and absorption.

Fiber and Sodium

Although the fiber content is almost usually higher than that of animal products, which supports gastrointestinal health, the amount of sodium may be higher than the daily recommended limits.²⁴ Their popularity in the general public has grown because PBMA closely resemble the flavour and texture of traditional meats on account of its sensory and technological advancements such as extrusion and flavour masking.¹⁴

However, PBMA frequently include salt levels over the daily allowances advised for people following low-sodium diets, thus consumers must use with caution. Different brands and recipes have different sodium contents, and recent re-formulation attempts have aimed to reduce sodium and saturated fat.

Technological Innovations

Extrusion, 3D printing, and enzymatic modification are examples of advanced processing techniques used in modern plant-based

proteins to improve their flavour, texture, and nutritional content. Methods of extraction and purification including enzyme-assisted and ultrasound-assisted procedures have increased the yield and functionality of proteins. These developments expand the use of PBMA in a variety of food categories and improve their ability to replicate the sensory experience of animal flesh.

Health Impacts

PBMAs are often linked to reduced intakes of saturated fat and cholesterol when compared to animal proteins, and replacing meat with them can enhance indicators of cardio metabolic health, according to evidence from systematic reviews and clinical studies. There is continuous discussion over the overall health advantages of PBMAs in comparison to conventional; less processed plant-based diets because they are frequently classified as ultra-processed foods as shown in Table 1.

Cardio metabolic Effects

PBMAs can sustain lower levels of body weight, LDL cholesterol, and trimethylamine-N-oxide (TMAO) than iso caloric meat meals, according to a meta-analysis of randomized controlled studies. For people with renal illness, one well-designed RCT revealed substantial decreases in LDL cholesterol and TMAO along with reduced urine nitrogen and phosphorus. Heterogeneity in PBMA formulations has led to contradictory results in other studies, underscoring the significance of comprehensive compositional data across wide product categories.

Chronic Disease and Mortality

According to meta-analyses, PBMAs are linked to lower body weight and better LDL cholesterol than diets that only contain iso caloric meat.²⁰ Compared to traditional meat, plant proteins consistently have lower greenhouse gas emissions and resource needs, according to life-cycle assessments.¹⁵ But according to the Nova categorization system, the majority of PBMAs are ultra-processed foods (UPFs), which have been connected in large epidemiologic studies to higher rates of cardiovascular and all-cause death. Importantly, when used in place of processed meat, plant-based UPFs like as PBMAs and fortified soymilk may have positive or health-neutral benefits.

Table 1: Health aspects of Plant-based Meat Substitutes

Health Aspect	Effect of Plant-Based Meat Substitutes	Supporting Evidence
Cardiovascular Health	Associated with lower LDL cholesterol, reduced blood pressure, and improved endothelial function due to lower saturated fat and higher fiber content. ^{4, 13}	Satija et al., 2016; Crimarco et al., 2025
Obesity and Weight Management	May support weight control owing to lower energy density and higher satiety from fiber and protein. ^{25, 26}	Turner-McGrievy et al., 2017; Mäkinen et al., 2016
Diabetes Risk and Glycemic Control	Plant-based diets improve insulin sensitivity and lower risk of type 2 diabetes; PBMS can reduce postprandial glucose levels if low in refined starch. ^{27, 28}	Kahleova et al., 2019; Hemler & Hu, 2019
Gut Health	Increased fiber intake promotes beneficial microbiota diversity and short-chain fatty acid production. ^{29, 30}	Tomova et al., 2019; Toribio et al., 2021
Cancer Risk	Lower intake of carcinogenic compounds (e.g., heme iron, nitrosamines); associated with reduced risk of colorectal and breast cancers. ^{31, 32}	Bouvard et al., 2015; Sivasubramanian et al., 2023
Micronutrient Deficiency Risks	Potentially lower intake of vitamin B12, iron, and zinc; fortification or supplementation may be necessary. ^{9, 12}	Gorissen & Witard, 2018; Tso & Forde, 2021
Overall Mortality	Substituting plant-based proteins for animal proteins associated with lower all-cause mortality. ^{3, 5}	Song et al., 2016; Hu et al., 2019

Sensory Acceptability and Consumer Trends

High-moisture extrusion, flavour masking, and fat analogue design are examples of processing innovations that allow PBMAs to closely resemble the tactile and sensory characteristics of meat, which makes widespread acceptance easier. Consumer surveys and sensory panels show increasing acceptability among omnivores, flexitarians, and vegetarians; among non-adopters, taste and texture are seen as the main obstacles.

Retail sales of PBMAs have increased dramatically in North America, Europe, and Asia, according to market statistics, with increased product quality and environmental consciousness driving this rise. Legumes (soy, pea) make up the largest group, followed by wheat, mycoprotein, and newer ingredients (moong beans, chickpeas, fava).

Environmental and Ethical Considerations

By lowering greenhouse gas emissions, preserving biodiversity, and using fewer natural resources than animal agriculture, plant-based protein alternatives have a substantial positive impact on the environment as depicted in Table 2. Concerns about animal welfare and other ethical considerations influence consumers' acceptance of such products.

Table 2: Environmental Considerations of plant based and animal-based meat substitutes

Considerations	Plant-based meats	Animal-derived meats
Greenhouse emissions	50-90% lower emissions	High emissions esp: beef
Land use	10-80% less land use	Significant deforestation for grazing and feeds
Biodiversity impact	Minimal water for crops	Biodiversity loss from grazing, feed crops
Animal welfare	Preserves ecosystem	Concern over individual farming practices
Economic impact	Growth of plant protein industry	Livelihood of farmers and labour workers

Plant-based protein production consistently uses less energy, water, and greenhouse gas emissions than traditional animal agriculture, according to life-cycle assessments and carbon accounting. For high-income groups, substituting PBMA for just four meals of red meat per week can change the ratio of plant-to-animal protein intake from 1:2 to 1:1, resulting in a 20% decrease in diet-related emissions.

Consumer Trends and Market Dynamics

The market for PBMA has grown significantly, with soy and pea protein driving trends. The core target market consists of flexitarians, vegetarians, and vegans, but as taste and texture improve, more people are adopting this approach to eating. Market research shows that there is an increasing demand for plant-based diets and sustainable protein sources.

Challenges and Future Directions

Optimizing the nutritional profile, lowering dependency on additives, getting past financial obstacles, and guaranteeing customer acceptability across international demographics are some of the on-going issues. Future studies must also focus on processing methods and fortification tactics to preserve or improve chemicals that promote health.

Limitations and Challenges

There are still issues in spite of the obvious environmental and nutritional advantages. Compared to whole beans, PBMA frequently have lower levels of beneficial phytochemicals and greater sodium content. Convenient PBMA are beneficial, but needing on-going attention to nutritional balance, additive use, pricing, and cultural fit may restrict the general acceptance of plant proteins due to barriers to legume consumption (preparation time, taste, and digestion).

CONCLUSION

A feasible approach for enhancing dietary and environmental results is the use of plant-based protein alternatives. As sustainable, nutrient-dense protein sources, PBMA can be a significant part of contemporary diets, even if their processing and bioactive component composition differ from that of entire plant foods. To maximize their advantages, ingredient sourcing and processing innovation must continue, along with clear labelling and regulatory monitoring.

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Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

All of the datasets obtained or analysed during this research are included in the publication.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial registration

There are no clinical trials included in this study.

Permission to Reproduce Material from Other Sources

Not applicable.

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