

Review

## Food Biodiversity Loss, Climate Change, and Malnutrition: Implications for Sustainable and Healthy Diets

Israel Rios-Castillo <sup>1,2,\*</sup>, Leslie Landaeta-Díaz <sup>3</sup>, Karla Santos-Guzmán <sup>1</sup>, Laura Merelez-Ceuppens <sup>1,4</sup>, Alex Brito <sup>5</sup>

1. Food and Agriculture Organization of the United Nations (FAO), Subregional Office for Mesoamerica, Panama, Panama; E-Mails: [israel.rios@fao.org](mailto:israel.rios@fao.org); [santosguzmankarla@gmail.com](mailto:santosguzmankarla@gmail.com); [lauramereles@qui.una.py](mailto:lauramereles@qui.una.py)
2. Nutrition School, University of Panama, Panama, Panama
3. Nutrition School, University of the Americas, Santiago, Chile; E-Mail: [llandaeta@udla.cl](mailto:llandaeta@udla.cl)
4. Faculty of Chemical Science, National University of Asuncion, Biodiversity, Food and Health Group, Asuncion, Paraguay
5. Independent Researcher, Santiago, Chile; E-Mail: [abrito@micronutriomics.com](mailto:abrito@micronutriomics.com)

\* **Correspondence:** Israel Rios-Castillo; E-Mail: [israel.rios@fao.org](mailto:israel.rios@fao.org)

**Academic Editor:** Korach-André Marion

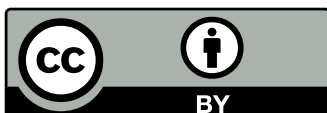
**Special Issue:** [Obesity, Sustainable Nutrition and Health](#)

*Recent Progress in Nutrition*  
2026, volume 6, issue 3  
doi:10.21926/rpn.2603014

**Received:** January 01, 2026  
**Accepted:** July 02, 2026  
**Published:** July 09, 2026

### Abstract

Climate change, biodiversity loss, and malnutrition are interconnected global challenges that increasingly threaten food security, healthy diets, and environmental sustainability. Current dietary patterns characterized by high consumption of ultra-processed foods have negative environmental impacts, including increased greenhouse gas emissions, water and land use, malnutrition, and biodiversity loss. Sustainable and healthy diets that emphasize plant-based foods, minimize food waste, and promote ecosystem conservation can substantially reduce the environmental footprint of food systems, mitigate climate change, and help address the global obesity epidemic. The biodiversity-climate-nutrition nexus highlights the central role of food systems in supporting ecosystem functions, providing nutritious options, and mitigating



© 2026 by the author. This is an open access article distributed under the conditions of the [Creative Commons by Attribution License](#), which permits unrestricted use, distribution, and reproduction in any medium or format, provided the original work is correctly cited.

the effects of climate change. Strategies to promote sustainable and healthy diets include public nutrition education, government policies, economic incentives, and technological innovation. Leveraging neglected and underutilized species, valorizing food by-products, and adopting climate-resilient agricultural practices can enhance biodiversity, improve nutrition, and build resilience to climate change. Critical research and policy gaps include better incorporating biodiversity data, examining trade impacts, and promoting multidisciplinary approaches. Coordinated actions among stakeholders are needed to develop integrated solutions addressing the interconnected challenges of biodiversity, climate change, and nutrition for long-term food security and environmental sustainability.

### **Keywords**

Nutrition; climate change; food security; sustainability; healthy diets; sustainable diets

## **1. Introduction**

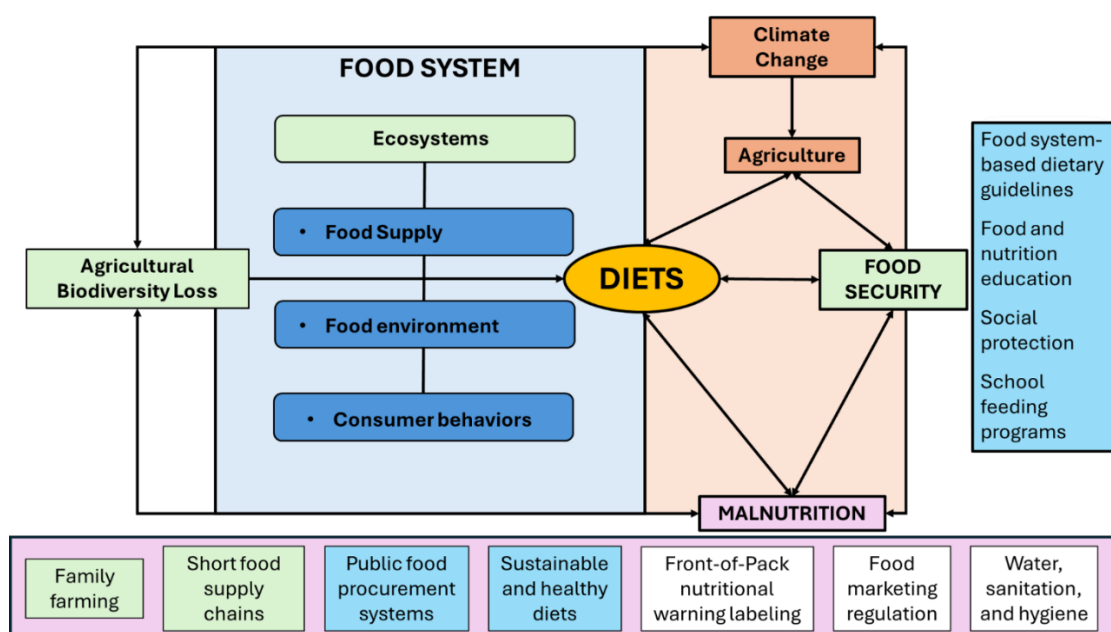
Inequality in access to affordable, healthy and sustainable diets is a major global challenge affecting all regions of the world [1]. Despite the critical role of diets in promoting human health and environmental sustainability, an estimated 2.6 billion people were unable to afford a healthy diet in 2024, while 2.3 billion experienced moderate or severe food insecurity [2, 3]. This issue is further intensified by climate change [3], the loss of food biodiversity [4], and malnutrition [5]. Healthy diets are characterized by eating patterns that promote individual health and well-being, exert minimal environmental impact, and are accessible, affordable, safe, and equitable [6]. Healthy diets also respect cultural relevance [7]. Moreover, healthy diets must meet four essential principles: (i) adequacy, (ii) balance, (iii) diversity, and (iv) moderation [8]. Despite their importance, 3.1 billion people worldwide lack sufficient resources to access healthy diets [2].

Poor diet quality, characteristic of Western dietary patterns [9], is associated with the difficult situation of overweight, obesity and non-communicable diseases (NCD) [10]. These dietary patterns contain a large amount of ultra-processed foods (UPF) with excessive content of sugar, fat, and salt [11, 12]. UPF are industrial formulations made from substances derived from foods or synthesized from other organic sources [13]. The high consumption of UPF poses a challenge to human health because they have poor nutritional quality, are hyperpalatable, attractive, and sometimes even quasi-addictive, have a long shelf life, and are ready to eat, requiring little or no culinary preparation [14]. High consumption of UPF has been linked to the development of obesity and NCD [15]. Additionally, UPF-based diets not only affect human health but also negatively impact the environment [16]. UPF are mass-produced and consumed due to their high palatability, promoted by aggressive marketing strategies that require many resources in their development, and increase plastic and other packaging waste that ends up polluting the environment [17, 18].

Therefore, understanding the impact of dietary patterns on sustainability is essential for designing public actions and programs aimed at combating all forms of malnutrition and food insecurity, as well as addressing the challenges posed by climate change [19-21]. On the contrary, a diet based on fresh foods, such as fruits, vegetables, greens, legumes, nuts, fresh fish and seafood, among others, not only promotes human health but also has a lower carbon and water footprint,

resulting in a reduced environmental impact [22]. Furthermore, a better environmental impact can be achieved if dietary patterns are linked to local consumption strategies through short supply chains at community fairs or through local public procurement systems, such as school feeding programs [23].

A recent review reported a link between urban systems and water and carbon footprints, highlighting that increased urbanization of territories raises water consumption, results in high CO<sub>2</sub> emissions, and hurts the environment and climate [24]. Another review that included 41 articles evaluated the water footprint of diets and concluded that shifting dietary patterns towards more sustainable models would reduce the planet’s water footprint [25]. Changes in dietary patterns, largely mediated by the trade and advertising of UPF, as well as rapid urbanization and globalization, have enormous consequences for human and planetary health [26]. Despite this, few reviews have focused on describing the relationship between healthy, sustainable activities and high UPF consumption. Therefore, the present review aims to analyze the interconnections among loss of food biodiversity, climate change and malnutrition, focusing on the promotion of sustainable and healthy diets as a fundamental strategy to address contemporary challenges in food security, nutrition, health, and environmental sustainability. To facilitate understanding of these complex, interrelated pathways, Figure 1 presents the conceptual framework that guided this review. The framework illustrates the bidirectional relationships among climate change, biodiversity loss, malnutrition, dietary patterns, and food systems, highlighting the central role of healthy and sustainable diets as a potential pathway to improve both human and planetary health. The following sections examine each of these interactions in greater detail and outline strategies based on a food systems approach to improve sustainability and nutrition. Examples such as Chile’s front-of-pack labeling and Brazil’s school feeding programs are cited.



**Figure 1** Conceptual framework of the food systems nexus illustrating the critical interrelation between agriculture biodiversity loss, climate change and malnutrition, and identifying strategic public policy interventions to mitigate negative impacts. Key public policy to address these challenges are highlighted in the boxes on the right and bottom of the figure.

## **2. Methods**

This study was conducted as a scoping review. A structured evidence-mapping approach was used to identify, organize, and synthesize the available literature on the relationships among food biodiversity loss, climate change, malnutrition, and sustainable diets. The review encompassed peer-reviewed scientific literature and selected national or international technical reports published between January 2015 and August 2025 in English, Spanish, or Portuguese. The literature search was conducted using the bibliographic databases Scopus, Web of Science (WOS), PubMed, and SciELO. Search terms were selected according to the main themes addressed in the review. They included combinations of keywords such as biodiversity, food biodiversity, climate change, nutrition, malnutrition, food security, sustainable diets, healthy diets, food systems, agrifood systems, public policies, systems approach, food industry, processed foods, and ultra-processed foods, among others. Equivalent terms were used in English, Spanish, and Portuguese to maximize the retrieval of relevant literature. The search strategy combined controlled vocabulary and free-text terms using Boolean operators (AND/OR). An example of the search strategy used was: (“biodiversity” OR “food biodiversity”) AND (“climate change”) AND (“nutrition” OR “malnutrition” OR “food security”) AND (“sustainable diets” OR “healthy diets” OR “food systems” OR “ultra-processed foods”). The search syntax was adapted as necessary for each database. In addition, grey literature, including reports, technical documents, and case studies from international organizations, was reviewed to provide contextual information and examples of policies, programs, and interventions related to biodiversity, climate change, and nutrition. Studies and reports addressing the relationships among biodiversity, food systems, diets, climate change, food security, and nutrition were included. Documents not directly related to the objectives of the review, duplicate records, or lacking sufficient information on these topics were excluded. For country examples and policy experiences, priority was given to cases reporting concrete actions, outcomes, or documented impacts.

The identified records were screened based on title, abstract, and full-text review according to predefined eligibility criteria and their relevance to the objectives of the study. The selected literature was analyzed through evidence matrices developed using Microsoft Excel for Microsoft 365 (Microsoft Corp., Redmond, WA, USA), which systematically compiled key information, including publication year, country, study design, objectives, main findings, and conclusions. Studies were subsequently grouped into thematic categories corresponding to the main areas addressed in the review, including ultra-processed foods, sustainable diets, climate change, biodiversity, food security, and nutrition. The evidence was synthesized narratively to identify recurring themes, knowledge gaps, emerging trends, and policy implications related to the promotion of healthy and sustainable food systems.

## **3. Impact of UPF on Dietary Patterns and Sustainability**

The shift from traditional diets to high consumption of UPF has had a significant impact on the planet’s sustainability [14]. UPF are typically produced in a central location and then transported worldwide [27]. Initially, UPF were predominantly produced and consumed in high-income countries [28]. However, since the 1990s, major UPF corporations have expanded their geographical reach to low- and middle-income countries (LMIC) [29]. By 2019, the global UPF industry was 4.7 times larger in market capitalization, twice as large in assets, and 1.6 times larger in revenue than the global food production and food processing industry [29].

Social media, cinema, television, sports events, and radio are among the primary channels through which the food industry implements its advertising strategies, including price promotions to create demand, generate brand loyalty, and create new eating behaviors around UPF [30]. Globally, but especially in South America, food companies add micronutrients to UPF to make health claims on their packaging and labels [31]. Additionally, since 2000, there has been a trend in the food industry to include animal welfare and environmental ethics claims in new formulations [29]. However, substantial efforts are underway in LAC to counter the power of these industries [32]. Chile, for example, has been a pioneer by linking its front-of-package nutritional warning labeling policy with restrictions on UPF marketing, removing attractive characters from package designs and advertising of foods labeled with warning seals “high in” from children’s television, and banning their marketing within schools [30].

Each process within UPF production involves various negative environmental impacts, including significant land use, soil degradation, herbicide use, eutrophication, greenhouse gas (GHG) emissions, intensive water resource use, loss of food biodiversity, energy use due to intensive processing and packaging, and plastic pollution from packaging dependency [27, 30, 31]. These impacts occur throughout the entire supply chain [27].

UPF is one of the largest contributors to diet-related water use, with no major differences in water use between animal- and plant-based UPF [27]. However, there are other differentiated environmental impacts, for example, animal-based UPF are the main drivers of land use, GHG emissions, and nitrogen use, while plant-based products drive phosphorus use and energy inputs [27].

Recent studies indicate that UPF account for 17%-39% of total diet-related energy [27]. Additionally, UPFs are among the largest contributors to diet-related GHG emissions compared to other food groups [27]. The environmental degradation caused by UPF is significant due to the intrinsic ecological importance of the areas affected by loss of food biodiversity, the avoidable nature of these impacts given that UPF are discretionary, non-essential products in human diets, and the large quantity of UPF consumed worldwide [27].

UPF consumption is high in rich countries, a trend also replicated in LMIC over the past five decades [30]. However, within countries, consumption is not uniform. In Brazil, for example, UPF consumption is higher among women, adolescents, Caucasians, individuals with higher incomes and educational levels, and urban residents [33]. As incomes rise, workers consume more UPF to save time in food preparation [30]. Additionally, economically disadvantaged populations in countries are increasingly consuming UPF due to its low cost and availability at multiple points of sale [30]. These challenges underscore the need for dietary patterns that support both human and environmental health. Consequently, sustainable and healthy diets emerge as a key strategy to address the interconnected challenges of malnutrition, climate change [34, 35], and biodiversity loss.

#### **4. Sustainable Diets and Climate Change**

While various strategies for climate adaptation are proposed at policy, governance, and individual demand levels, consumers can also be agents of change, establishing a culture of sustainability in dietary habits [36]. Sustainable diets are defined as those that have a low environmental impact, contribute to food and nutritional security, are accessible and affordable for all, protect and respect biodiversity and ecosystems, and are culturally acceptable [7]. Among the

principles governing sustainable diets, reducing meat and animal-source foods stands out. Diets high in animal products, especially red meat and dairy, have a significant carbon footprint [36]. Reducing consumption of these products and replacing them with plant-based protein sources can considerably decrease GHG emissions [37]. Sustainable diets emphasize increasing the consumption of plant-based foods, such as fruits, vegetables, legumes, nuts, and whole grains, which generally have a lower environmental impact and benefit personal health [38]. Another relevant principle is minimizing food waste, as about one-third of all food produced globally is lost or wasted, making waste reduction essential for improving food sustainability [39, 40]. Choosing sustainably produced foods is important for ecosystem conservation, as it involves selecting foods grown using agricultural practices that preserve natural resources and biodiversity, thereby generating fewer negative impacts and being more environmentally friendly. By adhering to these principles, sustainable diets aim to nourish the population while preserving the planet's resources for future generations, contributing to individual health and addressing global environmental challenges [41].

Current diets have a significant environmental impact, with food systems responsible for up to 30% of global GHG emissions [42]. Plant-based diets can potentially reduce food-related emissions by 50%, while also addressing other environmental concerns [43]. Animal products, particularly beef, require substantially more land and water than plant-based foods [44]. For instance, producing 1 kg of beef may consume up to 15,000 liters of water, whereas the same amount of wheat needs only about 1,500 liters [45]. Moreover, intensive agricultural practices and the expansion of croplands for animal feed production have led to deforestation and habitat loss, severely impacting biodiversity [46].

Strategies to promote the adoption of sustainable diets include public education and awareness campaigns, government policies and regulations, economic incentives, and technological innovation [47, 48]. These approaches aim to inform the population about the environmental and health benefits of sustainable eating patterns, implement actions that promote sustainable food production and consumption [49, 50], offer subsidies and tax benefits for sustainable food products [51-53], and promote research and development of sustainable food technologies [54]. Examples of sustainable diets include the Mediterranean diet, rich in fruits, vegetables, legumes, whole grains, and olive oil, which is recognized for its low environmental impact and health benefits [55]. Another example is the planetary diet, proposed by the EAT-Lancet Commission, which balances human health and environmental sustainability by recommending increased consumption of plant-based foods and a significant reduction in meat and dairy intake [22]. Adopting more sustainable eating habits can substantially reduce GHG emissions, improve public health, and protect natural resources [56]. Governments, the food industry, consumers, and cooperation agencies need to collaborate in promoting and implementing sustainable food practices based on healthy agri-food systems and dietary patterns [57-59].

## **5. Biodiversity, Climate Change, and Nutrition**

The interrelationship between climate change, loss of food biodiversity and malnutrition is complex and multifaceted, encompassing aspects of human health, environmental sustainability, and ecosystem resilience [46, 60]. Biodiversity is the foundation of the nexus between climate, food, water, and health, and extends its positive impacts to energy and transportation sectors [61]. This intricate interplay highlights the important role of biodiversity in supporting sustainable

development and mitigating the adverse effects of climate change, thereby enhancing the overall resilience of ecosystems and human societies [62].

The challenge lies in understanding how climate change, loss of food biodiversity and malnutrition are interconnected and how their interactions affect both the environment and global food security and nutrition, particularly in local contexts [63]. By examining these concepts separately, we can identify a common denominator, foods. Foods are central when considering factors that impact biodiversity loss, dietary nutrient deficiencies, and climate-related effects on food security and nutrition [60]. Intensive crop expansion threatens biodiversity, nutrient deficiencies are linked to monotonous diets, and extreme climate events in vulnerable areas directly and indirectly affect food security by impacting food availability and access, respectively [64]. Moreover, after transportation, food production has the second-largest negative impact on biodiversity [65].

Biodiversity refers to the variety of life in all its forms and plays an important role in the stability and functionality of food systems and ecosystems [62]. It supports key functions such as pollination, pest control, soil fertility, and water regulation, which are essential for food production [66, 67]. Agricultural biodiversity, including crops and livestock varieties, contributes to food security by providing a range of nutrients and enhancing resilience against pests and diseases [68]. However, this biodiversity has significantly declined throughout human history. Of approximately 30,000 edible plant species, only 6,000-7,000 were historically cultivated for food, and today we commercially use just 170 crops [69].

Climate change impacts both natural and human systems, directly affecting agriculture, food production, and food security through rising temperatures, altered precipitation patterns, and extreme weather events that reduce crop yields and livestock productivity [70]. Extreme events and prolonged droughts can lead to food shortages, price increases, and malnutrition, disproportionately affecting the most vulnerable communities [64, 71]. A healthy diet relies on the availability and access to a variety of sustainable and nutritious foods [5, 72]. However, excessive reliance on a few staple crops is a major cause of poor dietary diversity and malnutrition [73].

Current research on the nexus among biodiversity loss, climate change, and malnutrition suggests the holistic policies and management options [74]. Unsustainable agricultural methods, which produce foods that account for more than 40% of the global dietary energy intake (such as rice, wheat, and maize), lead to soil degradation, biodiversity loss, and GHG emissions. These practices adversely affect the availability of nutritious foods, necessitating urgent attention and the implementation of strategies to mitigate their impacts on biodiversity and climate change [60].

Human activity, particularly food consumption, is a significant contributor to GHG emissions [75]. This environmental impact is expected to worsen, with global waste generation projected to reach a staggering 3.4 billion tons by 2050, accompanied by a substantial carbon footprint [76]. The collection, transportation, and treatment of household waste are global issues [68]. Approximately 14% of the world's food is wasted post-harvest, and an additional 17% is wasted in homes and retail establishments, resulting in one-third of the annual global food production being classified as food waste, which could feed 1.26 billion undernourished people [77]. Inadequate management and poor disposal of food waste can have severe environmental consequences [76], releasing an estimated 3.3 billion tons of CO<sub>2</sub> equivalent annually, accounting for 8% of all human-induced GHG emissions [78]. Agricultural biodiversity loss reduces ecosystem resilience to climate change, which

in turn exacerbates biodiversity loss [79]. However, in some regions, changing climatic conditions may positively influence biodiversity vulnerability and food production [74].

Climate change substantially impacts food production quality and quantity, affecting human nutrition and agricultural diversification. This can lead to less varied diets and nutritional deficiencies [80]. Climate change, maternal and child malnutrition, and obesity are now considered a global syndemic [4]. These three interacting pandemics require urgent, interconnected solutions [81]. Emerging scientific evidence suggests climate change will alter food production and cause yield losses [82]. These interrelationships have been evaluated in various studies [79, 83-86]. Geyik et al. [85] estimated the GHG emissions other than CO<sub>2</sub> resulting from closing the global nutrient gap in diets for energy, protein, iron, zinc, vitamin A, vitamin B12, and folate in five climate-friendly intervention scenarios for 2030. According to the same authors, improving agricultural and livestock productivity and reducing food loss and waste can close the nutrient gap with up to 42% fewer emissions compared to usual supply patterns with a persistent nutrient gap [85].

Increasing the production and trade of vegetables, eggs, roots, and tubers can effectively address nutrient deficiencies while minimizing emissions in most countries. This could lead to a  $\geq 23\%$  increase in total caloric production by 2030 compared to 2015 [85]. A study by Kim et al. [74] examined the relationship between biodiversity and various nexus elements, revealing that out of 354 identified links, 53% were negative, 29% were positive, and 18% exhibited both positive and negative influences.

The primary types of negative environmental impacts can be categorized into four main areas; (i) land and water use changes; (ii) land and water degradation; (iii) climate change; and (iv) direct species mortality due to infrastructure collisions [87]. These impacts are often interconnected and can have far-reaching consequences for ecosystems and biodiversity. While biodiversity generally has positive effects on the environment, there are limited instances where it can negatively impact other elements of the ecosystem, primarily through the introduction of invasive species and the spread of vector-borne diseases [74]. These negative effects, however, are typically the result of human-induced disturbances to natural ecosystems rather than inherent problems with biodiversity itself.

Given that biodiversity supports essential functions and services for agriculture, a greater consideration of its role in the food system is highly relevant [72]. An enabling environment for agricultural diversification, grounded in a food system-based approach is essential to achieve zero hunger and promote sustainable food production, processing, and consumption [73]. This includes leveraging a wide range of neglected and underutilized species that were historically popular but have lost their status within agricultural systems [88]. These crops often possess adaptability, nutritional attributes, and socioeconomic potential, making them suitable for production [89].

The valorization of food and by-products or food bio-residues is an innovative approach to reduce waste and create economic opportunities through the production of value-added goods [90]. Collaboration between scientists, policymakers, farmers, and communities is relevant to developing sustainable solutions that benefit both the planet and its inhabitants. Robust research is required to fill knowledge gaps and address the shortcomings of most identified species of interest, as concrete scientific data is not widely available globally [91]. Ongoing strategies allow for adapting crops to climate change, including methods to match crop varieties to current and anticipated environments, optimizing breeding goals, management practices, and crop microbiomes to improve yield and sustainable production, as well as the domestication of wild crops and recent technological

innovations like rapid breeding, selection, and genome editing to enhance the environmental resilience of existing crop varieties or develop new crops [92].

Sustainable agricultural practices are the path to a positive interrelationship among biodiversity conservation, climate change adaptation, and improving current rates of food insecurity and malnutrition [93]. A recent study explored the climate-biodiversity-health nexus in food systems in Canada, identifying the relationships between food systems, climate change, biodiversity, and health issues and strategies in the region, including a system map that can be used as a framework to elucidate how various strategies align with or conflict with different imperatives of the nexus and can be used to support integrated community sustainability planning and policymaking efforts [68].

Some critical research and policy gaps are highlighted, including the need to better incorporate biodiversity into large-scale studies, improve the availability, access, and coverage of biodiversity data, examine the interactions between biodiversity and climate change, and consider trade as a facilitator of biodiversity and climate impacts, with additional biodiversity measures in impact assessments. Lastly, it is essential to promote and enable transdisciplinary and systems-based approaches in biodiversity studies. At the policy level, there is a need for greater recognition of international trade within biodiversity goals, targets, and policies [79].

The growing complexity of food systems challenges highlights the need to strengthen a systems approach across sectors. Although biodiversity loss, climate change, food insecurity, and malnutrition are deeply interconnected, they are often addressed through sector-specific perspectives and institutional mandates. For example, the health sector may prioritize the prevention of obesity and diet-related non-communicable diseases. In contrast, the agricultural sector may focus on ensuring food production and availability, and environmental institutions may emphasize climate change mitigation and biodiversity conservation. Although these perspectives are all legitimate, they may result in fragmented or poorly coordinated interventions when implemented in isolation. Recognizing the interdependencies among these objectives is therefore essential. Effective responses require institutional spaces that facilitate dialogue, coordination, and consensus-building among stakeholders to identify solutions that simultaneously address sectoral priorities and shared societal goals. In this context, global, regional, and national food security and nutrition governance mechanisms can play a critical role in promoting policy coherence and advancing a systems approach to food systems transformation.

## **6. Conclusions**

The findings of this review highlight that addressing the global syndemic of climate change, biodiversity loss, and malnutrition requires a systems-based approach to agrifood systems. The bidirectional relationship between agricultural biodiversity loss and climate change affects ecosystems and destabilizes food supply systems, food environments, and consumer behaviors, ultimately influencing food security and nutrition. Malnutrition should therefore be understood not as an isolated health outcome, but rather the result of environmental and systemic drivers that must be mitigated through coordinated policy interventions across the entire food system. As illustrated in Figure 1, healthy and sustainable diets constitute the key nexus linking food systems, food security, climate change, biodiversity conservation, and nutrition outcomes, highlighting the need for integrated policy actions across these interconnected domains.

Addressing food security and nutrition requires considering the complex interconnections among biodiversity loss, climate change, and the current malnutrition pandemic. This review highlights the importance of interdisciplinary approaches that account for these relationships to develop more sustainable food systems. As current dietary patterns rely heavily on UPF, this has a profound impact on environmental sustainability. GHG emissions, water and land depletion, and biodiversity loss from food production and consumption highlight the need for more sustainable and healthy food systems. Therefore, achieving this transition will require concerted and clearly defined roles across stakeholders: governments should strengthen regulatory and policy frameworks; the food industry should foster healthier and more sustainable food production and marketing practices; consumers should be empowered to make informed dietary choices; and researchers should generate the multidisciplinary evidence needed to guide effective decision-making. Achieving these objectives will require strengthening multisectoral governance mechanisms that facilitate dialogue and coordination across health, agriculture, environment, and food system actors within a common systems approach. Only through coordinated and integrated action across these sectors can food systems simultaneously advance human health, planetary sustainability, and socioeconomic resilience.

Conserving food biodiversity is relevant for ensuring long-term food security and nutrition. The link between these elements emphasizes the need to protect and promote genetic diversity in healthy food production. Concerted action among key food system stakeholders is required to develop sustainable solutions addressing the interrelated challenges of biodiversity, climate change, and nutrition. Policies and normative frameworks promoting biodiversity conservation, climate change mitigation, and sustainable agricultural technology innovation are essential.

Critical research and policy gaps include better incorporating biodiversity into studies, improving data availability, considering international trade, and promoting multidisciplinary approaches. This highlights the importance of developing more integrative strategies that address the links among biodiversity, climate change, and nutrition, as well as of understanding the interconnections among all components of the food system through a system-based approach. Ultimately, healthy and sustainable diets should be viewed not only as a strategy to mitigate climate change and biodiversity loss, but also as an investment in human health and resilient food systems. Their promotion can simultaneously help reduce obesity and diet-related non-communicable diseases, improve food security and nutrition, supporting local food economies, and strengthen the sustainability of agrifood systems. This convergence of environmental, health, and socioeconomic benefits reinforces the need for coordinated actions at global, national, and local levels to accelerate the transition towards more sustainable food systems.

## **Acknowledgments**

Authors acknowledge FAO headquarters colleagues for their valuable comments and contributions, in special to Ms. Nancy Aburto, Ms. Ana Islas and Mr. Israel Klug from Food System and Nutrition Division.

## Author Contributions

Israel Rios-Castillo and Leslie Landaeta-Díaz: Conceptualization, writing original draft, review and editing. Karla Santos, Laura Merelez and Alex Brito: writing, review and editing. All authors have read and approved the published version of the manuscript.

## Funding

This research was funded by FAO Mesoamerica, Technical Cooperation Project number TCP/SLM/4001.

## Competing Interests

Authors declare no conflicts of interest.

## AI-Assisted Technologies Statement

Artificial intelligence (AI) tools were used solely for basic grammar correction and language refinement in the preparation of this manuscript. Specifically, Microsoft Copilot version from the Microsoft 365 suite (Microsoft Corporation, Redmond, WA, USA) was employed to improve the readability and linguistic clarity of the English text. All scientific content, data interpretation, and conclusions were developed independently by the authors. The authors have thoroughly reviewed and edited the AI-assisted text to ensure its accuracy and accept full responsibility for the content of the manuscript.

## References

1. FAO, IFAD, UNICEF, WFP, WHO, ESCWA. Near East and North Africa – Regional Overview of Food Security and Nutrition 2024: Financing the Transformation of Agrifood Systems [Internet]. FAO, IFAD, UNICEF, WFP, WHO, ESCWA; 2024. Available from: <https://openknowledge.fao.org/items/872c4b81-d90b-42b2-9ecb-85b5f165c880>.
2. FAO, IFAD, UNICEF, WFP, WHO. The State of Food Security and Nutrition in the World 2025 – Addressing high food price inflation for food security and nutrition [Internet]. FAO, IFAD, UNICEF, WFP, WHO; 2025. Available from: <https://openknowledge.fao.org/items/4b1f7d26-267d-4a81-aed4-4f9de4d93f85>.
3. Godfray HC, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, et al. Food security: The challenge of feeding 9 billion people. *Science*. 2010; 327: 812-818.
4. Tscharntke T, Clough Y, Wanger TC, Jackson L, Motzke I, Perfecto I, et al. Global food security, biodiversity conservation and the future of agricultural intensification. *Biol Conserv*. 2012; 151: 53-59.
5. Swinburn BA, Kraak VI, Allender S, Atkins VJ, Baker PI, Bogard JR, et al. The global syndemic of obesity, undernutrition, and climate change: The lancet commission report. *Lancet*. 2019; 393: 791-846.
6. Fanzo J, Swartz H. Attaining a healthy and sustainable diet. In: *Sustainable diets: Linking nutrition and food systems*. Wallingford, UK: CABI; 2019. pp. 99-112.

7. FAO, WHO. Sustainable healthy diets – Guiding principles [Internet]. FAO, WHO; 2019. Available from: <https://openknowledge.fao.org/items/9bc01348-eb71-4041-96d8-bf149844aaf8>.
8. Seligman HK, Levi R, Adebisi VO, Coleman-Jensen A, Guthrie JF, Frongillo EA. Assessing and monitoring nutrition security to promote healthy dietary intake and outcomes in the United States. *Annu Rev Nutr.* 2023; 43: 409-429.
9. Cordain L, Eaton SB, Sebastian A, Mann N, Lindeberg S, Watkins BA, et al. Origins and evolution of the Western diet: Health implications for the 21st century. *Am J Clin Nutr.* 2005; 81: 341-354.
10. Fung TT, Rimm EB, Spiegelman D, Rifai N, Tofler GH, Willett WC, et al. Association between dietary patterns and plasma biomarkers of obesity and cardiovascular disease risk. *Am J Clin Nutr.* 2001; 73: 61-67.
11. Monteiro CA, Cannon G, Moubarac JC, Levy RB, Louzada ML, Jaime PC. The UN decade of nutrition, the NOVA food classification and the trouble with ultra-processing. *Public Health Nutr.* 2018; 21: 5-17.
12. Fardet A. Minimally processed foods are more satiating and less hyperglycemic than ultra-processed foods: A preliminary study with 98 ready-to-eat foods. *Food Funct.* 2016; 7: 2338-2346.
13. PAHO, WHO. Pan American Health Organization Nutrient Profile Model [Internet]. Washington, D.C.: PAHO; 2016. Available from: <https://iris.paho.org/items/38d7ee18-e9c0-4c01-838d-ee14a75e43a>.
14. Fardet A, Rock E. Ultra-processed foods and food system sustainability: What are the links? *Sustainability.* 2020; 12: 6280.
15. Vandevijvere S, Jaacks LM, Monteiro CA, Moubarac JC, Girling-Butcher M, Lee AC, et al. Global trends in ultraprocessed food and drink product sales and their association with adult body mass index trajectories. *Obes Rev.* 2019; 20: 10-19.
16. Fanzo J, Rudie C, Sigman I, Grinspoon S, Benton TG, Brown ME, et al. Sustainable food systems and nutrition in the 21st century: A report from the 22nd annual Harvard nutrition obesity symposium. *Am J Clin Nutr.* 2022; 115: 18-33.
17. Lustig RH. Ultraprocessed food: Addictive, toxic, and ready for regulation. *Nutrients.* 2020; 12: 3401.
18. Bishop G, Styles D, Lens PN. Environmental performance of bioplastic packaging on fresh food produce: A consequential life cycle assessment. *J Clean Prod.* 2021; 317: 128377.
19. Hendrie GA, Rebuli MA, James-Martin G, Baird DL, Bogard JR, Lawrence AS, et al. Towards healthier and more sustainable diets in the Australian context: Comparison of current diets with the Australian Dietary Guidelines and the EAT-Lancet Planetary Health Diet. *BMC Public Health.* 2022; 22: 1939.
20. Lacour C, Seconda L, Allès B, Hercberg S, Langevin B, Pointereau P, et al. Environmental impacts of plant-based diets: How does organic food consumption contribute to environmental sustainability? *Front Nutr.* 2018; 5: 307640.
21. Grosso G, Fresán U, Bes-Rastrollo M, Marventano S, Galvano F. Environmental impact of dietary choices: Role of the mediterranean and other dietary patterns in an Italian cohort. *Int J Environ Res Public Health.* 2020; 17: 1468.
22. Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, et al. Food in the Anthropocene: The EAT-Lancet commission on healthy diets from sustainable food systems. *Lancet.* 2019; 393: 447-492.

23. FAO. Public purchases of food from family farming, and food and nutrition security in Latin America and the Caribbean: Lessons learned and experiences [Internet]. Rome, Italy: FAO; 2017. Available from: <https://openknowledge.fao.org/server/api/core/bitstreams/c164607e-1db6-41d6-bae9-788d78ea5031/content>.
24. Han X, Shi WY, Yao YX. A review of the water-carbon nexus in urban systems. *Water*. 2023; 15: 1005.
25. Harris F, Moss C, Joy EJ, Quinn R, Scheelbeek PF, Dangour AD, et al. The water footprint of diets: A global systematic review and meta-analysis. *Adv Nutr*. 2020; 11: 375-386.
26. Hatjiathanassiadou M, Rolim PM, Seabra LM. Nutrition and its footprints: Using environmental indicators to assess the nexus between sustainability and food. *Front Sustain Food Syst*. 2023; 6: 1078997.
27. Anastasiou K, Baker P, Hadjikakou M, Hendrie GA, Lawrence M. A conceptual framework for understanding the environmental impacts of ultra-processed foods and implications for sustainable food systems. *J Clean Prod*. 2022; 368: 133155.
28. Kliemann N, Al Nahas A, Vamos EP, Touvier M, Kesse-Guyot E, Gunter MJ, et al. Ultra-processed foods and cancer risk: From global food systems to individual exposures and mechanisms. *Br J Cancer*. 2022; 127: 14-20.
29. Wood B, Williams O, Baker P, Sacks G. Behind the 'creative destruction' of human diets: An analysis of the structure and market dynamics of the ultra-processed food manufacturing industry and implications for public health. *J Agrar Change*. 2023; 23: 811-843.
30. Popkin BM, Ng SW. The nutrition transition to a stage of high obesity and noncommunicable disease prevalence dominated by ultra-processed foods is not inevitable. *Obes Rev*. 2022; 23: e13366.
31. Popkin BM, Barquera S, Corvalan C, Hofman KJ, Monteiro C, Ng SW, et al. Towards unified and impactful policies to reduce ultra-processed food consumption and promote healthier eating. *Lancet Diabetes Endocrinol*. 2021; 9: 462-470.
32. Mialon M, Corvalan C, Cediel G, Scagliusi FB, Reyes M. Food industry political practices in Chile: "The economy has always been the main concern". *Global Health*. 2020; 16: 107.
33. Louzada ML, Cruz GL, Silva KA, Grassi AG, Andrade GC, Rauber F, et al. Consumption of ultra-processed foods in Brazil: Distribution and temporal evolution 2008-2018. *Rev Saude Publica*. 2023; 57: 12.
34. Schiermeier Q. Eat less meat: UN climate-change report calls for change to human diet. *Nature*. 2019; 572: 291-293.
35. Pradhan P, Kropp JP. Interplay between diets, health, and climate change. *Sustainability*. 2020; 12: 3878.
36. Rosenzweig C, Mbow C, Barioni LG, Benton TG, Herrero M, Krishnapillai M, et al. Climate change responses benefit from a global food system approach. *Nat Food*. 2020; 1: 94-97.
37. Poore J, Nemecek T. Reducing food's environmental impacts through producers and consumers. *Science*. 2018; 360: 987-992.
38. Springmann M, Clark M, Mason-D'Croz D, Wiebe K, Bodirsky BL, Lassaletta L, et al. Options for keeping the food system within environmental limits. *Nature*. 2018; 562: 519-525.
39. Ishangulyyev R, Kim S, Lee SH. Understanding food loss and waste-why are we losing and wasting food? *Foods*. 2019; 8: 297.

40. FAO. The State of Food and Agriculture 2019: Moving forward on food loss and waste reduction [Internet]. Rome, Italy: FAO; 2019. Available from: <https://openknowledge.fao.org/items/ba08937f-4a41-4ff5-a4e7-e495e5f5f599>.
41. Pouta E, Liski E, Tienhaara A, Koikkalainen K, Miettinen A. Ecosystem-based food production: Consumers' preferred practices and willingness to buy and pay. *Sustainability*. 2021; 13: 4542.
42. Aleksandrowicz L, Green R, Joy EJ, Smith P, Haines A. The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: A systematic review. *PLoS One*. 2016; 11: e0165797.
43. Clark MA, Domingo NG, Colgan K, Thakrar SK, Tilman D, Lynch J, et al. Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. *Science*. 2020; 370: 705-708.
44. Xu X, Sharma P, Shu S, Lin TS, Ciais P, Tubiello FN, et al. Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. *Nat Food*. 2021; 2: 724-732.
45. Mekonnen MM, Hoekstra AY. A global assessment of the water footprint of farm animal products. *Ecosystems*. 2012; 15: 401-415.
46. Tilman D, Clark M. Global diets link environmental sustainability and human health. *Nature*. 2014; 515: 518-522.
47. Vos M, Deforche B, Van Kerckhove A, Michels N, Geuens M, Van Lippevelde W. Intervention strategies to promote healthy and sustainable food choices among parents with lower and higher socioeconomic status. *BMC Public Health*. 2022; 22: 2378.
48. Patra E, Kokkinopoulou A, Pagkalos I. Focus of sustainable healthy diets interventions in primary school-aged children: A systematic review. *Nutrients*. 2023; 15: 2460.
49. Lencucha R, Pal NE, Appau A, Thow AM, Drope J. Government policy and agricultural production: A scoping review to inform research and policy on healthy agricultural commodities. *Global Health*. 2020; 16: 11.
50. Grech A, Howse E, Boylan S. A scoping review of policies promoting and supporting sustainable food systems in the university setting. *Nutr J*. 2020; 19: 97.
51. Searchinger T. Redirecting Agricultural Subsidies for a Sustainable Food Future [Internet]. Washington, D.C.: World Resources Institute; 2020. Available from: <https://www.wri.org/insights/redirecting-agricultural-subsidies-sustainable-food-future>.
52. Broeks MJ, Biesbroek S, Over EA, Van Gils PF, Toxopeus I, Beukers MH, et al. A social cost-benefit analysis of meat taxation and a fruit and vegetables subsidy for a healthy and sustainable food consumption in the Netherlands. *BMC Public Health*. 2020; 20: 643.
53. Heyl K, Ekardt F, Sund L, Roos P. Potentials and limitations of subsidies in sustainability governance: The example of agriculture. *Sustainability*. 2022; 14: 15859.
54. Khan N, Ray RL, Kassem HS, Hussain S, Zhang S, Khayyam M, et al. Potential role of technology innovation in transformation of sustainable food systems: A review. *Agriculture*. 2021; 11: 984.
55. Dernini S, Berry EM, Serra-Majem L, La Vecchia C, Capone R, Medina FX, et al. Med diet 4.0: The mediterranean diet with four sustainable benefits. *Public Health Nutr*. 2017; 20: 1322-1330.
56. Perignon M, Masset G, Ferrari G, Barré T, Vieux F, Maillot M, et al. How low can dietary greenhouse gas emissions be reduced without impairing nutritional adequacy, affordability and acceptability of the diet? A modelling study to guide sustainable food choices. *Public Health Nutr*. 2016; 19: 2662-2674.

57. Traill WB, Shankar B, Brambila-Macias J, Bech-Larsen T, Aschemann-Witzel J, Strand M, et al. Interventions to promote healthy eating habits: Evaluation and recommendations. *Obes Rev.* 2010; 11: 895-898.
58. Mikkelsen BE. Declining role of governments in promoting healthy eating: Time to rethink the role of the food industry? *Scand J Nutr.* 2005; 49: 127-130.
59. Allender S, Gleeson E, Crammond B, Sacks G, Lawrence M, Peeters A, et al. Policy change to create supportive environments for physical activity and healthy eating: Which options are the most realistic for local government? *Health Promot Int.* 2012; 27: 261-274.
60. FAO. Climate change, biodiversity and nutrition nexus – Evidence and emerging policy and programming opportunities [Internet]. Rome, Italy: FAO; 2021. Available from: <https://openknowledge.fao.org/items/aee57d9f-8a68-48ea-bbdd-f3e9aeab18aa>.
61. Whitmee S, Haines A, Beyrer C, Boltz F, Capon AG, de Souza Dias BF, et al. Safeguarding human health in the Anthropocene epoch: Report of the Rockefeller Foundation-Lancet Commission on planetary health. *Lancet.* 2015; 386: 1973-2028.
62. Mereles Ceuppens L. Bioprospección y revalorización de alimentos biodiversos para la seguridad alimentaria y nutricional [Internet]. Rome, Italy: FAO; 2025. Available from: <https://openknowledge.fao.org/items/5e0b2d07-7096-4988-b75a-76d22324cdfa>.
63. Mereles L, Tranoy C, Añino I, Meza L, Ríos-Castillo I. Transformación sostenible de los sistemas alimentarios mediante soluciones basadas en la naturaleza: Experiencias y aprendizajes en la región del Sistema de la Integración Centroamericana [Internet]. Rome, Italy: FAO; 2025. Available from: <https://openknowledge.fao.org/items/00679887-ae92-4ece-82e0-051c55e20e01>.
64. Leisner CP. Climate change impacts on food security-focus on perennial cropping systems and nutritional value. *Plant Sci.* 2020; 293: 110412.
65. Abdi AM, Carrié R, Sidemo-Holm W, Cai Z, Boke-Olen N, Smith HG, et al. Biodiversity decline with increasing crop productivity in agricultural fields revealed by satellite remote sensing. *Ecol Indic.* 2021; 130: 108098.
66. Sufiyan A. The role of biodiversity in food security. *Int J Sch Res Sci Technol.* 2022; 1: 1-8.
67. Frison EA, Cherfas J, Hodgkin T. Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security. *Sustainability.* 2011; 3: 238-253.
68. Ghadiri M, Krawchenko T, Newell R. Applying a climate-biodiversity-health framework to support integrated food systems planning and policy. *J Environ Manage.* 2024; 358: 120769.
69. FAO. The State of the World's Biodiversity for Food and Agriculture [Internet]. Rome, Italy: FAO; 2019. Available from: <https://openknowledge.fao.org/items/b355c300-72ed-4a63-be07-8295c80ec7f1>.
70. Newton AC, Johnson SN, Gregory PJ. Implications of climate change for diseases, crop yields and food security. *Euphytica.* 2011; 179: 3-18.
71. Thompson HE, Berrang-Ford L, Ford JD. Climate change and food security in sub-Saharan Africa: A systematic literature review. *Sustainability.* 2010; 2: 2719-2733.
72. Burlingame B, Charrondiere UR, Dernini S, Stadlmayr B, Mondovì S. Food biodiversity and sustainable diets: Implications of applications for food production and processing. In: *Green technologies in food production and processing.* Boston, MA: Springer; 2011. pp. 643-657.
73. Li X, Siddique KH. Future smart food: Harnessing the potential of neglected and underutilized species for zero hunger. *Matern Child Nutr.* 2020; 16: e13008.

74. Kim H, Lazurko A, Linney G, Maskell L, Díaz-General E, Březovská RJ, et al. Understanding the role of biodiversity in the climate, food, water, energy, transport and health nexus in Europe. *Sci Total Environ.* 2024; 925: 171692.
75. Ivanovich CC, Sun T, Gordon DR, Ocko IB. Future warming from global food consumption. *Nat Clim Change.* 2023; 13: 297-302.
76. Kaza S, Yao L, Bhada-Tata P, Van Woerden F. *What a waste 2.0: A global snapshot of solid waste management to 2050.* Washington, D.C.: World Bank Publications; 2018.
77. Liu Z, De Souza TS, Holland B, Dunshea F, Barrow C, Suleria HA. Valorization of food waste to produce value-added products based on its bioactive compounds. *Processes.* 2023; 11: 840.
78. Bhatia L, Jha H, Sarkar T, Sarangi PK. Food waste utilization for reducing carbon footprints towards sustainable and cleaner environment: A review. *Int J Environ Res Public Health.* 2023; 20: 2318.
79. Ortiz AM, Outhwaite CL, Dalin C, Newbold T. A review of the interactions between biodiversity, agriculture, climate change, and international trade: Research and policy priorities. *One Earth.* 2021; 4: 88-101.
80. Myers SS, Smith MR, Guth S, Golden CD, Vaitla B, Mueller ND, et al. Climate change and global food systems: Potential impacts on food security and undernutrition. *Annu Rev Public Health.* 2017; 38: 259-277.
81. FAO. A guidance note to enhance nutrition sensitivity in Global Environment Facility (GEF) investments and programming [Internet]. Rome, Italy: FAO; 2023. Available from: <https://openknowledge.fao.org/items/61f70626-2dd1-4143-98e9-6a5659ecdeb3>.
82. Sharma S. Impact of climate change on food security. *J Sci Innov Nat Earth.* 2023; 3: 37-40.
83. Singh BK, Delgado-Baquerizo M, Egidi E, Guirado E, Leach JE, Liu H, et al. Climate change impacts on plant pathogens, food security and paths forward. *Nat Rev Microbiol.* 2023; 21: 640-656.
84. Giulia S, Lea BF, Carol ZC, Lisa M, Harper SL, Elizabeth CJ. The effect of climatic factors on nutrients in foods: Evidence from a systematic map. *Environ Res Lett.* 2020; 15: 113002.
85. Geyik Ö, Hadjikakou M, Bryan BA. Climate-friendly and nutrition-sensitive interventions can close the global dietary nutrient gap while reducing GHG emissions. *Nat Food.* 2023; 4: 61-73.
86. Fastré C, van Zeist WJ, Watson JE, Visconti P. Integrated spatial planning for biodiversity conservation and food production. *One Earth.* 2021; 4: 1635-1644.
87. Krykhtina YO, Dombrovska SM, Maistro SV, Stankevych SV. Review of public policy for reducing the transport environmental impact. *Ukr J Ecol.* 2021; 11: 12-15.
88. Li X, Yadav R, Siddique KH. Neglected and underutilized crop species: The key to improving dietary diversity and fighting hunger and malnutrition in Asia and the Pacific. *Front Nutr.* 2020; 7: 593711.
89. Chivenge P, Mabhaudhi T, Modi AT, Mafongoya P. The potential role of neglected and underutilised crop species as future crops under water scarce conditions in Sub-Saharan Africa. *Int J Environ Res Public Health.* 2015; 12: 5685-5711.
90. Siddique F, Ali Z, Arshad M, Mubeen K, Ghazala A. Exploration of novel eco-friendly techniques to utilize bioactive compounds from household food waste: Special reference to food applications. *Front Food Sci Technol.* 2024; 4: 1388461.
91. Malik AA, Chaudhary G. Global food security: A truncated yield of underutilized and orphan crops. In: *Biotechnology Products in Everyday Life.* Cham: Springer International Publishing; 2018. pp. 161-171.

92. Gao L, Kantar MB, Moxley D, Ortiz-Barrientos D, Rieseberg LH. Crop adaptation to climate change: An evolutionary perspective. *Mol Plant*. 2023; 16: 1518-1546.
93. Glantz MH, Gommers R, Ramasamy S. Coping with a changing climate: Considerations for adaptation and mitigation in agriculture [Internet]. Rome, Italy: FAO; 2009. Available from: <https://www.fao.org/4/i1315e/i1315e.pdf>.