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Review Article

Agricultural biodiversity and human health nexus: A review

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ABSTRACT

Agricultural biodiversity refers to the variety of biological elements essential for food production and the functioning of agricultural ecosystems, known as agroecosystems. This concept encompasses the genetic, species, and ecosystem diversity necessary to support vital ecological processes. Agricultural biodiversity results from complex interactions among genetic resources, environmental factors, and various farming practices, shaped by both natural selection and human innovation over time. This biodiversity is crucial for human health and well-being, providing not only food but also essential raw materials such as cotton, wood, medicinal herbs, and biofuels, as well as sustaining livelihoods, particularly for subsistence farmers. Furthermore, agricultural biodiversity offers key ecosystem services, including pollination, soil and water conservation, and maintenance of soil fertility, all of which are fundamental to human survival. The genetic diversity within agricultural systems also enhances resilience, enabling species to adapt to changing conditions, such as extreme temperatures and pest pressures. This adaptability is increasingly important as we face shifting environmental challenges. Each domesticated crop embodies the ongoing management of biodiversity, continuously evolving to meet new demands while supporting health and sustainability in our agricultural landscapes.

KEYWORDS: *Agroecosystems, Biodiversity, Ecosystem Services, Human Health, Resilience*

INTRODUCTION

Biodiversity and agriculture are deeply interconnected; agriculture relies on biodiversity for its foundation. The development of farming systems over millennia has depended on domesticated plant and animal species, all derived from diverse ecosystems. This biodiversity is crucial for the ecosystem services that sustain both agriculture and human well-being, providing essential resources for food security, nutrition, and livelihoods (FAO, 2014). However, agriculture faces significant challenges related to biodiversity. Key issues include maintaining essential ecosystem services and mitigating the negative impacts of agricultural practices on non-target biodiversity. Factors influencing these challenges range from climate change and resource availability to socioeconomic dynamics, such as trade and population growth (Botkin *et al.*, 2007). The rapid loss of biodiversity threatens the sustainability of agriculture and its capacity to adapt to environmental changes, endangering food security and livelihoods. A primary goal for agriculture is

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to enhance food production while implementing sustainable practices that conserve biodiversity (Lapola *et al.*, 2009). This involves understanding agricultural biodiversity, which includes genetic resources from crops and livestock, organisms that support ecosystem services, abiotic factors influencing these systems, and the cultural dimensions shaped by human management. To ensure food security and sustainable livelihoods for the future, agriculture must balance production needs with the preservation of biodiversity and ecosystem health (Alo and Wang, 2008).

SYNERGIES BETWEEN AGRICULTURE AND BIODIVERSITY

In agriculture, soil organisms play a crucial role in plant growth by producing and transforming essential nutrients, such as nitrogen and phosphorus, which are more abundant in these microorganisms than in all vegetation combined. While plants absorb macro and micronutrients from the soil to create biomass, their growth is facilitated by interactions among soil microbes, microfauna, and abiotic factors like temperature, pH, and moisture. The physical breakdown of plant residues by various soil fauna is vital for nutrient and energy release (El-Mahrouk *et al.*, 2021). Additionally, soil organisms, such as arbuscular mycorrhizal fungi and nitrogen-fixing bacteria, can enhance agricultural sustainability by reducing the need for synthetic fertilizers and lowering greenhouse gas emissions linked to their production (El-Ramady *et al.*, 2021[a]).

Synergies between soil biodiversity and climate change

Soil biodiversity plays a vital role in addressing climate change by influencing the balance between greenhouse gas emissions and carbon sequestration. Healthy soils can store more carbon than the combined carbon in the atmosphere and vegetation, thanks to the activities of soil organisms. These organisms either fix carbon from plant and animal waste or utilize atmospheric CO_2 as an energy source (Youssef *et al.*, 2021). However, agricultural practices contribute significantly to greenhouse gas emissions, with soil nitrous oxide and methane from rice cultivation accounting for a substantial portion. Therefore, managing soil ecosystems effectively is crucial for reducing these emissions and enhancing sustainable soil management practices (Bayoumi *et al.,* 2021).

Synergies between soil biodiversity and human health

Soil biodiversity significantly impacts human health by managing diseases and enhancing food production. Many medications, including antibiotics like penicillin and cancer treatments, have been derived from soil organisms, highlighting their potential in combating drug-resistant diseases (Calderón *et al.,* 2022). Healthy soils also improve plant defenses against pathogens, thereby reducing foodborne illnesses. The diversity of soil microbial communities influences the presence and virulence of harmful bacteria, such as Listeria monocytogenes (Zhang *et al.,* 2022). Additionally, plants enriched by soil biodiversity produce beneficial compounds, such as antioxidants, which support our immune systems and overall health. Research suggests that early exposure to diverse soil microbes may help prevent chronic inflammatory conditions, including allergies, asthma, and depression (Ahmad *et al.,* 2022)

Synergies between soil biodiversity and environmental protection

Protecting soil biodiversity is crucial for maintaining and enhancing above-ground biodiversity. Soil organisms form intricate food webs that transport nutrients and energy to various species, including birds and mammals (Lyu *et al.,* 2022). Soil biodiversity also plays a vital role in bioremediation, helping to mitigate threats to ecosystem services by filtering and degrading contaminants through processes like biostimulation and bioaugmentation. Techniques that incorporate organisms such as worms (vermiremediation), plants (phytoremediation), and bacteria are effective for removing hydrocarbons from contaminated soils. Furthermore, soil macrofauna, like ants, termites, and earthworms, significantly enhance soil structure and aggregation, improving resilience against erosion caused by wind and water (Ahmed *et al.,* 2022).

Synergies between biodiversity and water

Over the past century, global water demand has surged six-fold and is projected to keep rising. Water, the largest terrestrial freshwater resource, is a crucial ecosystem service provided by soil, essential for food production in agroecosystems. It plays a vital role in the interconnectedness of food, energy, and climate. However, by 2030, the global water deficit could reach 40%. Irrigated agriculture accounts for 80% of total water use worldwide, rising to 90% in arid regions, with 20% of irrigated land producing 40% of the world's food, despite low Water Use Efficiency (WUE) in conventional systems (Marshman *et al.,* 2019).

Improving WUE is critical given the competing demands for water from domestic, industrial, and recreational uses. To conserve water effectively, it is important to minimize losses through runoff, evaporation, and deep percolation. Water quality, particularly for irrigation and drinking, is closely tied to its availability. Understanding soil hydrology, and how water is retained and transmitted across landscapes is essential for managing water resources, including tracking contaminants and optimizing land use (Schoeneberg and Wysocki, 2005).

SYNERGIES BETWEEN BIODIVERSITY AND FOOD SYSTEMS

a. Food availability

Food availability relies on the production and distribution of a diverse array of nutritious foods to meet the population's needs. This supply is heavily dependent on both domesticated and wild biodiversity. Recent genetic advancements have allowed food production to keep pace with the growing global population. However, the emphasis on a limited number of species, breeds, or varieties has led to a loss of genetic diversity, threatening the resilience of food systems to adapt to emerging challenges (FAO, 2019).

b. Food utilization

Food utilization involves how food items are combined and prepared to create nutritious diets. The nutrient composition of foods varies among plant species, types, and breeds. In addition to the food products themselves, safe and nutritious diets rely on the services provided by biodiversity. For example, many communities depend on local ecosystems for clean water and fuelwood, while livestock dung serves as a vital cooking fuel in some regions. Microorganisms also play a crucial role in food processing, such as in cheese and bread production, as well as in preservation methods like fermentation (FAO, 2019[a]).

c. Access to food

Access to food relies on effective distribution, local availability, and affordable pricing for all. Addressing the physical, social, and economic barriers to food acquisition is essential to ensure that everyone, especially the poorest, can obtain the food they need. Biodiversity not only provides the means for many people to grow, gather, or hunt food but can also serve as a source of income to purchase food or invest in production, storage, or processing, thereby enhancing access to food (FAO, 2019[b]).

d. Stability

Stability refers to the consistent availability, use, and access to food over time. Biodiversity plays a crucial role in enhancing food supply stability in various ways. Different plant and animal species can provide food across different seasons and environmental conditions, with some species particularly resilient to challenges such as drought or pest outbreaks. When cultivated crops are affected, wild biodiversity can serve as an alternative food source. Additionally, entire ecosystems support food supply stability by reducing the risk of damage from storms or floods and providing habitats for diverse wild species and pollinators, which helps maintain essential ecosystem services. Preserving biodiversity is vital for ensuring food availability to address current challenges and for the benefit of future generations (FAO, 2019[c]).

SYNERGIES BETWEEN CLIMATE CHANGE AND BIODIVERSITY LOSS ON FOOD AND NUTRITION

Climate change and biodiversity loss significantly impact food systems and nutrition. Rising carbon dioxide levels affect crop yields and the nutritional quality of plant-based foods, particularly cereals and legumes. Additionally, the loss of genetic diversity limits the ability to breed climate-resilient crops and reduces the variety of available foods necessary for a healthy diet. Increased temperatures have been linked to higher levels of contaminants, like arsenic in rice, and more frequent foodborne pathogens and mycotoxins during production and storage (FAO, 2020).

Indigenous and vulnerable rural communities, reliant on agriculture and natural resources, are disproportionately affected due to their limited access to technology, infrastructure, and water. The high perishability of nutritious foods further complicates availability, quality, and affordability, pushing markets towards highly processed, nutrient-poor options (Scheelbeek *et al.*, 2018). Climate change and biodiversity loss disrupt various pathways related to nutrition, from food production to dietary practices. Extreme weather events threaten ecosystems and food systems, potentially leading to a drastic reduction in crop productivity and the loss of essential pollinators and pest predators. Maintaining high biodiversity is crucial for ensuring the availability of micronutrients in diets and supporting nutritious local food systems (Mbow *et al.*, 2019).

SYNERGIES BETWEEN BIODIVERSITY AND INDIGENOUS PEOPLE'S EXISTENCE

Indigenous peoples’ food systems are among the most sustainable globally, and closely aligned with nature (United Nations, 2017). Though they occupy only 28% of the Earth’s surface, indigenous lands harbor 80% of the planet's biodiversity (Garnett *et al.*, 2018). This rich biodiversity supports diverse diets for Indigenous Peoples, consisting of numerous edible and nutrient-dense species. Additionally, the traditional knowledge, languages, and worldviews tied to this biodiversity enhance their ability to adapt to environmental changes (FAO, 2021).

Indigenous ancestral knowledge underpins many modern resource management practices for climate adaptation and mitigation, such as sustainable forest management and agrobiodiversity conservation (Parrotta *et al.*, 2016). With approximately 476 million Indigenous people worldwide, their food systems often include hunting, gathering, and fishing, alongside farming. Thus, policies must recognize the unique aspects of these systems to effectively support them.

Intercultural food policies that co-create knowledge are essential to enhance the climate resilience, nutritional quality, and food security of Indigenous food systems. However, government programs often overlook the impact of these systems, leading to diminished genetic diversity, access to resources, and adverse effects on the livelihoods and cultures of Indigenous communities, especially youth. Limited access to land disrupts cultural transmission, while inadequate intercultural education affects younger generations food practices and knowledge (Hunter *et al.*, 2020). Therefore, global initiatives aimed at enhancing climate resilience, conserving biodiversity, and addressing malnutrition must prioritize the rights of Indigenous Peoples to protect their lands, cultures, and traditional knowledge.

SYNERGIES BETWEEN BIODIVERSITY AND GENDER

Gender is a significant factor influencing access to food and nutritional status. Despite having greater nutritional needs, women and girls are more likely to face food insecurity and various forms of malnutrition, including undernutrition, micronutrient deficiencies, and obesity (FAO, 2020). A mother's diet directly impacts her children's long-term health, making it crucial for women to access healthy foods to break intergenerational cycles of malnutrition (WHO, 2019).

Dietary disparities currently affect the suitability of supplemental feeding for young children, and these issues are expected to worsen due to climate change and its associated variability. Research indicates that women's seasonal employment can negatively influence pregnancy outcomes, such as low birth weights (Wijesinha *et al.*, 2013). Agrobiodiversity can help shield women from food insecurity, but it is threatened by climate change and poor land management (WHO, 2019). Therefore, policy interventions must empower women and address their unique vulnerabilities linked to seasonality and climate change threats to enhance environmental and nutritional outcomes (IPCC, 2019).

SYNERGIES BETWEEN BIODIVERSITY AND THE POTENTIAL OF NEGLECTED AND UNDERUTILIZED (NUS) SPECIES FOR IMPROVING DIETS AND NUTRITION

Homogeneous diets, inadequate food access, and underdeveloped markets for nutrient-rich neglected species contribute to persistent malnutrition and poverty (Caron *et al.*, 2018). Utilizing locally adapted, nutrient-dense crops can support biodiversity and offer environmental and health benefits. Currently, rice, maize, and wheat dominate global diets, limiting nutritional diversity. Innovative strategies are needed to enhance food variety and nutrition, especially as conventional agriculture often overlooks these aspects (KC *et al.*, 2018). While current food systems produce large quantities of food, they fail to provide a range of nutrient-dense options, marginalizing many valuable crops. Underutilized species, such as fruits, vegetables, and grains, have significant potential to improve nutrition and preserve biodiversity (Willett *et al.*, 2019). However, there is a lack of consensus on the number of edible plant species, complicating efforts to leverage this potential. The Royal Botanic Gardens Kew (2016) identifies 5,538 plant species used for food, recent research also identified 1,097 vegetable species that could diversify agricultural systems.

NUS provide essential macronutrients and micronutrients that support health, yet their potential is often underutilized. Research indicates that traditional varieties, such as local bananas contain over 8,000 times more pro-vitamin A carotenoids than common varieties, while some sweet potato cultivars differ drastically in carotenoid content. Despite the nutritional advantages of various NUS like minor millets and African leafy vegetables research on their genetic diversity and nutritional value is limited and often sporadic. However, integrating these species into diets could address nutrient deficiencies and offer sustainable, culturally relevant solutions to malnutrition (Biodiversity International, 2017).

Many countries, especially those rich in biodiversity, are home to nutrient-rich neglected and underutilized species (NUS), which are vital for cultural practices, food security, and resilience (Willett *et al.*, 2019). Custodians like smallholder farmers, pastoralists, and indigenous communities work to preserve these species, many of which are endangered and stored in gene banks for research and breeding. This preservation is increasingly important as we shift focus from traditional agricultural yields to the nutritional value of crops (Springman, 2018).

SYNERGIES BETWEEN BIODIVERSITY AND HEALTH IN THE FACE OF CLIMATE CHANGE

Climate change significantly affects both human health and biodiversity, with increasing occurrences of heat waves, droughts, and floods disrupting ecosystems and diminishing vital services. These environmental changes contribute to rising healthcare costs and a surge in non-communicable diseases (Gibbs, 2014). However, managing and preserving biodiversity can offer nature-based solutions to enhance human health and mitigate climate change effects. Growing awareness of the connection between biodiversity and public health is fostering synergies between health improvement, climate adaptation, and conservation efforts (Zinsstag *et al.*, 2011). Biodiversity loss influences human health by altering ecosystems, which can affect the emergence and transmission of infectious diseases. Approximately 60% of human infectious diseases, including COVID-19 and malaria, are zoonotic, originating in animals before crossing into human populations. For instance, the HIV/AIDS virus is believed to have originated from chimpanzees hunted for bushmeat in Africa, illustrating the risks posed by wildlife interactions. Currently, an estimated 10,000 zoonotic viruses are circulating in wildlife, potentially poised to infect humans (McMahon *et al.*, 2015).

The link between biodiversity and health is increasingly critical, especially in the context of climate change. While the exact source of COVID-19 remains unclear, a significant portion of infectious diseases 60% of all and 70% of emerging diseases originate from animals and natural environments. Human activities like urbanization and deforestation disrupt ecosystems, heightening the risk of zoonotic diseases, as seen in recent outbreaks of monkeypox and Ebola (Bunch *et al.,* 2011). Such disruptions alter organism interactions and ecosystem functions, influencing the patterns of infectious diseases. Major factors like deforestation, land use changes, climate variability, and the introduction of pathogens affect disease transmission. Moreover, traditional medicine plays a vital role in healthcare, with around 60% of people relying on it, particularly in areas dependent on medicinal plants sourced from diverse ecosystems. The loss of biodiversity threatens potential medical advancements and the search for cures, underscoring the importance of maintaining healthy ecosystems for both human health and disease prevention (Gregorich *et al.,* 2006).

CONCLUSION

The intricate relationship between agricultural biodiversity and human health underscores the vital role that diverse biological resources play in ensuring food security and ecological sustainability. As highlighted in this review, agricultural biodiversity is not merely an asset for food production; it is a cornerstone for the resilience of agroecosystems, contributing to essential ecosystem services that support human well-being. The preservation and enhancement of this biodiversity are critical, particularly in the face of escalating environmental challenges and changing climatic conditions. By recognizing the interconnectedness of agricultural practices, biodiversity conservation, and human health, we can foster more sustainable agricultural systems that promote both ecological balance and the health of populations. Future efforts must prioritize policies and practices that safeguard agricultural diversity, ensuring that it continues to provide essential benefits for generations to come.

RECOMMENDATIONS ON THE WAY FORWARD

- **Agribusinesses and retailers**

To effectively reduce food loss and waste, agribusinesses and retailers should enhance food storage, processing, packing, distribution, and transportation practices. Public-private partnerships, such as those in the FAO-NORAD project focused on empowering small-scale women producers, can help these producers minimize food loss and improve product safety while achieving sustainable livelihoods. Implementing geographical indications can promote sustainable value chains by informing consumers about the origin and production methods of their food, thus benefiting local producers. Initiatives like the Slow Food Presidia can empower small-scale producers to preserve regional biodiversity and foster direct relationships with consumers. Additionally, technology solutions like the Too Good To Go app can help mitigate food waste by connecting customers with unsold perishable items at reduced prices

- **Academia**

Academia should lead efforts to bridge knowledge gaps regarding the impacts of ecosystem changes, food production methods, and consumption patterns on climate change, biodiversity loss, and nutrition. It is essential to explore emerging fields that connect environmental health with nutrition. Further research is needed to understand the effects of various environmental factors, such as CO_2, ozone, and temperature, on food quality across different climates. Additionally, scholars should investigate the relationship between the soil microbiome and the human gut microbiome, as well as their connection to agrobiodiversity, to better integrate diets, agri-food systems, and soil health.

- **Development partners**

Development partners, including the United Nations, governments, and donors, should promote access to nutritious meals for all while avoiding the promotion of harmful foods that negatively impact nutrition and the environment. Emphasizing sustainable and healthy consumption habits is essential. Organizations like the FAO must play a key role in raising awareness about the connections between nutrition, biodiversity, and climate change. This awareness is vital for leveraging climate finance to support the development of nutritious diets and resilient, sustainable agri-food systems. Additionally, funders and international organizations should focus on assessing the impacts of agricultural programs on nutrition and climate change. The FAO's 2021–2025 Vision and Strategy for Nutrition offers a valuable framework for integrating these issues effectively.

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Authors' Contributions

FMO conceived the review topic and managed all aspects of the manuscript, AAO, AOA, EFO, TIA contributed to the writing of the first draft of the manuscript. All authors read and approved the final manuscript.

Ethical Statement

Not applicable

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