Biodiversity Towards Sustainable Food Systems: Four Arguments

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1 Introduction

For several years, scientists have been warning that food systems have become significant drivers of environmental degradation, of various forms of malnutrition, and of food insecurity (Altieri 2004; Swinburn et al. 2019). The pandemic of COVID-19 demonstrates the practical effect of ignoring the evidence in the name of a narrow focus on food production (to see more about the relationship between environmental degradation and SARS-CoV-2 outbreak see Jacob et al. 2020a). We have never been so close to a global shutdown of our economic system, so close to living on a planet where all forms of life are under threat, and so distant from guaranteeing regular access to nutritious foods to households across the globe (IPES-Food 2020). The global food system is ripe for a change.

Food systems are formed by all activities in food production, transformation, distribution, and consumption, including those leading to food losses and waste.

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The interaction and interdependence of food systems, human health, and biodiversity are complex. Sustainable food systems are needed for human health, but the sustainability of food systems depends fundamentally on the preservation of their biodiversity. Sustainable food systems promote global outcomes of human and environmental health, social equity, and economic resilience (IPES-Food 2017). The task of transforming food systems to deliver sustainability requires integrated actions in order (1) to conserve biodiversity and to reduce the impacts on the environment; (2) to shift towards sustainable practices in production, processing, and consumption; (3) to improve socioeconomic welfare; and (4) to consider cultural adequacy of food practices (Béné et al. 2019). In this debate, the biodiversity of plants, animals, and micro-organisms used directly or indirectly for food and agriculture has a crucial role in promoting sustainable food systems (Blicharska et al. 2019). The *Convention on Biological Diversity* defines biodiversity as the variability among living organisms from all sources, including terrestrial, aquatic ecosystems, and the ecological complexes (United Nations 2016). Ecosystems, species, and genes are the three critical components in biodiversity, characterized by attributes, such as diversity, abundance, and composition (Kearns 2010).

In this chapter, we present arguments that highlight the role of biodiversity in making food systems more sustainable. In our analysis, we define biodiverse food plants as the plants of extensive use (e.g., beans, rice, corn) and unconventional food plants as usually native, often neglected, and of culturally limited use (Jacob and Albuquerque 2020). We also consider the non-edible biodiversity of agricultural interest, which includes a multitude of species, such as soil microbiomes, insects, birds, and mammals, which work pollinating crops, regulating pests, balancing nutrients in fields, and storing carbon in soils (Willett et al. 2019). This discussion can help inform food system transformation plans and actions.

2 Biodiversity Towards Sustainable Food Systems: Four Major Arguments

In Fig. 1, we summarize the main opportunities and barriers related to the four arguments to mainstream biodiversity into current food systems.

2.1 Biodiversity Is Central to Food and Nutrition Security[1]

The most authoritative and widely used definition of food security is that provided in the FAO's 2001 *State of Food Insecurity* report: "Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and

[1] In our book, we prefer to use "food and nutrition security" (FNS) instead of "food security" for two main reasons. First, FNS is the term used in Brazilian legislation (see Law 11.346/2006).

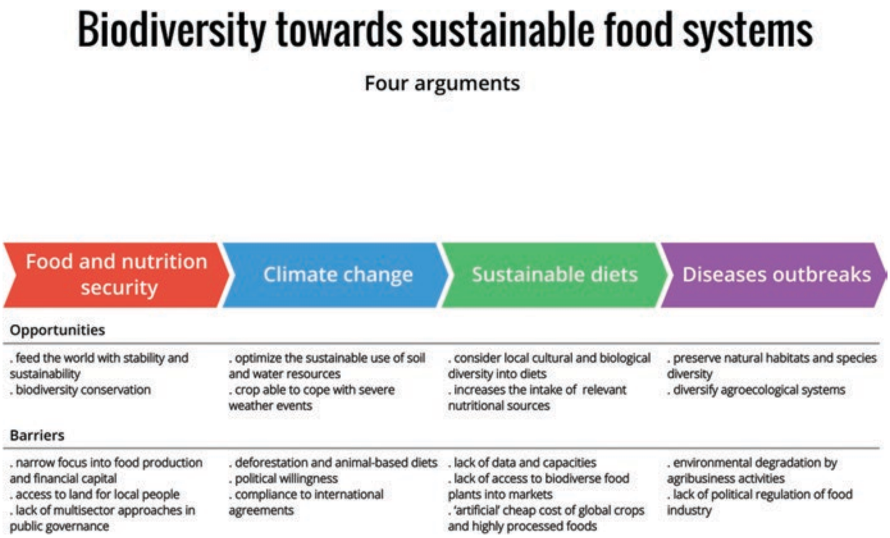

Fig. 1 Four major arguments to mainstream biodiversity into current food systems

nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO 2001). From this breathtaking, encompassing definition, many components can be discerned, particularly those addressing the *availability* of and the *access* to food, as well as the *utilization* of food (nutrition uptake), and the *stability* of food availability, access, and utilization. In its 2020 report, the High Level Panel of Experts (HLPE) of the Committee on World Food Security (CFS) proposes amplifying the concept of food security to more explicitly recognize two other dimensions: *sustainability* and *agency* (HLPE 2020).

While the endorsement of the HLPE leads to a more widespread recognition of the importance of sustainability and agency for food and nutrition security (FNS), many scholars and groups working in the area have incorporated these dimensions in their consideration of food security for many years. As an example, the Centre for Studies in Food Security at Ryerson University, Canada, since 2003 has considered the following dimensions of food security (defined collectively as "the 5 As of food security"):[2]

- *Availability*: Sufficient food for all people at all times
- *Accessibility*: Physical and economic access to food for all at all times

Second, the term "nutrition" signals that food also needs to offer quality in terms of nutritional health. To read further about this debate, see Ingram (2020). As we show in this section, FAO and the Centre for Studies in Food Security at Ryerson University maintain the original description of the concept (without the "nutrition"). However, the definitions presented by them include the quality component of food embraced by FNS.

[2] See at: https://www.ryerson.ca/foodsecurity/

- *Adequacy*: Access to food that is nutritious and safe and produced in environmentally sustainable ways
- *Acceptability*: Access to culturally acceptable food, which is produced and obtained in ways that do not compromise people's dignity, self-respect, or human rights
- *Agency*: Policies and processes that enable the achievement of food security

A "productionist" view of food security only focuses on the availability dimension, with little regard for issues of poverty and wealth distribution (preventing proper access); nutritional quality of diets and safety of the food made available; the environmental impact of food production; the social and cultural contexts for people accessing food; and little regard for the power dynamics preventing the realization of the human right to adequate food. For years, this "productionist" view has supported the development of an industrial agriculture paradigm, favoring monocultures and emphasizing quantity over quality, to the detriment of biodiversity, the environment, human health, cultures, and social well-being (IPES-Food 2016, 2017). True food and nutrition security depends on a food system that promotes health, fairness, and environmental sustainability.

In the past, using a strict "productionist" approach, biodiversity conservation and food security were often presented as mutually exclusive goals (Sonnino et al. 2014). In a finite resource world, the decisions taken to address one problem were seen to negatively affect the other (Chappell and LaValle 2011). Thus, for example, a conservation focus could limit food production requirements and, as a consequence, increase food insecurity (as if food security depended only on an increase in the absolute quantity of food). However, the practice of converting wildlands to intensive commercial agricultural use, ignoring biodiversity, can produce new challenges to FNS (e.g., pollinator diversity reduction, lower soil fertility). Biodiversity has proven to be central to FNS and vice versa (Sunderland 2011). Presenting these two challenges as an inevitable trade-off is part of a narrative[3] that has proven to be insufficient to analyze the complexity of both. The analysis needed requires a broader focus on food and nutrition security instead of a strict food production approach, with consideration of societal issues such as social justice and governance (Cramer et al. 2017).

However, as shown by Hanspach et al. (2017), a biodiverse environment does not guarantee FNS. They conducted a multivariate analysis of social-ecological data from 110 landscapes in the Global South to study the food-biodiversity nexus. In the landscapes studied, win-win outcomes were associated with high equity, ready

[3] A narrative defines the framings of the stories around the food system, beginning, middle, and end. Three points orient the construction of a food systems failure narrative: what is the failure about, what is threatened and need to be fixed, and where the priorities for action stand. The dominant and narrow narrative is *the food systems failure is their inability to feed the world population. FNS is under threat. The action required is to close the yield gap.* To broaden this narrative, we would prefer to tell the following story*: the food systems failure is their inability to produce equal and equitable benefits. Social justice, democratic process, and small-scale actors are under threat. The action required is decentralization and grassroots autonomy*. See Béné et al. (2019).

access to land for local people, and high human and social capital. On the other hand, trade-offs were related to a narrow focus on financial capital. The authors concluded that avoiding a narrow focus on infrastructure, commercialization, and built capital seems critical for fostering synergies between FNS and biodiversity conservation. It is crucial to broaden the focus by considering strengthening human capital, social capital, and equity to foster win-win relations.

Biodiversity can support FNS in many ways. Blicharska et al. (2019), for example, performed a review to discuss the breadth of ways in which biodiversity can support sustainable development. Analyzing the sustainable development goal 2 (Zero Hunger), they list the direct delivery benefits of biodiversity to FNS (United Nations 2015). Some of them are improving dietary quality; ameliorating soil fertility, structure, quality, and health; providing crop pollination; bearing pest control; expanding agricultural output and future yields; increasing resilience of agricultural systems; providing potential for new crops; and maintaining productivity in marine ecosystems.

Considerations of the synergies between biodiversity preservation and FNS have led to the promotion of agroecology. Diversified agroecological systems offer broader benefits for the environment and society (IPES-Food 2015). With a holistic approach, agroecology considers the sustainable use and management of natural resources and ecosystem services in agriculture. It also explicitly includes social issues into its principles, such as ethical considerations, changes in diet, and social justice (see Altieri 2004). Transitioning towards diversified agroecological systems is more urgent than ever. The COVID-19 outbreak has revealed how intricately linked human, animal, and ecological health are (Altieri and Nicholls 2020). However, a narrow scope without governance arrangements will fail to mainstream biodiversity into global food systems (De Clerck 2016). To prevent future health crises on a global scale, we need to connect agroecological strategies, public policies, and solidarity market arrangements (IPES-Food 2018; Nicholls and Altieri 2018).

2.2 Agricultural Biodiversity Strengthening Resilience to Climate Change

Food production has been a major driver of climate change, being responsible for 26% of all anthropogenic greenhouse gas emissions (Poore and Nemecek 2018). This fact represents a significant concern to FNS since climate change has adverse effects on food production, creating harmful feedback loops in the food-climate nexus (Jacques and Jacques 2012).

Resilience in social-ecological systems is the ability of a given system to sustain itself or recover quickly from difficulties, stresses, and shocks. It comprises three main characteristics: the capacity (1) to absorb shocks, (2) to self-organize, and (3) to learn and adapt. Agricultural biodiversity and associated knowledge strength the resilience to climate change-related stresses. This is the conclusion of a study on global food systems trends that reviewed 172 project reports and case studies from Africa, Central and South America, Asia, and the Pacific (Mijatović et al. 2013). Mijatović and colleagues reported the strategies to strengthen climate change resilience with agricultural diversity by dividing it into three levels. First, at the scale of the landscape, biodiversity protects and restores ecosystems and optimizes the sustainable use of soil and water resources. Second, at the scale of the farming system, biodiversity contributes to the diversification of crops, agroforestry, allowing various adjustments in practices (e.g., soil fertility, rainwater harvesting). Third, at the level of the species or variety, biodiversity improves the stress tolerance through selection and breeding techniques, amplifying the use of resistant species, varieties, and breeds. One clear example provided by the authors at the farming scale is that in agroforestry systems, trees, and shrubs regulate soil moisture and temperature.

Despite the scientific evidence that relates biodiversity and climate change mitigation, current food systems are in the opposite direction, facing an increasing trend towards homogeneity. For example, Khoury et al. (2014) analyzed changes in the diversity of the portfolio of crop species in the food supplies of 152 countries comprising 98% of the world's population from 1961 to 2009. They concluded that globally, national food supplies have become increasingly similar in composition, precisely 36% more similar over the past five decades. A suite of global crop plants builds these national portfolios: maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), and rice (*Oryza sativa* L.), also known as the "big three" cereals. These crops have been bred for intensive agriculture, and they may not be able to cope with the challenging weather events we are already facing (Massawe et al. 2016).

To cope with climate change is urgent to diversify agricultural biodiversity and supply chains. Although the world counts with at least 50,000 species of plants suitable for human consumption, fewer than 300 species make their way into the market (Jacques and Jacques 2012). Brazil has a big potential of biodiversity with an estimated flora of 49,056 species, including algae, angiosperms, bryophytes, fungi, gymnosperms, ferns, and lycophytes (Jardim Botânico do Rio de Janeiro, 2020). These plants are strategic to a massive social change toward plant-based diets. Plant-based diets have the potential to reduce deforestation and methane production by domesticated ruminants (Wolf et al. 2019). Reductions in global deforestation and ruminant numbers could substantially contribute to climate change mitigation goals (Ripple et al. 2014). As the climate change crisis has global as well as local implications, the actors of the international political arena will need to find common ground to achieve the mitigation goals. For example, a recent study by Rajão et al. (2020) shows that almost 20% of soy exports and at least 17% of beef exports from Brazil to the European Union (EU) are contaminated with illegal deforestation of the Amazon and the Cerrado (Brazilian biomes). Related to this fact, there are two significant concerns. First, the increase of greenhouse gas emissions from deforestation and forest fires in Brazil could cancel out EU climate change mitigation efforts. Second, international consumers are demanding to boycott Brazilian products contaminated by deforestation, impacting the national economy. Thus, political will and compliance to international agreements are necessary and urgent to advance the climate change issue.

2.3 Biodiversity Fosters Sustainable Diets

The simplification of global and local agricultural systems decreases the availability of diverse food and its consumption (see Khoury et al. 2014), increasing the risk of various forms of malnutrition, potentially leading to undernutrition as well as overweight and obesity. The FAO's report *The State of Food Security and Nutrition in the World* (FAO 2020) shows that in 2019 almost 750 million people, or 10% of the human population, were exposed to severe food insecurity levels. The same report shows that almost two billion people have no regular access to safe, nutritious, and sufficient food and that obesity is also on the rise in all regions of the world.

The consumption of biodiverse food plants is directly associated with a healthy diet. In a broad review of the contribution of wild and cultivated biodiversity to improve diets, Powell et al. (2015) argue that several studies that looked at nutrient intake found a possible relationship between crop diversity and mean nutrient adequacy (a quality diet indicator) across multiple nutrients. In an international research effort, Lachat et al. (2018) assessed data from 24-hour diet recalls from 6226 participants (women and children) in rural areas from seven low- and middle-income countries, to analyze the relationship between dietary species richness and dietary quality. Their dietary quality analysis comprised the mean adequacies of vitamin A, vitamin C, folate, calcium, iron, and zinc. By dietary species richness, they consider the number of species consumed by each individual. Their results showed a positive association between nutritional and biodiversity indicators (species richness), both in the wet and dry seasons. Concerning specifically unconventional food plants, Powell et al. (2013), studying dietary diversity and wild plants in Tanzania, showed that although these plants contributed only 2% of the total energy in the diet, they provided significant percentages of vitamin A (31%), vitamin C (20%), and iron (19%). Even considering that the analysis of biodiversity in diets of industrialized and urban settings needs to advance, the current state of evidence shows that biodiverse food plants are relevant sources of energy, micronutrients, and bioactive compounds (Penafiel et al. 2011). Thus, the consumption of these plants is at the core of the proposal of sustainable or healthy diets,[4] those consisting of a diversity of plant-based foods, with low amounts of animal source foods and low amounts of highly processed foods (Willett et al. 2019).

Brazil has a strong potential for mainstreaming biodiversity into diets. The national ordinance no. 284/2018 identifies 101 native species with nutritional

[4] We understand sustainable diets as a synonym of healthy diets. For us, as for Willet et al. (2019), to be healthy, in a broad sense and long-term, diets need to protect both the environment and human health. To better understand the distinctions made in some cases among sustainable and healthy diets, see Béné et al. (2019)

potential, fostering their integration into national public policies, such as the Food Acquisition Program (*Programa de Aquisição de Alimentos*-PAA) and the National School Food Program (*Programa Nacional de Alimentação Escolar*-PNAE). Nutritional data of these plants are available through the Information System of Brazilian Biodiversity (*Sistema da Informação da Biodiversidade Brasileira*-SiBBr).[5] Moreover, the Brazilian food guide promotes food diversity, considering its role in contributing to a higher variety of nutrients and in protecting the environment (Brasil 2014). Another public health tool is the report *Alimentos Regionais Brasileiros* (Brazilian Regional Foods), published by the Health Ministry (Brasil, 2015), with the purpose of spreading knowledge of the diversity of Brazilian plants, presenting plant information, culinary uses, recipes, and nutritional information. Finally, one of the food composition tables used in the country, the *Tabela Brasileira de Composição de Alimentos* (TBCA/USP), includes a database (*Biodiversidade e alimentos regionais*[6]), containing a variety of plants consumed in Brazil, their scientific name, and cultivar identification.

However, there are several barriers to overcome in the promotion of diets rich in local plants, integrating them into Brazil's food system (see Box 1). Some of them are related to our current knowledge of biodiverse food plants. Jacob and Albuquerque (2020) present four significant gaps that can help to collectively align the research agenda of scientists interested in the topic. First, there is a need to create better strategies to map the biodiverse food plants available in our territory. The creation of research networks and the development of systematic reviews could be strategic to gather these data on a large-scale (see Jacob et al. 2020b as an example). Second, we need to overcome the lack of culinary data in our studies. Some processing food techniques (e.g., to wash, to heat, to infuse, to germinate, to ferment, to cure) or the combination of different foods can modify the diet food matrix and the bioavailability of certain nutrients or toxins. Third, the scarcity of nutritional composition data puts a real barrier to dietary assessments. Finally, we need to improve our capacity to express the relationship between people, plants, and culture in our research tools and teams. As Powell et al. (2015) affirmed, this understanding of complex and dynamic biocultural food systems and landscapes will require that nutritionists, for example, think about landscapes and biodiversity as more than just calories. There is no doubt that the dialogue between nutrition, ethnobiology, anthropology, and agronomy is strategic for improving our capacity to work with biodiverse food plants.

Finally, it is crucial to highlight the virtuous loop between human and environmental health. Biodiverse diets protect the diversity of life by fostering sustainable agricultural practices. Consequently, agricultural diversity can stimulate productivity, stability, ecosystem services, and food systems' resilience (Frison et al. 2011; Khoury et al. 2014). The connecting point to boost this relationship is in our diets. As individuals and as a society, we need to be aware that in the food systems

[5] See at: https://ferramentas.sibbr.gov.br/ficha/bin/view/FN

[6] See at: http://www.tbca.net.br/base-dados/biodiversidade.php

Box 1: Barriers to Promote Biodiverse Food Plants into Diets

- Disconnect between the biodiversity, agriculture, health, education, and other sectors
- Continued lack of resources to develop research and extension systems focused in biodiversity
- Biodiverse food-based approaches all too often fall outside the traditional scope of clinical nutrition and public health
- Lack of skills and institutional capacity necessary to promote multisector approaches
- Lack of data linking biodiversity to dietary diversity and nutrition outcomes
- Relevant information is highly fragmented, scattered in various publications and reports or not easily accessible databases to policymakers and practitioners
- Poorly developed public policies, infrastructure, and markets for most of the biodiversity for food and nutrition
- Reach and influence of the modern globalized food system and trade policies which impede or undermine promotion and consumption of biodiversity for food and nutrition, favoring the consumption of unhealthy processed foods
- Negative perceptions and attitudes to local, nutritionally rich traditional biodiverse foods
- The “artificial” cheap cost of global crops or imported foods which externalize their health and environmental costs
- Lack of farmers’ seed networks that support crop diversity sharing
- Lack of innovative food recipes that involve less cooking time and are more in tune with modern food consumption habits and lifestyles
- Lack of consumer demand, which translates into a lack of product awareness

Adapted from Hunter and Fanzo (2013) and Raneri et al. (2019)

dynamic, changes in our consumption patterns have effects on food production (Lawrence et al. 2015). Healthy diets are unaffordable for more than three billion people in the world (FAO 2020). More research is needed to identify and analyze the hidden costs of unhealthy diets, proposing measures for tackling these costs and investing into food system transformation.

2.4 Boosts Food System Resilience to Disease Outbreaks

The health crisis driven by COVID-19 highlighted the risks, weaknesses, and inequities underlying the global food system. In the recent years, we have had to deal with epidemic zoonoses such as avian influenza (H5N1), Severe Acute Respiratory Syndrome (SARS), Ebola virus, and Middle East Respiratory Syndrome (MERS). Over 70% of infectious diseases that have arisen in humans are related to animals, mostly originated in wildlife (FAO 2017).

The emergence of new pandemic and epidemic outbreaks may become more common in the future, considering that ecological catastrophes and climate change increase the frequency of zoonotic diseases (Patz et al. 2005; Alirol et al. 2011). Diverse high-risk human activities, such as industrial livestock production, intensify viral transmission between animals and people (Johnson et al. 2020). For instance, livestock breeding in tropical forests is related to deforestation, which is associated with an increase in infectious diseases such as dengue, malaria, and yellow fever (Wilcox and Ellis 2006).

Another disturbing loop relates to the destruction of natural habitats, biodiversity loss, viruses transmission, and emerging infectious diseases (Olival et al. 2017). According to the United Nations report on zoonotic diseases (United Nations Environment Programme 2020), more virus transmission events occur within communities that have low species diversity, which is referred as dilution effect. The dilution effect occurs because communities with more diversity of animals dilute transmission events keeping the virus prevalence low, thus reducing the number of susceptible animals. Unfortunately, as humans occupy and transform these environments, they disrupt the ecology of wildlife, altering the ecosystem balance, and increasing the likelihood that viruses will find intermediate hosts (Volpato et al. 2020; Jacob et al. 2020a). The conservation of biodiversity and the ecosystem plays a critical role in protecting humans from emerging infectious diseases.

A paradigm shift from industrial agriculture to diversified agroecological systems is an urgent challenge towards resilience. A resilient global system will help us cope with future shocks, making them less likely and critical (Kahiluoto 2020). Experts identify a series of actions to trigger a shift towards resilient food systems, including redirecting agricultural subsidies and investments into research on agroecology (IPES-Food 2016). In some cases, traditional practices focused on agrobiodiversity exhibit greater productivity than conventional agricultural methods. Prieto et al. (2015) demonstrated that the production of animal fodder in managed pastures reduces environmental stress in diverse systems, with taxonomic (interspecies) and genetic (intraspecies) diversity playing different and complementary roles. For example, a study of 81 smallholder communities in Nicaragua after Hurricane Mitch found that farms that used agroecological methods suffered less soil erosion compared to conventional farms (Holt-Giménez 2002; IPES-Food 2016).

Reconciliation between humanity and nature requires collective action along the entire agri-food chain. Thus, implementing any change towards a more resilient future for food systems requires that key stakeholders, including industry, policymakers, governments, and consumers, all take an active role.

3 Food Sovereignty Is Needed for Biodiversity Preservation and Sustainable Food Systems

According to the *Declaration of Nyéléni* (2007), "food sovereignty is the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems." Food sovereignty is thus the right of peoples to make decisions, democratically, about the management of food resources and policies at global, regional, and local levels (Wittman 2011; Weiler et al. 2015).

Food sovereignty poses challenges in the public and political spheres, as it confronts the concentration of power and the consequent social inequalities in food systems (Plahe et al. 2013; Jacques 2015). Some of the principal demands of the food sovereignty movement include agrarian reform in benefit of landless producers (Rosset 2011), the fight against the control of transgenic seeds by transnational agribusiness companies (Kerr 2013), and the demarcation of indigenous lands and respect for their biocultural heritage (Rocha and Liberato 2013; Queiroz 2015).

Discussions on food sovereignty, biodiversity, and social justice are interconnected. There is evidence that biodiversity loss is associated with a country's economic growth and social inequality (Naidoo and Adamowicz 2001; Mikkelson et al. 2007). Holland et al. (2009), analyzing socioeconomic models and the proportion of threatened species of plants and vertebrates in 50 countries, concluded that inequality is an essential factor in predicting the loss of biodiversity. Thus, the proposal for reform in the use and management of natural resources to meet human and environmental well-being requires an integrative approach.

Agricultural diversity is necessary for sustainable development, FNS, and biodiversity conservation (Zimmerer and De Haan 2017). In the context of food sovereignty, agricultural diversity is the starting point for the construction of food policies focusing on the autonomy of peoples, the resilience of productive systems, the use and conservation of plant and animal genetic resources, and the recognition of the cultural identity and the affirmation of the rights of traditional peoples (see Altieri and Toledo 2011; Lenné and Wood 2011).

In the food sovereignty debate, biodiversity conservation in agricultural systems responds to a cultural need. Native plants have cultural and genetic roles, and preserving them means safeguarding biocultural diversity (Jacob et al. 2020b; UNESCO 2003). The preservation of traditional knowledge associated with plants is crucial to food sovereignty since people select plants in nature, rationally, with precise purposes (Moerman 1979). Rangel-Landa et al. (2017), studying socio-ecological factors that influence the decision to domesticate native species, concluded that uncertainty in resource availability is a major factor motivating the management of edible plants. In the case of medicinal and ceremonial plants, reciprocal interchanges, curiosity, and spiritual values are essential factors. So, the knowledge embedded into the decision to domesticate plants is relevant to safeguard the biodiversity heritage of a people.

Agricultural diversity and biodiversity conservation are also important in the context of agroforestry. FAO defines agroforestry as land-use systems and technologies where woody perennials are cultivated on the same land management units as agricultural crops and animals, in some particular spatial arrangement or temporal sequence (FAO 2013). Ethnoagroforestry analyzes traditional forms of agroforestry management, considering cultural, economic, and environmental factors from local communities (Moreno-Calles et al. 2016). Agroforestry practices connect synergically with the use and conservation of biodiversity, by integrating nature and culture, wild and domestic diversity, and, finally, different scales and forms of land management, providing the basis for food sovereignty and sustainability management of ecosystems (Moreno-Calles et al. 2016). For example, in Mexico, 80% of the forests belong to 30,000 traditional communities (INEGI 2008). Part of the agroforestry systems occurs mainly in indigenous areas. And most of the country's environmental movements are based on the distribution of agroforestry management zones, indicating the active participation of indigenous peoples as forest guardians and promoters of food sovereignty (Toledo et al. 2015). Studies in ethnoagroforestry have shown a relationship between traditional agroforestry and soil fertility (Garcíalicona et al. 2017), biological conservation (Franco-Gaona et al. 2016; Hill et al. 2019), and high diversity (Hoogesteger van Dijk et al. 2017).

There is no food sovereignty without biodiversity. And the preservation of biodiversity depends crucially on local people's rights to manage their natural resources. Therefore, some relevant pillars to food sovereignty policies are (1) genetic resources, ecology, and evolution; (2) governance policy, institutions and legal agreements; (3) food, nutrition, health, and disease; and (4) factors of global change with socio-ecological interactions (Zimmerer et al. 2019).

4 Final Considerations

Our review demonstrates the breadth of ways in which biodiversity supports the transformation of sustainable food systems, with positive outcomes for human and environmental health. We argued that biodiversity contributes to sustainable food systems and human health by supporting food and nutrition security, strengthening resilience to climate change, fostering sustainable diets, and boosting resilience to disease outbreaks. Unfortunately, we face the rapid decline of biodiversity globally, threatening more species with global extinction now than ever before. We will not achieve the goals of conserving biodiversity until 2030 without transformative changes across economic, social, and cultural factors that guide human decisions. These transformative changes demand new forms of food systems governance based on food sovereignty. This complexity of factors must guide our analysis and actions as scientists, politicians, professionals, and citizens towards sustainable food systems.

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