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THOMAS REVIEW

Food plant diversity in a rapidly changing world

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Societal Impact Statement

Diversity in food plants is essential to human and planetary health. On farms, in diets, and in many other areas of food systems, this diversity has undergone enormous change globally, including significant decline. We describe major trends in how food plant diversity has been changing, note the responses from conservation communities, highlight gaps in our current understanding about these trends, and outline priorities to further safeguard and promote the use of food plant diversity in a rapidly changing world.

Summary

Diversity in food plants is essential to human and planetary health. This diversity has undergone enormous change in human diets, crop production areas, agricultural research pipelines, and other aspects of food systems over the past century, and there is every indication that there is more change to come. We describe major trends in how food plant diversity has been changing, including increasing homogeneity across food systems based on a relatively narrow set of major crops and significant losses of local diversity and associated knowledge and practices. We provide an overview of the responses to these changes from conservation communities. We then highlight gaps in our current understanding about these trends and conclude by outlining priorities to further safeguard and promote the use of food plant diversity in a rapidly changing world.

KEYWORDS

biocultural diversity, crop diversity, food security, food systems, genetic erosion, global change, homogeneity, plant genetic resources

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1 | FOOD PLANT DIVERSITY IS INTEGRAL TO HUMAN AND PLANETARY HEALTH

Among the deepest relationships human beings have with other organisms are with the plants we eat. The terms of these relationships are the furthest possible from being superficial dalliances. Rather, they are an essential part of every day we are alive for every one of us, wherever we are on this planet.

Fruits and vegetables, grains and legumes, nuts and seeds, oils and sugars, herbs and spices, and other plant foods provide most of the energy and nutrients we need to function and grow (FAO, 2026a; Hanley-Cook et al., 2021, 2025; Rockström et al., 2025). But these relationships mean so much more than simple sustenance. Their flavors, textures, aromas, colors and other characteristics contribute to the pleasure of eating and influence how we define and differentiate ourselves, from individually to societally. The relationships connect us to specific places and seasons of the year. They are a centerpiece around which loved ones, friends, and communities come together to share, to celebrate, and to console. We are, in so many ways, what we eat.

These relationships have been incredibly diverse. Over 26,000 plant species, from a very wide range of botanical families, are documented as having been eaten by people worldwide (Diazgranados et al., 2026), demonstrating our tremendous botanical interest, need, and experimentation. Many of these plants have been managed by people, providing them greater opportunities to thrive by reducing competition from other plants in their habitats, protecting them from being eaten by other animals, or by pruning, transplanting, burning, or other practices (Casas et al., 2007; Cruz-Garcia, 2017). At least 7000 of these edible plant species are known to have been cultivated (Khoshbakht & Hammer, 2008), creating much more extensive interdependence between people and these food plants.

Several hundred cultivated plant species are currently grown, traded, and consumed extensively across the world (Khoury et al., 2023; Ulian et al., 2020), providing the primary botanical foundation of our contemporary global food system (Figure 1).

Additional plants contribute value to our food systems. Through crop breeding, wild progenitor species and other close wild relatives of agricultural plants have become critically important sources of pest and disease resistance, tolerance to abiotic stresses, and nutritional and other quality traits (Castañeda-Álvarez et al., 2016; Dempewolf et al., 2017; Hajjar & Hodgkin, 2007). Hundreds of these wild relative species are documented as having contributed to crop development, with over a thousand species identified as of high interest for further breeding research (USDA ARS NPGS, 2026; Vincent et al., 2013). Many additional plant species represent promising candidates as new food crops (Ciotir et al., 2019; Krug et al., 2023). Moreover, dozens of forage and fodder crops, along with hundreds of wild forage plant species, nourish livestock and thus indirectly feed humanity through eggs, milk, and meat (Khoury et al., 2023). In agroecosystems, a wide range of plant species contribute to productivity, sustainability, and resilience by creating more fertile soils, for example, through nitrogen fixation (Deng et al., 2017), by providing food and habitat for crop pollinators and other beneficial insects (Isaacs et al., 2009), and other services (Casas et al., 2007). Beyond food, plant species are central sources of medicine, fiber, and industrial products and are employed for ornamental, construction, fuel, forestry, environmental restoration, and other essential purposes (Diazgranados et al., 2020; Khoury et al., 2023; Ulian et al., 2020).

While the plant species diversity in our food systems is astonishing, it is matched by the breathtaking variation found within our cultivated food plant species. Crops are often represented by several thousand distinct varieties, adapted to different agroecological conditions and used for different cultural and culinary purposes (Figure 2).

This extraordinary species and varietal food plant diversity, and its underlying genetic, morphological, and biochemical variation, speak to the tremendous environmental diversity on this planet, with different climates, soils, pollinators, microorganisms, and other abiotic and biotic forces shaping cultivated food plants in different ways, in the wide range of places they have been planted, tended, harvested, processed, and eaten. At the same time, they reflect human ingenuity and care, and plant adaptability, combining through the remarkable biocultural processes comprising food plant domestication (Fuller et al., 2023; Hufford et al., 2019; Larson et al., 2014; Meyer et al., 2012; Milla, 2023). Distinct cultures across every inhabitable continent formed interdependent relationships with local plants, with both the plants and the people fundamentally changing through the process (Bragazzi et al., 2024).

Food plant diversity is, thus, biocultural diversity—a result of long-term interactions between different plants and different peoples in different environments across the planet, giving rise to different forms for different needs and desires, as well as specific cultural knowledge on how to cultivate, maintain, process, and eat them (Argumedo et al., 2021; Bridgewater & Rotherham, 2019). Food plant diversity is associated with linguistic and other aspects of cultural variation (Perales et al., 2005; Pieroni et al., 2020), with the greatest concentrations of this diversity found in the geographic areas [once called centers of origin, now more commonly referred to as regions of diversity (Khoury et al., 2016)] where coevolutionary processes between these plants and people have been underway for many hundreds or thousands of years (Figure 2) (Argumedo et al., 2021; Gavazzi, 2025; Hammer et al., 2025).

Food plant diversity underpins the productivity, sustainability, resilience, and adaptive capacity of agricultural systems (Khoury et al., 2021). In "traditional" farming systems, for example, an assortment of crops and varieties is typically planted in a combination of rotations, mixtures, and scattered fields to reduce pest and disease impacts, increase the efficiency of nutrient and water use, provide yield stability, and offer resilience during extreme weather and other climatic stresses (Goland, 1993; Holt-Giménez, 2002; Jarvis et al., 2008; Kremen et al., 2012; Smithson & Lenné, 1996). This diversity evolves in response to changing local conditions and cultural needs through cultivation, selection, and exchange (Bellon, 1996; Louette et al., 1997; Mercer & Perales, 2010). Food plants contribute to these agroecological and agroevolutionary services in interaction with surrounding biodiversity, including other plants, pollinators, seed

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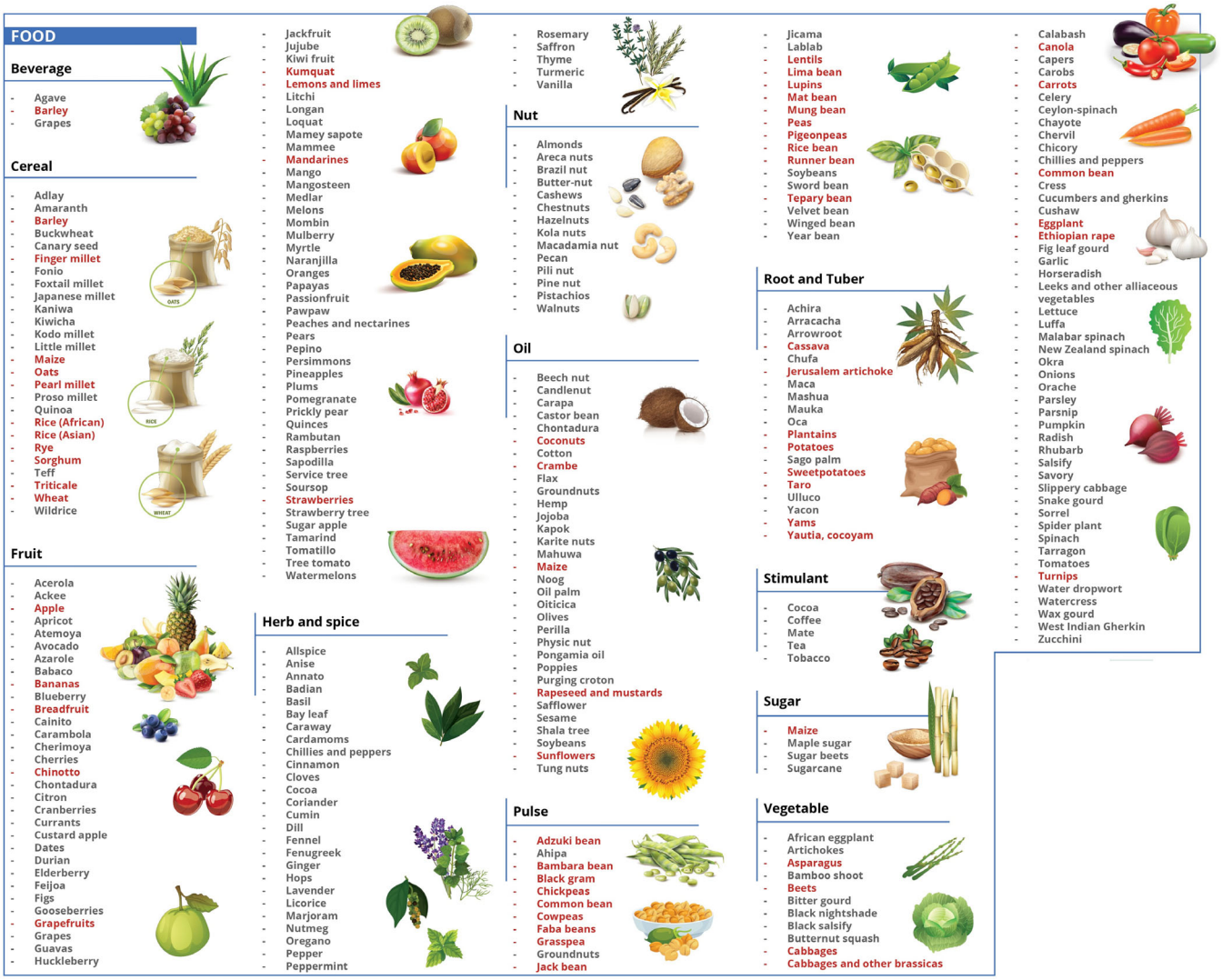

FIGURE 1 Food plants included in *The Plants that Feed the World* (Khoury et al., 2023), mainly comprising internationally significant crops and crop commodities. The plants in red are currently listed in Annex 1 of the International Treaty on Plant Genetic Resources for Food and Agriculture and are therefore covered under the Treaty's Multilateral System of Access and Benefit sharing, designed to facilitate access to plant genetic resources globally and to share through a standardized process the benefits derived from their use. Those in black are not currently listed. Figure adapted from Khoury et al. (2023) (CC-BY-NC-SA-3.0-IGO).

dispersers, soil- and plant-inhabiting microorganisms, livestock, and people, leading to unique agroecosystem-level diversity (Casas et al., 2007; FAO, 2019; Mastretta-Yanes et al., 2024; Pilling et al., 2020) (Figure 3a).

In "industrial" agroecosystems—which are typically much more homogeneous in terms of the crops, their varieties (cultivars), and the uniformity within varieties, and which often employ large machinery, irrigation, fertilizers, and biocides—food plant diversity is still essential. In these systems, cultivars are replaced frequently with new varieties to keep pace with changing weather, emerging pests and diseases, and evolving market demands, depending on temporal food plant diversity to mitigate low spatial diversity (Figure 3b) (Duvick, 1984). These systems rely on the consistent functioning of a research pipeline starting with crop genebanks and other ex situ (off-site) repositories—which maintain millions of accessions of traditional varieties (also called landraces or farmer varieties), wild relatives of crops, and other types of "genetic resources" held in cold storage, test tubes, cryotanks, or field collections. These genetic resources are distributed by the repositories to plant breeders employed at public or private institutions who develop cultivars based on these materials. The cultivars are further refined by seed companies and other organizations who subsequently market them to farmers (Esquinas-Alcázar, 2005; Gepts, 2006, 2023; Hoisington et al., 1999). Organic, regenerative, and other agroecological farming approaches often mix these strategies to varying degrees, employing both spatial and temporal diversity, and growing farmer-managed varieties as well as industry-developed cultivars (Barot et al., 2017; Gao et al., 2023; Westengen et al., 2023).

Given that crop production systems are the world's largest terrestrial land cover type—there are at least 1.9 billion hectares of

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croplands in the world, equating to 12.6% of global terrestrial area (USGS, 2017)—the diversity of plants in these agroecosystems is not only important to local productivity, sustainability, resilience, and adaptive capacity but also consequential to global environmental health (Fanzo et al., 2021; Kremen & Miles, 2012; Rockström et al., 2025; Wanger et al., 2020). Agriculture is a major contributor to anthropogenic greenhouse gas emissions (Chataut et al., 2023), consumes nearly 70% of freshwater globally (Ingrao et al., 2023), is the single greatest threat to terrestrial biodiversity, mainly due to habitat loss (Benton et al., 2021), and causes widespread pollution, soil erosion, and other forms of environmental degradation (Bodirsky et al., 2014; Foley et al., 2011; Godfray et al., 2010; Montgomery, 2007; Rockström et al., 2025). The food plants covering agroecosystems factor importantly in these impacts, given their different nutrient, water, biotic and abiotic stress protection, and other requirements, and the diversity among and within these plants offers opportunities to reduce or mitigate them (Springmann et al., 2018; Tilman & Clark, 2014).



FIGURE 2 A recently harvested mixture (*Chaqru*, in Quechua) of traditional potato (*Solanum* L. spp.) varieties cultivated together in the same field by Alberto Chura in the Paucartambo Province, Peru. Over 300 distinct potato varieties of several domesticated potato species are cultivated by communities across Paucartambo, an area that is located within the region of origin of the crop, where potatoes have been grown for ca. 7000 years. Photo by Stef de Haan.

Yet food plant diversity is not confined solely to crop production areas. It also fills our markets, kitchens, restaurants, dinner tables, and landfills—and thus contributes to the range of impacts caused by these environments (Boakes et al., 2024). This diversity is consequential to livelihoods of those households involved in producing, processing, marketing, and preparing food, which is nearly half of the world's population (Davis et al., 2023). In the case of wild edible plants and wild relatives of crops, this diversity occurs not only on farmlands but also in forests, grasslands, deserts, and other natural ecosystems (Castañeda-Álvarez et al., 2016; Khoury et al., 2019).

These are the reasons why edible botanical diversity is so profoundly connected to the well-being of both people and the planet. Food plant diversity is integral to human and planetary health, which is why loss of this diversity and associated knowledge and biocultural processes is a global concern.

2 | GLOBAL CHANGE IN FOOD PLANT DIVERSITY

Over the past 12,000 years of the Holocene, millions of forms of thousands of crop species arose through cultivation, selection, exchange, processing, and eating, adapting to unique environments and becoming central to biocultural practices and identities. Through these processes, people developed deeply interdependent



FIGURE 3 Examples of strategies for use of food plant diversity in agroecosystems. (a) Traditional agroecosystem containing an assortment of food plant species and varieties, including food trees, bananas and plantains (*Musa* L. spp.), and herbaceous food plants. Photo: CIAT. (b) Industrial rice (*Oryza sativa* L.) agroecosystem, where homogeneous varieties are typically replaced by new varieties every few years. Photo: ©2012CIAT/NeilPalmer.

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relationships with plants, which led to this global cornucopia of food crops and varieties.

As the pace and extent of human mobility increased, so did the spread of food plants. People brought, traded, gifted, stole, and otherwise moved this edible flora across the planet, developing new forms for new needs and opportunities in each new place. For example, the tomato (*Solanum lycopersicum* L.), of Andean and Mesoamerican origins (Razifard et al., 2020), became a diverse staple of Mediterranean cuisines; several species of chile peppers (*Capsicum* L.) from the American tropics transformed dishes across Africa and Asia (Tripodi et al., 2021), and coffee (*Coffea arabica* L., and later *Coffea canephora* Pierre ex A. Froehner), of African origins, came to be grown across the tropics worldwide. Such spread and dispersal of food plants over the centuries has fundamentally altered economies and societies worldwide (e.g., Bazile et al., 2016; Byerlee, 2020; Prodöhl, 2013; van de Loosdrecht et al., 2024; Vi et al., 2025) and has led to the vast and highly interconnected global food system we know today (Figure 4) (Khoury et al., 2016).

At the same time, and because of many of the same societal processes, the spread of cultivated food plants has reduced botanical diversity in our food systems. The agricultural revolution brought new plants to human diets, but those foods undoubtedly replaced a wider range of wild species (Larsen et al., 2019; Moubtahij et al., 2024). The more recent global spread of crops and associated agricultural and economic practices has led to considerable decline, marginalization, or loss of locally unique crop species and varieties as well as associated knowledge and practices (Frankel, 1974; Frankel & Bennett, 1970; Gepts, 2023; Harlan, 1972; Harlan & Martini, 1936; Hawkes, 1971; Hufford et al., 2019; van de Wouw et al., 2009; Wilkes, 1977).

The past 100 years—the period when these changes have been more comprehensively documented—has been one of further, and probably most extensive, reduction of food plant diversity globally, caused by tremendous economic, demographic, agricultural, technological, climatic, and political change (Gepts, 2006; Harlan, 1975; Hoisington et al., 1999; Khoury et al., 2021; Zimmerer, 2010). While food plant diversity is always evolving, the magnitude and pace of these changes over this period have severely disrupted the coevolutionary processes that have historically engendered this diversity in traditional agroecosystems. In this very short interval in comparison to the millennia of our agricultural history, the majority of traditional crop varieties that were previously cultivated have disappeared, are now grown in much reduced areas and quantities than formerly, or only persist as small samples in conservation repositories. Many wild edible plants and wild relatives of crops have also declined, in parallel with the degradation of their natural environments. Due to this "genetic erosion," that is, the loss of crop or wild relative diversity, typically measured by decline of species, varietal, or genetic variation (Bennett, 1964, 1968; Frankel & Bennett, 1970; Khoury et al., 2021; van de Wouw et al., 2009), the world may now be well past peak food plant diversity.

Further losses in food plant diversity are ongoing (Khoury et al., 2021). This is especially the case in places where the connectivity between traditional agricultural or Indigenous communities and wider systems of transport and economies is still increasing. It is where demographic shifts, such as out-migration and commercialization of land and labor, are occurring at a rapid pace. It is on small islands, in mountainous regions, and other areas where the impacts of climate change are most acute. It is in the many areas globally that are destabilized by war and civil strife. And, in terms of varieties used in

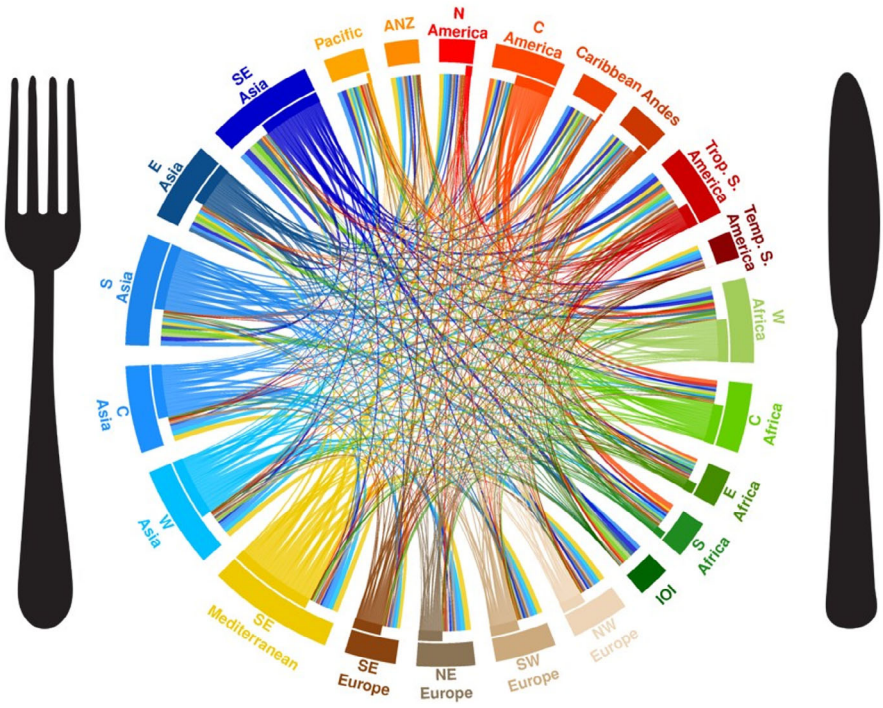

FIGURE 4 Global interconnectedness regarding the primary geographic regions of diversity of major food crops and their current importance in terms of calories (kcal capita^{-1} day^{-1}) in regional food supplies around the world. Each region has a color representing its own native major crops, and those colors are connected to other regions due to the importance of those crops in the food supply in other regions. The direction of the contribution is indicated by both the primary region's color and a gap between the connecting line and the consuming region's segment. The magnitude of contribution is indicated by the width of the connecting line. ANZ, Australia and New Zealand; C America, Central America and Mexico; IOI, Indian Ocean Islands. Adapted from Khoury et al. (2016) (CC-BY-4.0).

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industrial agriculture, it is where public breeding institutions are declining and where seed companies are consolidating (van de Wouw et al., 2010).

The global interconnectedness of human societies, subsequent availability of foods from across the planet to those that can pay for them (Khoury et al., 2016), and the consequent dissolution of traditional foodways in many regions appear to come at a significant cost to food plant diversity—losses of locally unique crops, varieties, wild relatives, farming systems, food processing techniques, dishes, and associated knowledge (Khoury et al., 2021). The result is a continuing increase in homogeneity in what and how we eat around the world (Khoury et al., 2014). The irony of the globalization of food systems is that it has led to a greater diversity of the internationally important crop species available for consumption worldwide, while also increasing similarity in what people eat (Figure 5).

If we are what we eat, these ongoing trends indicate that people worldwide are becoming ever more the same brand of global consumer, dependent on a relatively short list of major cereal, sugar, and oil crops, accompanied by a smattering of commodity vegetables, fruits, pulses, roots and tubers, and nuts and seeds. And, while it will probably always be overly reductionist to state that only a handful of food plants feed the world (FAO, 2004; Khoury et al., 2021), this oft-repeated narrative is surely truer now than it ever was before in human history.

These changes in food plant diversity have not gone unnoticed. They have sparked a global response, with scientists, activists, farmers, and communities mobilizing to address the accelerating loss of food plant diversity.

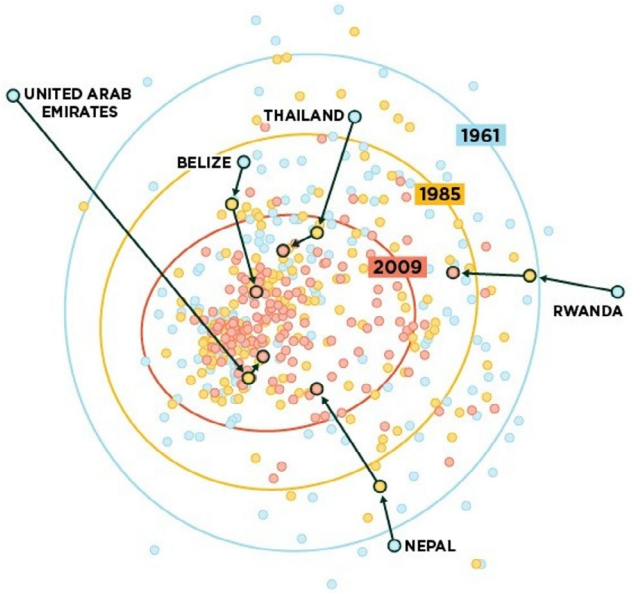

FIGURE 5 Global change in similarity (homogeneity) of national food supplies, as measured by Bray–Curtis dissimilarity from each country to the global centroid (mean composition) in each year, converted to similarity. The figure displays a multivariate ordination of crop commodity composition (i.e., both the number of crop commodities and the relative abundance/evenness of the crop commodities in each food supply) in contribution to calories in national food supplies in 1961 (blue), 1985 (yellow), and 2009 (red). Circles represent 95% CIs around the centroid in each year. Several countries are identified for illustrative purposes. Between 1961 and 2009, the area contained within these 95% CIs decreased by 68.8%, representing the decline (i.e., homogenization) in country-to-country variation of food plant commodity composition over this period. Adapted from Khoury et al. (2014).

3 | RESPONSES TO GLOBAL CHANGE IN FOOD PLANT DIVERSITY FROM CONSERVATION COMMUNITIES

In the early 20th century, crop researchers began to raise concerns about losses of food plant diversity on farms and in wild habitats (Baur, 1914; Harlan & Martini, 1936). The first genebanks—ex situ repositories built to maintain and distribute seeds and other plant tissues for crop introduction and development—had been established around this time, and these started to assume conservation responsibilities for this diversity (Esquinas-Alcázar, 2005; Gepts, 2006, 2023; Hoisington et al., 1999).

Distress over the growing magnitude and pace of loss of traditional crops and varieties, as well as wild relatives, increased during the mid-Century Green Revolution (Bennett, 1964, 1968; Fenzi & Bonneuil, 2016; Frankel, 1974; Frankel & Bennett, 1970). As industrial cultivars were developed from landrace and crop wild relative genetic resources, the widespread deployment of industrial cultivars in agroecosystems where these traditional forms of food plant diversity had arisen and evolved was likened to building the "roof with stones from the foundation," particularly in the absence of comprehensive efforts to conserve these genetic resources in repositories (Fowler & Mooney, 1991). The concerns led to the first major international efforts to collect and deposit threatened food plant diversity in genebanks (Esquinas-Alcázar, 2005; Plucknett et al., 1987). These activities were further motivated by emerging signs of susceptibility to crop loss in industrial cultivars, primarily from pests and diseases, as a result of their genetic uniformity (National Research Council, 1972; Tatum, 1971).

Extensive international efforts from the 1960s to 1980s resulted in the collecting and depositing into genebanks of hundreds of thousands of landrace and wild relative accessions; the establishment of international collections of cereal, pulse, root and tuber, and other staple crops; the formation of a new international center—the International Board for Plant Genetic Resources; and the enactment of the first international agreement prioritizing the conservation and sustainable use of food plant diversity, then recognized as global public goods (FAO, 1983; Thormann et al., 2019). Civil society organizations also formed in several regions to conserve food plant diversity in ex situ repositories and within farmer and gardener networks (Gepts, 2023).

Over the 1980s and 1990s, while further national, regional, and international ex situ food plant diversity collections were amassed, worries surfaced about the vulnerability of these collections due to inadequate funding, capacity, and infrastructure. Repositories began

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to duplicate their collections in partnering institutions to mitigate these challenges and to protect the diversity from natural disasters, war, and civil strife (Holden, 1984; Lyman, 1984; Peeters & Williams, 1984).

During this same period, recognition in scientific, research, and activist communities of the contributions of food plant diversity to the stability, resilience, sustainability, and adaptive capacity of traditional agroecosystems became more mainstream (Fenzi & Bonneuil, 2016; Mijatović et al., 2013). Increasing threats to other aspects of agroecosystem diversity, including to pollinators and livestock, were also becoming apparent (Allen-Wardell et al., 1998; Garibaldi et al., 2013; Tisdell, 2003). In response, in situ (on-site, in natural habitats) and on-farm food plant diversity conservation initiatives began to take root (Bellon, 2004; Brush, 1991; Wood & Lenne, 1997).

By the 1990s, biodiversity loss had become a global concern, resulting in the enactment of the Convention on Biological Diversity (CBD), which mandated its conservation, sustainable use, and the fair and equitable sharing of the benefits arising from such use (CBD, 2016). With the coming into force of the CBD, the previous international accord on food plant diversity (FAO, 1983) was revisited, resulting in the signing in 2001 of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA, also known as the Plant Treaty) (FAO, 2009). In alignment with the CBD, the objectives of the Plant Treaty are the conservation and sustainable use of PGRFA and the fair and equitable sharing of the benefits arising out of their use for sustainable agriculture and food security. The Plant Treaty established a Multilateral System (MLS) of access and benefit sharing covering 64 major crops and forages important to global food security (Figure 1); the Benefit Sharing Fund arising from the MLS supports in situ, on-farm, and integrated (ex situ and in situ) conservation, strengthening of local seed systems, and genetic resources research and innovation (FAO, 2026b).

In 2004, the Global Crop Diversity Trust (Crop Trust) was established to further secure and provide reliable, long-term funding for the ex situ conservation of food plant diversity worldwide (Esquinas-Alcázar, 2005). In alignment with the Plant Treaty, the Crop Trust has catalyzed food plant diversity conservation and use through knowledge generation and diffusion as well as direct support for these activities, both via its endowment, which has thus far largely focused on conserving collections in international genebanks, and through thematic projects aimed at strengthening the global genebank system.

Conservation and sustainable use of food plant diversity is now prioritized in a range of major international agreements, including those focused on food and agriculture (FAO, 2009; FAO, 2012), sustainable development (United Nations, 2008); Indigenous rights (United Nations, 2026), and biodiversity conservation (CBD, 2011; CBD, 2020; CBD, 2024; Global Partnership for Plant Conservation, 2025) (Khoury et al., 2026). As the perceived value of genetic and other information associated with this diversity has also increased, these data have in turn become subject to discussions around access and benefit sharing (Marden et al., 2023; Rohden & Scholz, 2021; Scholz et al., 2022).

Today, food plant diversity conservation efforts are substantial: The latest status report for the world's genebanks, the *Third State of the World's Plant Genetic Resources for Food and Agriculture* (FAO, 2025) estimates that over 850 genebanks collectively maintain close to 6 million accessions. Safety duplication of a substantial proportion of this diversity is known to be accomplished among institutions and at the Svalbard Global Seed Vault (Khoury et al., 2023; Westengen et al., 2013, 2020), where over 1.4 million samples are now stored (Norwegian Ministry of Agriculture and Food, 2026). Food plant diversity is also conserved ex situ in botanic gardens, universities, civil society organizations, community seedbanks, farmer and gardener networks, and public and private breeding programs. Information on these collections is much less readily available (Khoury et al., 2026). Protected areas offer habitat conservation for some crop wild relatives (Khoury et al., 2019) and, to a much more limited degree, landraces, although neither are typically prioritized in management plans (Khoury et al., 2020). A range of in situ and on-farm conservation efforts focus on specific crops and agrarian communities around the world (Argumedo et al., 2021), and on strengthening and protecting farmer-managed (i.e., "informal") seed systems (Westengen et al., 2023).

While these efforts over the past century have been widespread and substantial, many gaps in the conservation of food plant diversity persist, particularly regarding wild edible plants, wild relatives of crops, and neglected and underutilized (more recently termed "opportunity") crops (Castañeda-Álvarez et al., 2016; Engels & Ebert, 2021; FAO, 2025; Gepts, 2023; Khoury et al., 2019, 2021, 2023; Ramirez-Villegas et al., 2022). Meanwhile, global environmental and societal change continues, with the impacts of further habitat loss and climate change, among other factors, increasing the urgency to fill these gaps, while it is still possible to do so.

4 | GAPS IN OUR UNDERSTANDING OF FOOD PLANT DIVERSITY IN A TIME OF RAPID GLOBAL CHANGE

While we understand the general trajectory of food plant diversity over the Holocene, including decline in this diversity particularly in the past century, there is much that we still do not know about the magnitude, drivers, and impacts of these changes.

How much species, varietal, genetic, and other aspects of diversity in food plants and their wild relatives once existed, and how much has been lost over time, are not well understood, as trends in food plant diversity have not been systematically tracked at the global level until relatively recently (Khoury et al., 2021, 2023). A range of laboratory-, literature-, and field-based methods have been used by researchers to estimate losses and other changes based on available information primarily for annual field crops, providing the main insights we have into the erosion of food plant diversity (e.g., Fu & Dong, 2015; Hammer & Laghetti, 2005; Jordan et al., 1998; McLean-Rodríguez et al., 2019, 2021; Schouten et al., 2019; Thormann et al., 2017, 2018; van de Wouw et al., 2010; van Heerwaarden

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et al., 2009). A growing set of community-based methods focused on participatory monitoring are offering additional insights (De Haan et al., 2016; Ruck et al., 2024; Sotomayor et al., 2020). These include through community priority setting, baseline inventories and catalogues, establishment of local monitoring methods and tools, and development of collaborative information resources that feed into decision support systems.

New frontiers in understanding food plant diversity—such as differences in chemical composition and nutritional compounds—are just now beginning to provide insights into the remarkable levels of unseen variation that were largely unknown a few decades ago (Ahmed et al., 2022; Hart et al., 2025; Jarvis et al., 2024). Unfortunately, here too, there is scant information about how much of this diversity once existed or has been lost.

Further insights on the evolutionary drivers of crop domestication, particularly with regard to varietal diversification and maintenance, are needed to develop more effective in situ and on-farm conservation strategies supporting these dynamic biocultural processes (Allaby et al., 2022; Fuller et al., 2023; Gao et al., 2023; Hufford et al., 2019; Larson et al., 2014). Further, while considerable evidence about the functional role of food plant diversity in agroecosystems has been compiled, more research is needed to understand the specific benefits and trade-offs of the use of this diversity in different agroecosystems at different scales, including, pragmatically, how to maximize benefits while minimizing trade-offs (Holt-Giménez, 2002; Kremen et al., 2012).

The positives, drawbacks, and risks of increasing homogeneity in food plant diversity in the global food system are insufficiently understood. Regarding diets, many more human beings have been fed over the last century than ever before in human history, and in many places, the proportions of hungry people (as measured by caloric intake) have generally decreased over time (Costlow et al., 2025). On the other hand, the impacts of food plant diversity homogenization on micronutrient sufficiency are unclear, knowledge gaps that are critically important to fill given major, widespread, persistent deficiencies in key vitamins and minerals (Passarelli et al., 2024). Novel research is providing increasing evidence regarding the positive associations between dietary variety (especially of plant species) and more diverse and healthier human gut microbiomes (McDonald et al., 2018; Sonnenburg & Sonnenburg, 2019; Wiese et al., 2025). The impact of dietary homogenization on the diversity and health of the microorganisms within us is insufficiently understood, although it is likely to be significant (Adler et al., 2013; Lozupone et al., 2012).

Further, more information is urgently needed regarding dietary homogeneity, in particular the association between the globalized food plant commodities—which increasingly come to consumers as ingredients in highly- or ultra-processed shelf-stable products—and exponentially rising rates of diet-related diseases including Type 2 diabetes, heart disease, and several forms of cancer (De-Regil et al., 2025; Drewnowski & Popkin, 1997; Matji & Brero, 2025; Monteiro et al., 2025; Ng et al., 2025; Rockström et al., 2025; Scrinis et al., 2025).

What is clear is that the more humanity relies on a relatively limited set of globalized food plant species, the more these species must be productive, resilient, sustainable, healthy, available, and accessible for both people and the planet. We are becoming ever more interdependent on these plants. It is also evident that food systems at any given level can only hold so much diversity, and thus, there is a trade-off to further globalization. That is, underneath the very apparent global homogenization trend is ongoing loss, decline, and marginalization of locally distinct diversity, which is only partially documented, if at all. The long-term impacts of these changes in terms of human and planetary health are not clear.

The extent of homogenization across the wider spectrum of food system activities also merits wider study. For example, there is some evidence of increasing homogeneity in crop species richness across subcontinents (Martin et al., 2019) and among counties in the United States (Aguilar et al., 2015). Several studies assessing genetic diversity have found greater similarity in crop cultivars over time, even in contexts where they may be becoming more genetically diverse as a group compared to previous decades (Reif et al., 2005; Souza & Sorrells, 1989). This may be due, at least in part, to ongoing consolidation among companies dominating the agricultural seed industry (van de Wouw et al., 2010).

Homogenization trends have also been recorded in traditional farmer varieties and even in wild relatives, demonstrating diversification of local populations due to introductions of exotic forms as a result of the increasing connectivity of local regions with the wider world and of faster dispersion of new varieties to those regions. This has in turn resulted in ever fewer locations that harbor isolated, rare, or traditional forms and led to greater genetic homogeneity overall across wider landscapes (Olodo et al., 2020; Rice et al., 2006; Rojas-Barrera et al., 2019; Thormann et al., 2017, 2018). Increasing homogeneity and associated declines in local diversity are also documented in the ornamental plant nursery sector (Kinlock et al., 2023), and in many natural biological systems impacted by habitat modifications, nonnative species, pollution, and other changes (Baiser et al., 2012; Crispo & Chapman, 2010; Daru et al., 2021; Newbold et al., 2018).

While more information is needed about the magnitude and drivers of global change and especially loss in food plant diversity, even more important, practically speaking, is to better understand the degree to which current food systems are vulnerable because of increasing species, varietal, genetic, and other forms of uniformity. The theory that more uniform agroecosystems are more vulnerable to loss from biotic challenges such as pests and diseases, and abiotic challenges such as extreme weather events, has been well established since the Irish potato famine (1845 to 1852). Following the 1970 Southern Corn Leaf Blight epidemic in the United States—during which 15% of the country's crop was destroyed—the National Academy of Sciences published what remains the most comprehensive analysis of crop genetic vulnerability to date (National Research Council, 1972). Unfortunately, research following up on this antiquated publication has been rather scarce.

The extent of genetic uniformity in our contemporary crop production areas is poorly documented, and the degree of vulnerability as a result of this uniformity is even less well understood. We are just beginning to develop standardized metrics to track diversity among

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and within crops at the global level (Khoury et al., 2023). The research community has provided some information about the diversity among and within commercially available cultivars of some major crops in some regions (van de Wouw et al., 2010), but much less knowledge is available about the spatial diversity of these varieties in current production systems (Khoury et al., 2021). Curiously, although several major crop loss events have occurred since the Southern Corn Leaf Blight epidemic, for example, in coffee (Avelino et al., 2015) and banana (Dita et al., 2018), there have probably been fewer documented cases of severe events than projected or feared a half century ago. How much this is a result of proactive efforts from genetic resource conservation, plant breeding, and farming communities, versus simply good luck, is unclear.

To gain a better understanding of the potential vulnerability of agricultural production systems due to uniformity, it is necessary not only to quantify the crop diversity in these systems but also to study the potential and limitations of agronomic tools and technologies to mitigate this uniformity; to predict the biotic and abiotic stresses that crops will be facing in the future, including under increasing climate-related challenges; to assess whether and how genetic resource conservation systems and plant breeding efforts can keep up with these stresses as well as market demands; and to critically examine the effects of industry consolidation, intellectual property, novel breeding technologies such as gene editing, and other agricultural industry trends and innovations on food plant diversity. To do so, collaborative research involving a wide spectrum of expertise is needed, including farmers, plant genetic resource conservationists, crop breeders, agronomists, pathologists, entomologists, economists, and more. As crop development is increasingly privatized, access to information on field-level diversity is becoming less readily available (Burris et al., 2025; Heisey et al., 2001); it is thus critical to engage the private sector in such research. Through such an effort, it is possible to imagine the development of an early-warning system for crop vulnerability, including the timely identification of production areas where further diversification would be most prudent.

Finally, and critically, it is important to better understand how and why traditional and locally managed food plant diversity continues to persist to a such a remarkable extent in many regions around the world, despite enormous global change over the past century, a trend that would greatly surprise some of the international authorities of several decades ago who predicted the complete loss of traditional crops and of farmer landraces within a few decades (Frankel & Soule, 1981; Peres, 2016; Zeven, 1996). There has indeed been remarkable survival and resilience of traditional agriculture and its food plant diversity and associated traditions (Curry, 2022). Specific agroecological and cultural drivers of persistence have been documented (Khoury et al., 2021), but there is much more to understand about the full range of reasons for the survival of traditional food plant diversity, as well as how the custodians of this diversity see the future, especially in places where they have been the coevolutionary diversification agents with food plants for many hundreds or thousands of years (Argumedo et al., 2021). A deeper understanding of these factors may provide critical insights regarding opportunities for re- or further development of robust local to regional food systems, as well as for greater coexistence between these and globalized food systems.

5 | SAFEGUARDING AND ELEVATING FOOD PLANT DIVERSITY IN A TIME OF RAPID GLOBAL CHANGE

While much remains to be clarified about the magnitude, drivers, and impacts of food plant diversity change globally, enough is certainly known to justify increased action to better conserve and use this primary product of biocultural innovation of the past 12,000 years of human history.

The thousands of genebanks, botanic gardens, plant breeding institutions, farmer and gardener seed saving organizations, community seedbanks, and other food plant diversity conservation repositories and networks around the world are important to the survival of this diversity during this ongoing extinction period. These repositories and networks are where a significant amount of remaining food plant diversity now survives, and agricultural systems depend on them as sources of variation for crop breeding and innovation (Figure 6a) (Esquinas-Alcázar, 2005; Gepts, 2006, 2023; Hoisington et al., 1999).

The further development of more efficient, cooperative systems among repositories and networks is critically needed, especially given widespread financial and staffing resource constraints (Figure 6b) (Herbold & Engels, 2023), and with much food plant diversity—particularly of wild edible plants, crop wild relatives, and opportunity crops—in need of further protection (Khoury et al., 2019, 2020). Better integrating the efforts of food plant diversity conservation sectors that have historically worked in isolation—such as genebanks, botanic gardens, and farmer and seed saver networks—is also prudent, as it offers opportunities to leverage complementary strengths toward common goals (Figure 6d) (Heywood, 2011; Khoury et al., 2026; NYBG, 2025).

Further safety duplication of such ex situ materials among collaborating institutions as well as in secure backup repositories such as the Svalbard Global Seed Vault to enhance the chance of survival in the case of power loss, natural disasters, war and civil strife, and other vulnerabilities, is likewise essential (Figure 6c) (Westengen et al., 2020). Important steps have been made to improve safety duplication of crops which do not produce seed, those whose seed does not tolerate standard freezer conditions, and other vegetatively propagated crops (Ellis et al., 2025), but additional efforts are needed to back up the diversity in these particularly challenging food plants (Acker et al., 2017; Engels & Ebert, 2021).

Making the food plant diversity and associated information maintained in ex situ repositories maximally accessible for use is essential to our human health, environmental sustainability, and other goals. Major efforts are needed to prioritize and facilitate the distribution of germplasm to users, including diversity held in many national genebanks (Fowler, 2026; Rattunde et al., 2026; Wambugu et al., 2026). Ensuring that the original providers of food plant diversity and associated information can readily access the plants and are recognized for and benefit

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FIGURE 6 Ex situ conservation of food plant diversity. (a) Stephanie Greene, Supervisory Plant Physiologist (retired), in one of the cold rooms of USDA National Laboratory for Genetic Resources Preservation, one of the world's largest national genebanks. Photo: Neil Palmer/CIAT. (b) Quinoa (*Chenopodium quinoa* Willd.) and kiwicha (*Amaranthus caudatus* L.) collections held in ambient conditions at the Centro de Investigación de Cultivos Andinos, Universidad Nacional de San Antonio Abad del Cusco, among the largest and most diverse ex situ collections of these crops worldwide. Many genebanks such as this one lack cold storage and other critical infrastructure. Photo: Colin Khoury. (c) The entrance to the Svalbard Global Seed Vault, located on the Norwegian island of Spitsbergen, which now maintains as a safety-backup over 1.4 million accessions of food plant diversity from around the world. Photo: Michael Major for Crop Trust, CC-BY-NC-SA 2.0. (d) Living collections in botanic gardens, such as those at Gothenburg Botanical Garden, Sweden, maintain and display food plant diversity complementary to that held in genebanks. Photo: Ellinor Smederöd.

from their use is crucial, including to address historical injustices regarding acknowledgment and compensation. International agreements on conservation, sustainable use, and access and benefit sharing of food plant diversity, including the Plant Treaty and the CBD, are central avenues to achieving these aims globally. These require substantial further development and support to overcome barriers to access and to ensure appropriate benefit sharing regarding plant genetic resources and associated genetic and other data (Bertioli et al., 2025; Halewood et al., 2023; Scholz et al., 2022; Gepts, 2023; Marden et al., 2023; Muñoz-García et al., 2025) and to track and report such benefits (Nunez-Vega et al., 2025; Raposo et al., 2026). The expansion of the MLS of the Plant Treaty—which currently covers only 64 major crops and forages—to include all food plants important to global food security and sustainable agriculture is an urgent priority (Figure 1) (Khoury et al., 2016, 2023). Additional direct, voluntary, and otherwise innovative approaches to benefit sharing and to supporting farmers' rights also deserve exploration and investment, for example, those that facilitate more direct beneficial relationships between industries/markets and farmers (Argumedo et al., 2021).

But safeguarding food plant diversity in cold storage, laboratories, and botanic garden collections is not enough to ensure the long-term survival or to appreciably elevate the use, of this biocultural resource. To continue to evolve alongside changing biotic and abiotic conditions, biocultural traditions, and market demands, this diversity has to continue to be grown in farmers' fields and (for wild relatives and wild edible plants) to persist in natural habitats. Although experts several decades ago expressed doubts about the viability of in situ and on-farm conservation efforts for food plant diversity, there are many examples of functioning models in several regions. In Peru, for example, different initiatives include the Potato Park (Parque de la Papa) (Figure 7), the Association of Guardians of the Native Potato of Peru (AGUAPAN) initiative, and national agrobiodiversity zone designations (Argumedo et al., 2021; Khoury et al., 2021; NFP, 2025; Sotomayor et al., 2020; Tapia, 2000). These movements prioritize leadership by the communities that have been the custodians of this diversity for generations and often catalyze capacity-sharing and colearning among such communities, who often face similar challenges (Argumedo et al., 2021).

More widely, conserving and increasing the use of food plant diversity requires larger structural changes to food systems whereby farmers and other food system actors benefit as much or more from managing and caretaking diversity than from reducing or eliminating it (Drucker & Ramirez, 2020; van Zonneveld et al., 2020). The viability of agriculture as a livelihood option; rural vitality; intergenerational change; class, race, and other prejudices associated with traditional and local foods; and other factors represent major challenges lacking simple solutions. Avenues such as direct marketing to consumers and chefs, agroecotourism linked to local and regional food traditions

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FIGURE 7 The Potato Park (Parque de la papa), near Pisac, Cusco, Peru (https://parquedelapapa.org/). (a) Mountainous landscape of the Potato Park. (b) Smoke rising from underground earth ovens (*Huatia* in Quechua), a longstanding traditional technique of baking potatoes in the field. (c) Community activities during International Potato Day (May 30th). (d) Mixture of traditional potato landraces presented during the International Potato Day festivities. Photos by Colin Khoury.



FIGURE 8 A global selection of dishes incorporating locally unique food plant diversity. (a) Ceviche with rocoto (*Capsicum pubescens* Ruz & Pav.), ají amarillo (*Capsicum baccatum* L.), cassava (*Manihot esculenta* Crantz.), and other assorted vegetables and spices, Lima, Peru (b) Dotorimuk [an acorn jelly typically produced from several local oak (*Quercus* L.) species] with sesame seeds (*Sesamum indicum* L.) and vegetables, Sejong-si, Republic of Korea. (c) Whole grain couscous (*Triticum durum* Desf.) served with honey and amlou, a mixture of almonds (*Prunus amygdalus* Batsch), argan oil (*Sideroxylon spinosum* L.), and honey, near Laqsabi Tagoust, Morocco. (d) Cono de frijol [refried beans (*Phaseolus vulgaris* L.) in a crunchy maize (*Zea mays* L.) tortilla shell], a dish only known from Ensenada and surroundings, Baja California, Mexico. The dish was once common in the area, especially for primary school children but is becoming rare. Photos by Colin Khoury.

(Figure 7), creating value-added products based on local food diversity, and promotion of diversity in cuisines by chefs and other influential persons are becoming more common, and networks supporting locally managed food plant diversity are becoming larger and more sophisticated (Fadda et al., 2020; Graddy, 2014; Mier y Terán Giménez Cacho et al., 2018; Westengen et al., 2023). This said, up- and out-scaling such efforts for global impact implies nothing less than transformational change, refocusing society on achieving nutritional, social, and environmental needs. Broad, increased support from governments, international organizations and political fora, the private sector, and other pertinent institutions is necessary.

Food plant diversity is maintained and evolves through use, and a wider range of applications of this edible variation may provide more avenues for it to thrive in co-evolution with humanity. Further or reinvestment in public plant breeding, participatory seed networks, and other approaches using a broader set of food plant diversity is necessary to address the narrowing of genetic variation in major crop development systems (Burris et al., 2025; Coe et al., 2020; Hale et al., 2025; Rattunde et al., 2026; Westengen et al., 2023).

Technological innovation based on food plant diversity is occurring at rapid pace due to changing demands, challenges, and opportunities (e.g., plant-based milk and meat alternatives) and evolving

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technologies (e.g., genomics/genome editing and synthetic/in silico crop development), and our technological potential to develop new crops, varieties, and products that enhance human nutrition and environmental sustainability is probably greater than ever (Fernie & Yan, 2019; Gepts, 2023; Habib et al., 2025; Phillips et al., 2025; Riaz et al., 2025; Waqas et al., 2025). Food plant diversity and the information associated with this diversity provide the foundation for these activities. Like all innovations, care should be taken to assess the full range of potential impacts, including to ensure that the underlying food plant variation on which these new products are based is not further eroded (Westengen et al., 2023).

Finally, it is critical to continue talking about, asking questions about, and increasing appreciation of food plant diversity. Globalization enables vast disconnections between consumers and the places where their food comes from, and this has likely come at a major cost in terms of loss of diversity, knowledge, and practices. We need to communicate about food and its diversity in ways that people care about, such as family dishes and regional cuisines (Figure 8). The depth, proximity, and immediacy of human–food plant relationships will determine, ultimately, whether the coevolutionary diversification processes intertwining people and food plants can be strengthened, or will continue to further unravel.

AUTHOR CONTRIBUTIONS

Colin K. Khoury, Hannes Dempewolf, Alejandro Argumedo, Stef de Haan, Mauricio Diazgranados, Alex McAlvay, Alvaro Toledo, Maarten van Zonneveld, and Peter Wenzl contributed to the conceptualization of this article and to research discussed within it. Colin K. Khoury wrote the review. All authors edited the review.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable—no new data generated.

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