PNAS PERSPECTIVE OPEN ACCESS

Reversing vegetable biodiversity loss to diversify diets

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Edited by Neelima R. Sinha, University of California, Davis, CA; received December 5, 2025; accepted May 4, 2026 by Editorial Board Member Pamela C. Ronald

Vegetables are a critical component of diets, with inadequate intake of this essential food group leading to poor dietary quality and malnutrition. Food system assessments identify insufficient production, comparatively high prices, and sociocultural barriers as key constraints to vegetable consumption. We argue that vegetable biodiversity, spanning vegetable species and their varieties, as well as their wild relative species, is a central yet underutilized lever for enhancing vegetable consumption. Vegetables span a wider phylogenetic range than any other plant-derived food group, offering options for different climatic, cultural, and market niches worldwide. However, vegetable biodiversity is declining due to market homogenization, land-use change, and other threats. Its current conservation is insufficient, restricting in turn access to this diversity for research, breeding, and innovation, and making it more difficult to bridge the gap between current and recommended vegetable intake. Reversing this trend globally requires aligning conservation with dietary goals through four complementary action areas: i) Securing vegetable biodiversity by collecting, regenerating, and conserving local crop varieties and wild relatives of key vegetable species in biodiversity hotspots; ii) Harnessing vegetable biodiversity to deliver new varieties through collaborative research, breeding, and variety testing; iii) Promoting vegetable biodiversity to diversify diets, particularly among children and other vulnerable groups, by including nutrient-dense, climate-resilient vegetables into home and school meals; and iv) Integrating vegetable biodiversity into policy frameworks for long-term impact. Implementing this integrated approach in hotspots where vegetable biodiversity and malnutrition overlap can transform an overlooked opportunity into a cornerstone strategy for healthier diets.

vegetable genetic resources | dietary quality | malnutrition | genetic erosion | biodiversity decline

Low vegetable intake impacts health and biodiversity

Despite being essential for human nutrition and, therefore, health, vegetables are widely underrepresented in diets. Global Food Group Metrics on diets show that, on average across countries, people consume nearly 40% fewer vegetables than recommended (1) (Fig. 1). This shortfall is even greater in lower-income countries (2). This persistent underconsumption limits the potential of minimum dietary diversity to reach *Zero Hunger* goals (3, 4). Low vegetable consumption is one of the top five dietary risk factors contributing to the global burden of disease (3, 5, 6). Among children, it limits essential nutrient intake, reducing their capacity to thrive (4, 7). More than half of children under the age of five are estimated to have one or more micronutrient deficiencies (8), and more than 150 million children under the age of five are stunted (3). Low vegetable consumption is also associated with overweight and obesity, which recently surpassed undernourishment as the dominant manifestation of malnutrition among children and adolescents globally (9).

Vegetables are difficult to define botanically because they include a wide range of edible plant parts from many different species (Fig. 2). From a nutritional perspective, vegetables can be defined as plant foods that provide essential micronutrients, fiber, and bioactive compounds important for maintaining good health while typically being low in fat and starch. From a gastronomic perspective, vegetables are plant foods consumed raw or cooked, often at different stages of maturity, and are primarily prepared in savory dishes. Because culinary traditions and nutritional perceptions vary across regions, the specific edible parts and species considered vegetables can differ across cultures (11–13).

Recent global and national dietary guidelines particularly emphasize dark-green leafy vegetables, such as kale and spider plant, and orange-colored vegetables rich in vitamin A, such as pumpkin and carrot, as they contain high levels of essential micronutrients that are often lacking in diets (3, 16). Other types of vegetables contain complementary

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Author contributions: M.v.Z., C.K.K., C.F., and M.E.S. designed research; M.v.Z., C.K.K., S.G., L.M.W., and S.N. compiled data; M.v.Z., C.K.K., C.V., and S.G. analyzed data; M.v.Z., C.K.K., A.H., C.V., C.F., S.G., V.A., S.K., L.M.W., S.N., and M.E.S. reviewed and edited the paper; and M.v.Z., C.K.K., A.H., C.V., V.A., S.K., and M.E.S. wrote the paper.

The authors declare no competing interest.

This article is a PNAS Direct Submission. N.R.S. is a guest editor invited by the Editorial Board.

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This article contains supporting information online at https://www.pnas.org/lookup/suppl/doi:10.1073/pnas.2532063123/-/DCSupplemental.

Published July 24, 2026.

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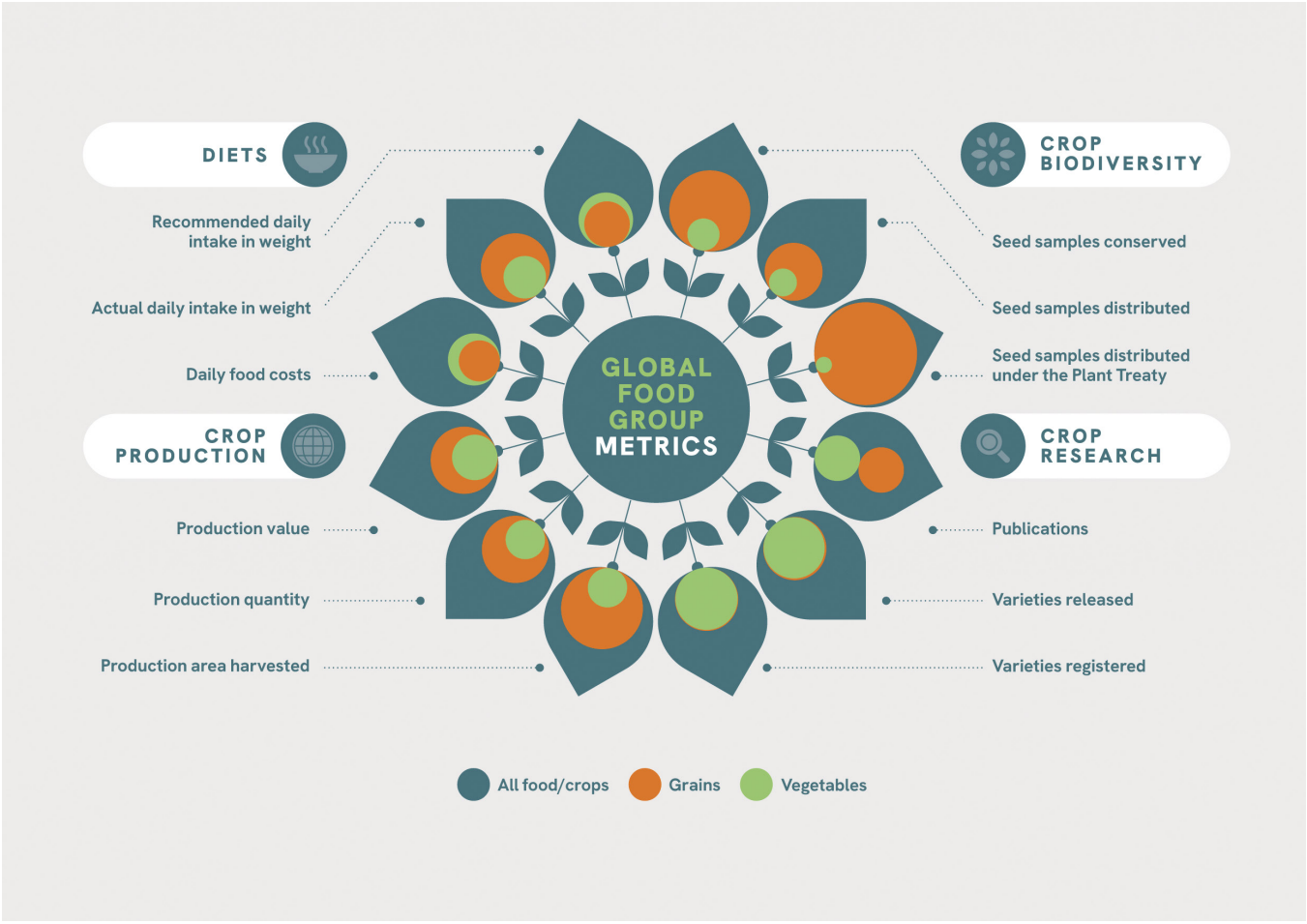

Fig. 1. 12 Global Food Group Metrics on diets, crop biodiversity, research, and production show the proportion of vegetables and cereal grains within food systems. Actual vegetable consumption remains far below recommended dietary levels, in contrast to the comparatively higher intake of cereal grains. This shortfall is linked to limited vegetable production relative to grain production. Although certain aspects of research on vegetables are comparable to those of cereal grains and exceed those of other plant-derived food groups, vegetables represent only a small fraction of the seed samples conserved and distributed globally. This imbalance indicates that vegetable research and production are supported by a narrow genetic base, leading to vulnerability in global vegetable supplies and potentially limiting their increase in the coming decades. The category "all food/crops" includes legumes, roots and tubers, and other food groups, in addition to cereal grains and vegetables. Legumes were categorized separately from the vegetable category to avoid overlap across food groups. The term "seed," as used here, refers broadly to all plant materials used for ex situ conservation, including true seeds, tissue cultures, and whole plants, while assuming that the majority of the vegetable and grain seed samples are effectively true seed. The SDG 2 icon, courtesy of the UN, is used to represent the diet-related metrics. The Global Food Group Metrics dataset provides a detailed description of each metric (10).

health-promoting properties, making a wide range of vegetable species integral to our diets (6).

Vegetables overlap with other food groups. Legumes, primarily eaten as pulses, include fresh pods, seeds, and leaves consumed as vegetables in some species, such as leafy cowpea and yard-long bean. Similarly, root and tuber crops include root vegetables, such as parsnip, while many are also valued for their dark green leaves, such as sweet potato. There is also overlap with fruit crops, as some crops may be consumed either as sweet fruits or fleshy vegetables, such as watermelon and tomato, depending on culinary use and cultural context. In addition, flowers, leaves, stems, and shoots from crops primarily grown for other food groups are sometimes consumed as vegetables.

In global assessments, vegetable species are often listed separately from species primarily associated with other food groups (14). However, regional and local evaluations often include legumes and roots and tubers as part of vegetable options and occasionally include crops for vegetable consumption that are primarily consumed as fruits, cereals, seeds, or nuts. This broader interpretation is reflected in the Global Vegetable Species dataset (17).

The factors contributing to poor dietary quality, low vegetable consumption, and malnutrition among children and other target populations for nutrition interventions remain poorly understood (4), although some reasons for low vegetable consumption are well known. To start with, current vegetable production, and therefore availability, is insufficient to meet recommended intake levels worldwide (18) (Fig. 1). Further, food-insecure households often compromise on vegetables because they are too expensive to purchase in sufficient quantities for health (3). Yet as incomes increase, people still may not eat more vegetables due to cultural perceptions, limited childhood opportunities to develop a taste for them, or concerns about food safety. Global assessments of food systems recommend increasing vegetable production by over 60% by 2050 to support healthy diets for all under climate change, accompanied by efforts to reduce food waste

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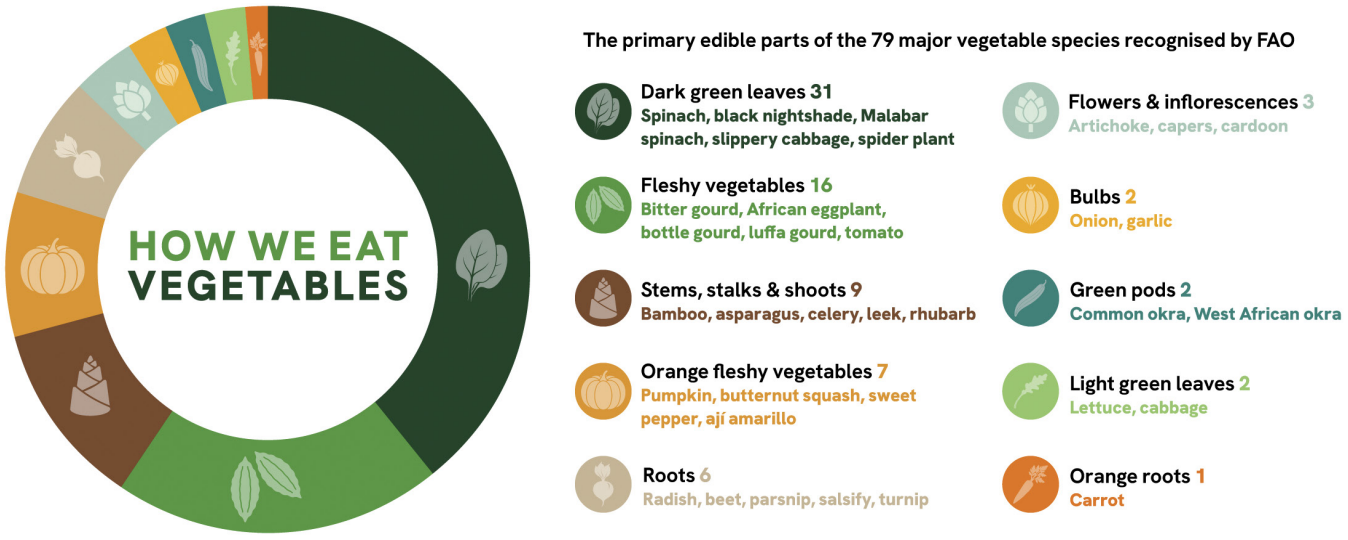

Fig. 2. Diversity in the primary edible parts was assessed across the 79 major vegetable species listed in FAO's *The Plants that Feed the World* (14). Orange-fleshed vegetables and orange roots refer to orange-colored vegetables that are rich in vitamin A. Legumes were categorized separately from vegetables in FAO's *The Plants that Feed the World* and are not included in this list. Fleshy vegetables refer to plants in which the primary edible parts are the botanical fruits. The Edible Plant Parts dataset provides detailed information on the edible parts of each vegetable species (15).

and loss, and to make vegetables more affordable and acceptable (3, 6).

Yet one key limitation remains overlooked: the underutilization of vegetable biodiversity to enhance vegetable production and consumption (19). Diversity in vegetable species and their varieties offers greater options for the myriad climatic, cultural, and market niches worldwide. Conserving and using this diversity can support healthy food production amid climate change and expand nutritious, appealing, and affordable diet choices globally.

However, vegetable biodiversity is declining. As diets and culinary traditions homogenize globally, and vegetable supply and consumption remain low, vegetable biodiversity in turn declines due to the loss of both the availability and knowledge of vegetable species and their varieties (e.g., 14, 20, 21). Increasing evidence shows that consuming a low number of food species, including limited vegetable species, is associated with poor health (22, 23). This results in a vicious cycle of decreasing dietary diversity and declining vegetable biodiversity, which reduces available options for healthy diets. Consequently, it may become increasingly difficult to meet the recommendations for vegetable intake. Reversing the loss of vegetable biodiversity is therefore crucial to broader efforts to improve diets.

Vegetable Biodiversity: A Biological Base for Closing Global Nutritional Gaps

We compiled a list of 1,482 vegetable species from multiple references (17). The global total is certainly even higher, as many locally wild-harvested vegetables are not included in standard references (24). Due to the diversity of edible parts and large number of species, vegetables span a wider phylogenetic range than any other plant-derived food group, encompassing flowering plants, gymnosperms, and ferns. This vast pool of species, along with their varieties and traits, presents enormous opportunities to adapt to climate change while providing nutrient-dense crops.

Many vegetable species have long traveled across regions and cultures, reflecting diverse histories of evolution, domestication, and adaptation (25, 26). A few species, such as lettuce, onions, and tomatoes, have become global crops and are part of diets worldwide. Many others, such as spider plant, slippery cabbage, and bitter gourd, which are typically denser in micronutrients and better adapted to challenging and resource-limited environmental conditions, are available only regionally, and very often neglected in large-scale food policies and strategies (27). Integrating these crops across food, climate, and health policies can improve vegetable availability, affordability, and consumption in a resource-efficient way (28).

Yet vegetable biodiversity is disappearing. Eighty percent of studies on vegetable genetic erosion report a significant loss of diversity over the last 100 y, particularly at the varietal and genetic levels (intraspecific diversity) (21). Preserving diversity among and within vegetable species is crucial for enabling crop improvement in response to emerging challenges, including climate change and the pests and diseases it exacerbates. The few observed increases in intraspecific diversity in published studies were primarily due to specific interventions and market demands, which required broadening the genetic base of breeding programs. Since such actions for crop improvement depend on access to and use of vegetable biodiversity, its conservation is essential.

Wild relatives of vegetable species, as with other crops, also possess valuable traits, which are increasingly used in crop breeding as sources of pest and disease resistance, climate resilience, and other critical characteristics that can strengthen new vegetable varieties (29). Many, including wild chilies and eggplants, are traditionally harvested and eaten directly, providing unique flavors and nutritional and medicinal benefits (e.g., 13, 30, 31). But these wild species are also

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threatened. An estimated 24% of the wild relatives of vegetables assessed at the species level are at risk of extinction, based on a review of 79 major vegetable species identified by the FAO (32). This number aligns with global estimates across threatened animal and plant species (33). While many vegetable wild relatives currently lack formal conservation assessments, this number already shows that biodiversity decline directly affects the wild plant species that are important genetic resources for our diets.

The loss of vegetable biodiversity also has social and cultural dimensions. Traditional and indigenous communities that use this biodiversity are often vulnerable, as the loss of neglected vegetables and other foods, combined with social marginalization, limits their access to diverse diets (33, 34). Studies demonstrate that over 90% of the wild edible plants and fungi surrounding traditional communities are declining in abundance, and that roughly one-third of these declining species are vegetables (35). This biodiversity decline accelerates the loss of knowledge and the use of local vegetable species and varieties in food practices (33).

The Global Food Group Metrics suggest that existing research and breeding infrastructure can be leveraged to boost vegetable supply and consumption, thereby closing nutritional gaps (Fig. 1). For example, published research outputs for vegetables are comparable to those for cereal grains, the world's main plant-derived food group.

That said, this research capacity is concentrated in a limited number of vegetable crops (14). For example, many nutrient-rich vegetables, particularly spider plant, slippery cabbage, and other dark-green leafy vegetables, receive little breeding attention due to their lower commercial value compared to crops such as pepper and tomato (27, 28, 36). In many countries, the scarcity of vegetable breeders further constrains crop improvement efforts, especially for these "opportunity" vegetables with significant unrealized potential to improve food security and dietary quality amid climate change (37, 38). This highlights the need to strengthen breeding capacity among both public and private organizations, combined with investment in participatory breeding with farmers, for these vegetables to reach consumers.

The main bottleneck for vegetable research and further food system transformation, however, is that conservation and use of vegetable genetic resources is insufficient, for example compared to that for cereal grains, as highlighted by the Global Food Group Metrics on crop biodiversity (Fig. 1). Vegetable genebank collections, which maintain diversity for research and crop improvement, are typically much smaller and less utilized than those of cereal grains, despite the existence of many more vegetable species than grain species. This results in a narrow genetic base for vegetable research, breeding, and innovation.

Current national and international policies often limit, rather than expand, access to vegetable biodiversity. The FAO International Treaty on Plant Genetic Resources for Food and Agriculture (i.e., Plant Treaty) facilitates seed exchange among countries for a list of crops, including a wide range of staple food crops and animal forage crops, as well as a few vegetables, such as eggplant, kale, cabbage, and carrots (14). Other mainstream vegetables, such as lettuce, onion, and tomato, as well as the wide range of underutilized vegetable species, are not currently included. Because of this gap, vegetable seed exchange between countries falls under the framework of the Nagoya Protocol on Access and Benefit-sharing of the Convention on Biological Diversity (CBD), requiring typically lengthy bilateral negotiations. Consequently, the bottleneck in access to vegetable biodiversity persists, limiting progress toward more diverse and resilient food systems.

The Way Forward

Momentum is gaining to reverse the intertwined drivers of decline in vegetable biodiversity and in dietary diversity. The EAT-Lancet Commission emphasized the importance of pursuing sustainable and culturally appropriate pathways to increase vegetable production (6). The UN's Kunming-Montreal Global Biodiversity Framework has introduced a financial mechanism to reverse biodiversity loss in fields and landscapes, while addressing the locally defined needs of traditional and Indigenous communities (39, 40). This framework enables communities to develop locally tailored solutions to improve diets by incorporating a diverse range of foods, including neglected vegetable species. A new UN minimum dietary diversity indicator has provided governments with tools to efficiently monitor the intake of vegetables in diets (3). Although discussions within the Governing Body of the Plant Treaty had not expanded its scope as of 2025, extending seed exchange to a broader range of crops, particularly vegetables, remains a key issue in ongoing discussions, given its relevance to dietary quality (41).

Building on this momentum, action is needed worldwide, especially in hotspots with both high vegetable biodiversity and high rates of malnutrition. Four vegetables illustrate the potential and challenges related to this diversity:

- Spider plant, a popular dark leafy green in parts of Africa, is highlighted as an opportunity crop in the FAO-CGIAR coordinated Vision for Adapted Crops and Soils, which aims to convert neglected species into opportunity crops that contribute to the supply of nutrient-dense foods under climate change (28, 42). Currently, only a few local varieties are conserved in genebanks, with many gaps in collections, constraining breeding and the development of improved varieties for larger-scale production (14, 26).
- Bitter gourd is another climate-resilient vegetable (27). Its fruits and leaves are prized across Asia and the Caribbean for their nutritional, medicinal, and cultural values. Most of its wild relatives are native to Africa, but they are often overlooked in conservation efforts, and some are endangered despite their value for crop improvement in Asia and the Caribbean (32).
- Slippery cabbage is among the most popular dark-green leafy vegetables in the Pacific for its unique texture and reported medicinal benefits, and with a high potential for diversifying the diets of women and young children (43, 44). It is usually propagated vegetatively and requires special attention in conservation, improvement, and the delivery of new varieties.

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- Pumpkin is a commercially important, nutrient-rich, and climate-resilient vegetable, yet its genetic resources remain underutilized and poorly conserved (14, 42). Native to the Americas, it is considered drought- and heat-tolerant, and its orange fruits are rich in beta-carotene, while its dark green leaves provide additional micronutrients. Many pumpkin varieties are conserved in genebanks; however, seed multiplication is insufficient since it is costly due to the species' outcrossing nature and the need for large fields. This causes regeneration backlogs, genetic bottlenecks, and an insufficient number of varieties from genebanks available to broaden the genetic basis for pumpkin breeding.

The ongoing biodiversity loss for these and the other 1,480-plus vegetable species occurs at a time when global food systems urgently need diversification. Experts worldwide have identified priority vegetables based on their nutritional quality, potential for climate change adaptation, economic potential, and cultural relevance, whose diversity should be the main target for collecting and conservation, breeding, and promotion (17). New initiatives, such as the Vision for Adapted Crops and Soils for Africa and the Pacific, the African Orphan Crop Consortium, and the Africa Vegetable Breeding Consortium, are enhancing the use of opportunity vegetables in sub-Saharan Africa and the Pacific through breeding and have begun promoting these vegetables to diversify diets (28, 36, 38, 45). However, these efforts remain fragmented, with geographic gaps, and coordination between dietary goals and the conservation strategies needed to sustain dietary diversification could be further strengthened.

Fully integrating vegetable biodiversity into food systems will require coordinated investment focused on hotspots where vegetable biodiversity and malnutrition co-occur. These hotspots are found worldwide, reflecting the overlap between centers of crop diversity and regions where malnutrition remains prevalent. Roadmaps developed for major world regions, such as Africa, Asia, the Americas, and the Pacific, can guide context-specific actions in these hotspots across the short, medium, and long term.

At the same time, alignment under a global initiative would ensure that local and regional efforts translate into improvements in diets at both the local and global levels.

This global initiative should focus on four action areas:

1. Secure vegetable biodiversity for the future: This forms the foundation of the initiative and should focus on collecting seeds of local varieties and crop wild relatives in hotspots of biodiversity and malnutrition through collaborative efforts before they are lost. Action should further prioritize regenerating and multiplying seeds of vegetable varieties collected earlier and stored in genebanks, which are overdue for regeneration and therefore risk being lost due to limited funding (46). The term "seed," as used here, refers broadly to all plant materials used for ex situ conservation, including true seeds, tissue cultures, and whole plants. These efforts to collect and recover varieties should be complemented with expanded efforts to conserve vegetable varieties and wild relatives in genebanks, farms, and protected areas to keep this diversity available for the future. This should also include restoring biodiversity on farms and in natural habitats by repatriating landraces to farmers and reintroducing wild relatives to degraded native areas.
2. Harness vegetable biodiversity to deliver new varieties: As highlighted by the Global Food Group Metrics (Fig. 1), farmers, researchers, and breeders need greater access to vegetable biodiversity under national and international legal frameworks. This diversity should be further characterized phenotypically and genomically and evaluated for relevant traits to accelerate research and development, with associated data made publicly available online (47). Such information can support partnership models linking genebanks, public and private breeding programs, and farmers to improve varieties across a wide range of vegetables, drawing on a broad genetic base, and to deliver quality seed that meets agronomic and market needs.
3. Promote vegetable biodiversity to diversify diets: This action area promotes the inclusion of locally and safely produced vegetables from a wide range of species in school and home meals. Linking vegetable biodiversity with school feeding and garden programs has strong potential to diversify diets and enhance micronutrient intake among large numbers of children (48). It can also provide new opportunities for children's education, showing how biodiversity, culture, conservation, and food are interconnected. Farmers should be connected to these school programs, as well as to broader markets, through platforms that facilitate market opportunities and help scale the supply of safely produced vegetables to reach more households.
4. Integrate vegetable biodiversity into policy frameworks for long-term impact: The conservation and sustainable use of vegetable biodiversity should be further incorporated into biodiversity, health, education, climate, and agriculture policy frameworks at national and regional levels (49). In addition, vegetable biodiversity should be embedded in academic programs to build long-term capacity for its conservation and use (38).

Such an integrated approach was used to develop a 10-y roadmap in Africa and was piloted in four vegetable biodiversity hotspots, demonstrating how biodiversity can be directly linked to improved diets (Box 1). The approach provides a scalable model for other regions where biodiversity and malnutrition overlap and could be connected through a global initiative. Linking vegetable biodiversity with diets offers a pathway to simultaneously address malnutrition and biodiversity loss, transforming this overlooked opportunity into a cornerstone of healthier diets and a more sustainable planet.

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Box 1.

Connecting vegetable biodiversity with diets in Africa.

The implementation of the four action areas in four hotspots in Africa through a US$8 million project from 2021 to 2024 demonstrates that aligning biodiversity conservation with dietary goals is feasible at scale. This approach can be scaled up further in these four hotspots and applied to other hotspots worldwide where vegetable biodiversity and malnutrition overlap.

Secure vegetable biodiversity for the future: Seeds of over 17,000 vegetable varieties were collected across four identified hotspots in Benin, Tanzania, Eswatini, and Madagascar (26, 50). These activities adhered to biodiversity regulations, including the Plant Treaty and the CBD Nagoya Protocol, with seed shared via the Multilateral System of the Plant Treaty under a Standard Material Transfer Agreement for research, breeding, and training, as well as for direct use by farmers, schools, and communities in line with Article 9 of the Plant Treaty on Farmers' Rights. Two genebanks were built, and two were upgraded to improve the conservation of vegetable biodiversity and enhance access to it for researchers, breeders, and farmers.

Harness vegetable biodiversity to deliver new varieties: Collected and conserved varieties of targeted crops, including amaranth, okra, gboma eggplant, and jute mallow, have been genotyped and incorporated into breeding programs across sub-Saharan Africa, and have become part of the Vision for Adapted Crops and Soils (42). This diversity is now becoming more broadly available for screening, breeding, and variety testing, including to members of the Africa Vegetable Breeding Consortium (38), through the development of public–private models that screen genetic resources for breeding (37, 51) and large-scale participatory variety selection involving farmers through citizen science approaches (52).

Promote vegetable biodiversity to diversify diets: Promising varieties of targeted crops were grown by smallholder producers and schoolchildren in Eswatini through 7,200 school, home, and community gardens for local consumption, reaching more than 120,000 people, including 30,000 children, with fresh vegetables from opportunity crops for home and school meals between 2021 and 2024 (50).

Integrate vegetable biodiversity into policy frameworks for long-term impact: A regional 10-y roadmap to guide investment in securing, harnessing, and using vegetable biodiversity to diversify diets across Africa was developed by three African plant genetic resources groups (49). It is an African Union official document endorsed by its member states in 2025. It supports investment, policy, and the transformation of Africa's agrifood systems within the framework of the Comprehensive Africa Agriculture Development Programme (CAADP).

Data, Materials, and Software Availability. Datasets have been deposited in Figshare (10, 15, 17, 32).

ACKNOWLEDGMENTS. This paper builds on recommendations from the 2025 convening on *Vegetable biodiversity for a healthy and resilient future,* supported by the Rockefeller Foundation Bellagio Center Conference Program. The Taiwan Ministry of Agriculture supported this research through the Vegetable Innovation Project of World Vegetable Center–Low Emission Production and Biodiversity. The CGIAR Food Frontiers and Security Science Program supported the article processing charges. The NL-CGIAR Senior Expert Programme II, grant number INT.1723.24.016 supported M. Eric Schranz. Marco Wopereis, Pepijn Schreinemachers, and Neil Palmer from WorldVeg provided comments on an earlier draft. Melanie Schori from USDA and Wei-Hsun Hsieh from Academia Sinica provided data on crop wild relatives. Jim Smith designed the figures.

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