United Nations Food Systems Summit 2021
Scientific Group
https://sc-fss2021.org/

**Food Systems Summit Brief**
**Prepared by Research Partners of the Scientific Group for the Food Systems Summit**
***April 2021***

# SAFEGUARDING AND USING FRUIT AND VEGETABLE BIODIVERSITY

by

**Maarten van Zonneveld, Gayle M. Volk, M. Ehsan Dulloo, Roeland Kindt, Sean Mayes, Marcela Quintero, Dhrupad Choudhury, Enoch G. Achigan-Dako, Luigi Guarino**

## ABSTRACT

Fruit and vegetable species and varieties, their wild relatives, and pollinators and other associated organisms underpin diverse food production systems and contribute to worldwide health and nutrition. This biodiversity, however, is threatened, remains poorly conserved, and is largely undocumented. Its loss leads to a narrowing of new crop options, reduced variation for breeding, a yield gap due to pollinator decline, and it constrains long-term progress towards the 2030 Sustainable Development Goals and any future goals set thereafter. It will require a global awareness campaign to safeguard and sustainably use fruit and vegetable biodiversity and a 10-year global rescue plan to reduce and reverse the decline in this biodiversity. A diverse team of experts should formulate this global rescue plan and define clear goals. Success will depend on a global partnership of custodians and users of fruit and vegetable biodiversity, and requires an investment of at least 250 million USD over 10 years.

## FRUIT AND VEGETABLE BIODIVERSITY CONTRIBUTES TO A DIVERSE FOOD SUPPLY AND QUALITY DIETS

From a dietary perspective, fruits are reproductive plant parts with high sugar or oil content that are usually eaten fresh, as a snack, in desserts, or in drinks[1]. Vegetables are plant parts, such as leaves, fruits, or immature pods, that are eaten raw or cooked, in salads and as part of savoury dishes in general[2]. What both fruits and vegetables have in common is that they are rich in micronutrients and present an astonishing diversity of forms, tastes, and colours, adapted to myriad environments. Fruit and vegetable biodiversity—defined as the variety of fruits and vegetables at genetic, species, and ecosystem levels, including crop wild relatives (CWR) and pollinators and other associated organisms—underpins diverse food production systems for both local and global economies and contributes significantly to worldwide health and nutrition[3]. Fruits and vegetables play an increasingly prominent role in a new global research and development agenda that emphasizes nutrition and healthy diets alongside climate action, safeguarding biodiversity, ending poverty, and improving livelihoods[3,4]. Even so, most fruit and vegetable biodiversity remains unexplored and is increasingly threatened.

About 1,100 vegetable species are recognized worldwide[5] and there are at least 1,250 documented fruit species in the Neotropics alone[1]. This pool of diversity includes species with exceptionally high nutritional values and some that are adapted to harsh environments: it offers an untapped resource to make nutrient-dense foods accessible and affordable to consumers under the challenges of global climate change. Examples include micronutrient-rich African leafy vegetables adapted to rain-fed conditions[6] and vitamin-rich Amazonian fruit trees that withstand flooding and waterlogging[7,8]. Below the species level, local fruit and vegetable varieties are part of a cultural heritage with unique tastes and histories[9]. They are an important resource for developing new climate-adapted varieties with novel flavours, high nutritional values, and resistance to pests and diseases. Wild populations of fruit and vegetable species and the wild relatives of fruit and vegetable crops are an additional source of genetic variation that is increasingly used by breeders and researchers to increase genetic diversity in new cultivated varieties[10,11]. Wild populations also support key ecosystem functions[12], and serve as a direct food source in traditional systems, contributing up to 30% of the daily intake of vitamins A and C of people of rural and forest communities in certain local food systems[13]. In addition, most fruit crops and some vegetable crops depend heavily on pollinators for sustainable yields[14]. These pollinators together with seed dispersers are also key to maintain the viability of wild populations of fruit and vegetable species and their relatives.

## DECLINING BIODIVERSITY LIMITS OPTIONS FOR A SUSTAINABLE AND HEALTHY FOOD SUPPLY

Fruit and vegetable biodiversity continues to decline in farmers' fields and natural ecosystems[15] in line with the global rapid decline in biodiversity[16]. The loss of this heritage, and the resulting narrowing of new crop options, reduced variation for breeding, and a yield gap due to pollinator decline, will likely limit progress in achieving the 2030 Sustainable Development Goals (SDGs): SDG 1, No Poverty; SDG 2, Zero Hunger; SDG 12, Responsible Consumption and Production;

SDG 13, Climate Action; and SDG 15, Life on Land; and any future goals set thereafter.

Globally, ecosystems in 88% of the 846 terrestrial ecoregions are poorly conserved, degraded, or disappearing in the Anthropocene[17]. The richness and abundance of wild fruit and vegetable species, as well as their relatives and pollinators and dispersers, decline with the degradation and loss of these ecosystems under the pressures of land-use change, global climate change, and other threats[15,16]. Local cultivated varieties are being lost because farmers replace them with higher yielding and disease-resistant modern varieties. The loss of wild species and populations, and local varieties is of great concern because they are the source of genetic diversity for developing nutritious new varieties that taste good, resist pests and diseases, and are adapted to climate change. So far, no global estimates have been made about these losses. For some crops, such as tomato (*Solanum lycopersicum* L.), farmers have already replaced most local varieties in many regions[18,19] and the development of new varieties relies almost entirely on the diversity safeguarded in genebanks[20].

In contrast to tomato, the genetic resources of most fruit and vegetable species are poorly conserved by genebanks or not at all. For example, 39% percent of 883 assessed wild fruit and vegetable species requires urgent conservation because they are poorly or not conserved in genebanks and protected areas; another 58% has a medium priority for conservation; and for only 3% is genetic variation already well conserved[21] (Table 1). A quarter of the 1,100 recognized vegetable species worldwide is not conserved in any genebank[5]. Most fruit tree species and their wild relatives, particularly those of tropical origins, are not in genebanks. Their seed is recalcitrant and does not tolerate desiccation and low temperatures of conventional seed storage while maintaining fruit trees in high-quality field genebanks is expensive[22]. All these fruit and vegetable genetic resources without genebank back-up are at risk of being lost forever.

**Table 1.** Classification of 883 wild fruit and vegetable species in priority categories for conservation actions by Khoury and co-authors as part of a global conservation assessment of wild edible plants[21].

| Priority for conservation actions | Number of fruit species | Number of vegetable species | Number of species combined* |
|---|---|---|---|
| High | 200 | 185 | 346 |
| Medium | 341 | 246 | 510 |
| Low | 11 | 25 | 27 |
| Total | 552 | 456 | 883 |

* Includes species that have been classified as both fruit and vegetable.

Over the last four decades, populations of terrestrial insects declined on average by 45% across several studies and the annual decline in abundance is estimated to be between 1 to 2%[23,24]. These studies are thought to represent global trends of rapid decline because insect biodiversity is affected worldwide by a multitude of pressures[23]. During the same time period, mean relative yield of crops that depend on these insects for pollination, such as most fruits and some

vegetables, was 13% lower than for pollinator-independent crops[25]. This pollination-yield gap will likely further increase under the current trends of pollinator decline. This decline will also further increase the extinction risk of wild plant populations that depend on cross-fertilization by pollinators for propagation[26,27].

Complex access and benefit sharing policies and regulations[28], in particular domestic policies and regulations that implement the Nagoya Protocol of the Convention on Biological Diversity (CBD), increasingly govern international efforts to conserve and use the diversity of local varieties and wild populations. Many of these policies recognize the rights of countries and local communities over genetic resources in their territories, yet these countries and communities from different countries depend on each other for genetic resources of fruit and vegetable crops for food and nutrition, including for neglected and underutilized species[29,30]. This interdependence is expected to increase under global climate change[31]. The International Treaty on Plant Genetic Resources for Food and Agriculture (Plant Treaty) has a multilateral system for a negotiated list of crops to enhance the exchange of germplasm—including seed and any other living plant tissue—between countries for food and agriculture. Unfortunately, most fruit and vegetable crops and their wild relatives are not included on this list.

There are at least six important trends increasing the conservation and use of fruit and vegetable biodiversity in food systems at global and local levels. First, there is greater global awareness about the benefits of diverse diets with sufficient fruits and vegetables[3,4]. Second, the proportion of fruit and vegetable crops contributing to global food production is increasing[32–34]. Third, some neglected and underutilized fruit and vegetable species have regained relevance in urban diets through public and private initiatives in gastronomy and niche markets for local, healthy, or ethnic food[7]. Fourth, cities are becoming important hubs of crop diversity because immigrants bring planting material from their home areas[35,36]. Fifth, advanced biotechnologies are now accessible to public and private breeders and researchers globally to mainstream genetic diversity of fruits and vegetables into new crop varieties[11,37]. Sixth, the coverage of protected areas has tripled in the last 40 years[38], and at least 35% of the terrestrial protected areas is owned and/or managed by local and indigenous communities who play and important role in maintaining agrobiodiversity[16].

Although these trends could possibly bend the curve of decline in fruit and vegetable biodiversity, they may not completely halt, let alone reverse it. For example, the expansion of protected areas provides some opportunities for conservation, but ecosystems in these areas may be degraded and wild populations within the landscape may decline[38]. These trends may also come with trade-offs in biodiversity use and conservation. For example, global increases in crop diversification with limited numbers of new crops may cause less use and therefore decline in abundance and richness of local fruit and vegetable crops as diets tend to become more homogenous globally[33]. In addition, successful national and international markets for previously underutilized species, such as cherimoya (*Annona cherimola* Mill.) and avocado (*Persea americana* Mill.) that originate from the Neotropics, can lead to a decrease in local

varieties in their primary centres of diversity due to product homogenization and consumer preferences[39].

Policies and initiatives should stimulate the positive trends mentioned above, with better conservation in natural habitats and traditional production systems (*in situ*) with back-ups in genebanks (*ex situ*) to reduce and reverse the decline of fruit and vegetable biodiversity. This will require a global awareness campaign to safeguard and sustainably use fruit and vegetable biodiversity and a concerted, coordinated global rescue plan

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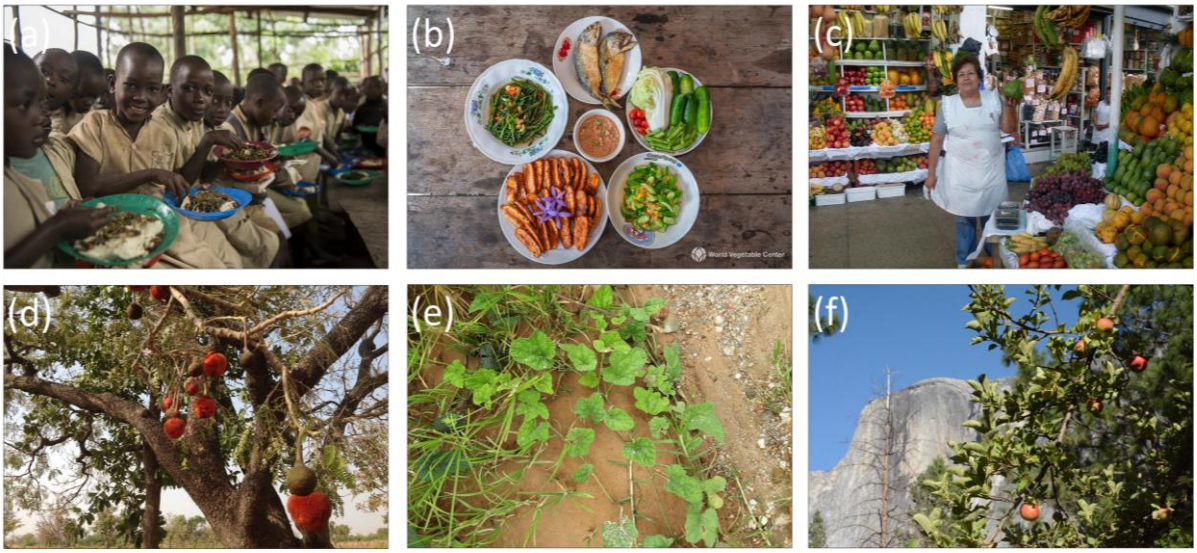


**Figure 1.** Examples of activities to safeguard and use fruit and vegetable biodiversity: a) Engaging young people through school-feeding programs with fresh vegetables in Burundi; b) Thai traditional meal with local bananas and a rich variety of vegetables; c) Fruit vendor in Lima, Peru with a fruit of cherimoya (*Annona cherimola* Mill.) of the locally-grown cumbe variety; d) Populations of the multi-purpose tree species néré (*Parkia biglobosa* (Jacq.) R. Br. ex G. Don) are maintained in parklands in Benin and so far do not have a genebank back-up; e) *Cucumis* spp. - wild cucumber from Nyika National Park delimited as a crop wild relatives (CWR) genetic reserve in Malawi as part of Darwin Initiative SADC/CWR project 26-023; f) Heirloom apple (*Malus domestica* (Suckow) Borkh.) trees in Yosemite National Park in the United States are maintained *in situ* and have a back-up in the USDA field genebank. Photo credits: a) WFP, Hugh Rutherford; b, c) WorldVeg; d) University of Abomey-Calavi, Enoch Achigan-Dako; e) Malawi PGR Centre; f) USDA, Gayle Volk.

## RAISING AWARENESS TO SAFEGUARD AND SUSTAINABLY USE FRUIT AND VEGETABLE BIODIVERSITY

Governments and NGOs should engage with young people to create increased awareness about why biodiversity matters in a new generation and gain in this way long-term support for biodiversity conservation[38]. For fruits and vegetables, governments and NGOs can do this by showing young people and their families the benefits of conserving and using fruit and vegetable biodiversity for diets and business opportunities. School-feeding programs in combination with biodiversity education are a promising tool to do this;

they become successful when they involve multiple stakeholders, rely on stable procurement markets, and are embedded in national policies[40] (Figure 1a). For example, government programs in Brazil use farm-to-school models to purchase fruits and vegetables of local crops from nearby producers to offer diverse school meals and to diversify farm systems with shorter supply chains for fresh produce[7]. In this way, local crops are being maintained in local and diverse food systems. About 368 million children worldwide are estimated to be fed daily through school-feeding programs, with a yearly investment between US$47-75 billion[41]. These programs should be linked to biodiversity education and their budget should be increased and focus especially on the fast-growing group of young people in sub-Saharan Africa. Part of the money should be used to promote consumption and sustainable cultivation of local fruit and vegetable crops.

Cooks, chefs, and other food innovators can promote local fruit and vegetable crops as a complement to global staples among urban consumers by emphasizing the taste, cultural, and health aspects of local crops[42,43] (Figure 1b). To be successful, these efforts must be linked to value-chain development to increase and sustain supply of local crops including investment in good agricultural practices, effective postharvest management, product preservation and processing, food safety, and market access for farmers[44,45] (Figure 1c). These farmers need good quality, safe, and appropriate planting material. To develop and deliver appropriate planting material of fruit and vegetable crops now and in the future, their genetic resources need to be conserved, characterized, and accessible.

## RESCUING FRUIT AND VEGETABLE BIODIVERSITY

A global rescue plan for fruit and vegetable genetic resources is needed to strengthen the existing network of genebank collections and fill gaps. This plan should also aim to protect wild populations of fruit and vegetable species, their relatives, and their pollinators and dispersers in natural habitats and traditional production systems.

Large national fruit and vegetable germplasm collections have been established in North America, South America, Asia, and Europe[46–49]. For instance, the Vavilov Institute in Russia has a famous collection of 75,000 fruit and vegetable germplasm samples[49]. Australia has recently established a seed bank for native food plants[50]. These national efforts are complemented with international initiatives that have resulted in the collection of at least 1,330 banana and 12,000 other fruit and 39,000 vegetable germplasm samples[51,52]. Wild relatives of fruit and vegetable crops, and neglected and underutilized fruit and vegetable species, poorly represented in this network, should be the focus of new plant explorations worldwide (Figure 1d). Sub-Saharan Africa presents a gap in the genebank network; investment in genebank infrastructure in this region will help to maintain and document sub-Saharan African fruit and vegetable genetic resources. At the same time, several collections from the existing genebank network are vulnerable because they have large backlogs of old or original fruit and vegetable germplasm samples[53]. These collections need investment in germplasm multiplication and rejuvenation. Without such support, there is a risk that part of this already-conserved diversity gets lost too.

Workable agreements for germplasm access and benefit sharing provide a framework for new plant exploration efforts[54]. The 2011-2021 global CWR Project led by the Crop Trust showed how global partnerships for collecting, conservation, and germplasm availability are possible for wild relatives of fruit and vegetable crops that fall under the framework of the Plant Treaty: eggplant (*Solanum* spp.), carrot (*Daucus carota* L.), apple (*Malus* spp.), and banana (*Musa* spp.). In this way, germplasm becomes available for farmers, breeders, and researchers under internationally established policies and regulations. Similar agreements should be made for plant explorations for other fruit and vegetable species following all applicable current laws and regulations at national and international levels.

For *ex situ* conservation, seeds of most vegetable species are usually dried and stored at low temperatures in conventional seed banks for national and international distribution and long-term conservation. In contrast, fruit species are usually maintained in field or greenhouse conditions. Apart from the fact that the recalcitrant seed behaviour of many fruit species impedes conventional storage, most fruit cultivars have specific genetic combinations that can be maintained only through vegetative propagation.

The lack of international fruit conservation programs—with the exception of banana—results in increased reliance on national genebanks to protect cultivars and wild relatives of fruit crops. National fruit conservation programs must become more synergistic on a global scale, as field and greenhouse collections are particularly vulnerable to environmental threats, theft, and pests and diseases.

For some economically important clonal fruit and vegetable crops, such as banana and garlic (*Allium sativum* L.), collections can be secured in tissue culture or by using cryogenic storage[55]. The development and application of tissue culture and cryopreservation protocols to a broader range of species, in combination with global investment in cryo-capacity, are essential to safeguard the diversity of clonal and recalcitrant fruit and vegetable species in *ex situ* conditions.

A global rescue plan must be accompanied with documenting genetic variation in traits of newly-collected and already-conserved fruit and vegetable germplasm. This is especially relevant for traits related to nutritional quality because species and varieties vary widely in levels of micronutrient concentrations and phytonutrient concentrations in general including antinutrients[56]. This information will help to select varieties with exceptional high values for health-promoting nutrients and low values for antinutrients. These varieties can be used to develop and grow nutrient-dense varieties, minimize effects of micronutrient dilution in breeding for yield increase, and develop varieties with special flavours for niche markets such as tasty tomatoes and gourmet chillies (*Capsicum* spp.)[11,56–58]. The mapping of genomic regions related to high or low phytonutrient concentrations will greatly enhance the development of varieties with high nutritional quality and specific taste profiles[57].

The rescue plan must be further complemented with *in situ* conservation in natural habitats and traditional production systems to maintain local fruit and vegetable crops and varieties that play important ecological and dietary roles, and to stimulate evolution of new traits through natural and human selection. Recognizing the importance of *in situ* conservation and the sovereign rights of countries over their natural resources, the

CBD encourages contracting parties to take measures to protect natural ecosystems and viable populations both within and outside protected areas, restore degraded habitats, and control invasive species among other threats[59]. Countries must put in place enabling policies and regulations to protect threatened species and populations as well as promote sustainable use and protection of local communities' traditional knowledge. Both the Plant Treaty and FAO Second Global Plan of Action provide further support to *in situ* conservation of plant genetic resources for food and agriculture[60,61].

A common strategy for *in situ* conservation of CWR is for countries to carry out conservation planning exercises that prioritize CWR according to specific criteria, given that large numbers of CWR species may exist in a given country and it will not be possible to target them all in national strategies[62]. The development of a National Strategy and Action Plan for *in situ* conservation of CWR is recommended to guide implementation and monitoring of conservation activities such as the established of genetic reserves in protected areas (Figure 1e). Wild relatives of fruit and vegetable crops are seldom included as a priority in national inventory lists; it is important to raise awareness of the need to conserve the wild relatives of these crops.

Local fruit and vegetable crops and varieties are still maintained by women and men champion farmers and communities in different production systems—diversified farms, home gardens, orchards, or other cultivated areas of high species and varietal diversity[63] (Figure 1f). These plants provide nutritional and food security, income-generating opportunities, and ecosystem services, and contribute to cultural identity[64]. Governments should recognize and protect unique and traditional production systems such as some countries are doing already for important agricultural heritage systems[65]. They should further support these farmers and communities to maintain these local crops and varieties by linking them to farm-to-school programs and niche markets for more resilient livelihoods, and by providing other types of incentives to maintain diversity in traditional production systems[63].

Finally, good agricultural practices and national and regional conservation strategies to protect pollinators and dispersers and their natural habitats must be implemented to safeguard these critical associated organisms of fruit and vegetable species[23,66]. These strategies should be embedded in various biodiversity and agricultural policy frameworks at national and international levels to stimulate integrated approaches for agrobiodiversity conservation. Pollinator conservation strategies have already been developed in the United States, and in several countries of the European Union and the Global South; such strategies require urgent development and implementation elsewhere.

## CONDITIONS FOR SUCCESS

A successful plan to rescue fruit and vegetable biodiversity requires clear goals and an adequate timeline; it should be developed by a global team of experts from different sectors and disciplines under the umbrella of a global initiative endorsed by the Plant Treaty and supported by innovative research to better conserve, understand, and monitor this biodiversity. This plan should delineate priorities, establish clear objectives, prioritize actions, and develop a transparent approach to track progress in line with the

2030 Agenda for Sustainable Development. It should also align strategies that are currently developed separately to safeguard fruit and vegetable genetic resources and to protect pollinators and other associated organisms. A second condition for success is the establishment of a global partnership among custodians of fruit and vegetable biodiversity—such as women and men champion farmers, national parks, genebanks, and botanic gardens—and users of this diversity, including farmer groups, small and large seed companies, and public breeding programs. Workable access and benefit sharing agreements and an open network for farmers, breeders, and researchers to conserve, access, and exchange genetic resources will be essential to the success of this partnership. Finally, a long-term funding mechanism to rescue and maintain fruit and vegetable biodiversity is key to a revised research and development agenda focusing on nutrition and well-being. Only with sufficient, sustained funding can a global rescue plan for fruit and vegetable biodiversity become a success. As a ballpark estimate, a 10-year global rescue plan for fruit and vegetable biodiversity would require at least 250 million USD.

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***The authors are:***

**Maarten van Zonneveld**, World Vegetable Center
**Gayle M. Volk,** National Laboratory for Genetic Resources Preservation, U.S. Department of Agriculture
**M. Ehsan Dulloo,** Bioversity International
**Roeland Kindt**, World Agroforestry, CIFOR-ICRAF
**Sean Mayes,** Crops For the Future
**Marcela Quintero,** International Center for Tropical Agriculture (CIAT)
**Dhrupad Choudhury,** International Centre for Integrated Mountain Development (ICIMOD)
**Enoch G. Achigan-Dako,** Laboratory of Genetics, Biotechnology and Seed Sciences, University of Abomey-Calavi
**Luigi Guarino,** Crop Trust

For further information about the Scientific Group,
visit **https://sc-fss2021.**org or
contact **info@sc-fss2021.org**
**@sc_fss2021**