Empowering genebanks to transform agrifood systems

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This paper underscores the urgent need for transforming agrifood systems to address global challenges of food insecurity, climate change, and biodiversity loss. The preservation and utilization of food plant diversity, maintained in genebanks, is crucial. Crop diversity, at species and genetic levels, enhances productivity, resilience, sustainability, equity, and health in agrifood systems. We emphasize the importance of empowering genebanks through sustainable funding to drive this transformation.

We must urgently transform our agrifood systems if we are to resolve the linked, overlapping crises of food and nutrition insecurity, climate change, and loss of biodiversity that humanity faces. Such a transformation will depend on many different actors doing many things differently, but it cannot happen without securing and using the diversity of hundreds of food plants, from our staple grasses to trees of all kinds. Although this diversity is disappearing from many farmers' fields, it is being conserved in genebanks, from where it can be accessed and used, which enables its benefits to be returned to farmers. In this paper, we highlight how crop diversity, at both species and genetic levels, makes agrifood systems more productive, resilient, sustainable, equitable and inclusive, as well as more healthy for humanity and for the planet. We describe how genebanks preserve diversity in the face of continuing erosion and make it readily available for use by researchers, plant breeders and farmers. We also point out that genebanks currently face substantial challenges and conclude that if they are to catalyze the transformation of agrifood systems for the better they must be empowered to do so. Such empowerment will depend primarily on adequate and sustainable funding, combined with renewed commitment to the transformational power of genebanks.

We need to transform agrifood systems

Agrifood systems include the totality of the stakeholders, interactions and decisions that contribute to how agricultural products are grown, harvested, processed, packaged, marketed, transported, distributed, traded, sold, bought, prepared, consumed, and disposed of. Agrifood systems have sustained the global population and allowed humanity to flourish for more than ten thousand years. However, some of the ways in which agrifood systems have developed have also contributed to food insecurity, poor human health, environmental degradation, and socio-economic instability and inequality. The dominant agrifood systems of today also contribute significantly to climate change and biodiversity loss[1]. A paradigm shift is necessary to address these 21st century challenges. Agrifood systems around the world can be transformed and made more sustainable by reinforcing their positive features while minimizing their negative impacts. In this way, they can become a driving force for ecological restoration and climate stability, while properly nourishing all of humanity.

1. Food security. The principal reason why agrifood systems must be transformed is to better ensure the long-term food and nutritional security of a growing global population. Despite astonishing advances in food production in recent decades, over 800 million people still suffer from hunger and undernourishment. Systematic and enduring improvements of agrifood systems are needed to ensure the availability, accessibility, and affordability of culturally appropriate, healthy and diverse food for all. This is vital to eradicate food and nutritional insecurity around the world by 2030, as called for by Sustainable Development Goal 2: Zero Hunger.

2. Public health. Current agrifood systems have been implicated in major global public health crises. Unhealthy diets that are high in ultra-processed foods, refined sugars, and saturated fats have contributed to unprecedented rises in

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obesity, diabetes, and cardiovascular ailments, which coexist with pervasive problems of undernutrition. More than 1.9 billion adults are overweight, and of these over 650 million are obese[2]. At the same time, micronutrient deficiencies remain high and globally prevalent. In less economically developed countries, more than 40% of women are anaemic, nearly 20% of the population suffers from the disorders of iodine deficiency, and about 25% of children have a subclinical deficiency of vitamin A[3]. Micronutrient deficiencies and imbalances lead to impaired growth and cognitive development, birth defects and blindness, as well as subpar school and work performance, and poor general health. New kinds of agrifood systems are needed that promote healthier diets and that can help eliminate the double burden of undernutrition and chronic lifestyle diseases.

3. Sustainability. Though indisputably productive in terms of the bulk provision of calories, current agrifood systems are significant contributors to environmental degradation even as they feed us. In many parts of the world agrifood systems have been, and continue to be, a leading driver of habitat loss, including deforestation, soil degradation, and the contamination of air and water. They are also responsible for perhaps 25% of the global greenhouse gas emissions that contribute to climate change[4]. Our long-term future depends on transforming agrifood systems so that they are more environmentally sustainable and can help restore and repair the environment, stabilize the climate, and safeguard the biodiversity and broader ecological systems on which we all ultimately depend. Failing to act increases the risk of a 'doomsday scenario' in which agrifood systems collapse. We should not be eating our way through the only planet we have – and we do not need to. Agriculture done well can nourish people while also enhancing nature, conserving forests, building soils, purifying air and water, and sustaining diverse and resilient ecosystems.

4. Resilience. Almost daily we are reminded that current agrifood systems are fragile. They are susceptible to disruptions of various kinds that impact people through shortages and price spikes. The global Covid-19 pandemic, the war in Ukraine and other violent conflicts, extreme floods in Pakistan, locust outbreaks in East Africa, fires across North America, and extensive droughts in the Amazon all have impacted agrifood systems. The interlinked and increasingly frequent challenges of extreme climate events, crop pest and disease outbreaks, as well as social unrest and economic perturbations, exacerbate these and other harmful impacts. We must strengthen the ability of agrifood systems to withstand and recover from shocks of these kinds, whether anticipated or unforeseen, to ensure the long-term stability of our food supply in the face of increasing demand.

5. Social equity. Agrifood systems must be more inclusive and more socially just, and thus better support livelihoods, enrich the diversity of human cultures, combat poverty, recognize Indigenous peoples and underpin rural development. For example, 60% of those experiencing food insecurity globally are women and girls[5]. The transformation of agrifood systems must benefit all, and explicitly consider women, the disabled, the poor, small-scale farmers, Indigenous peoples and marginalized groups and communities of all kinds.

Only by transforming agrifood systems in the ways outlined above can we ensure food security and health for humanity, safeguard our planet's biodiversity and climate, and secure the benefits of cultural diversity and traditional knowledge. Urgent action is needed, before more people are lost to starvation, before more lives are marred by malnutrition, and before the climate reaches a tipping point. Ecosystems are being destroyed and degraded, and the diversity of crops of all kinds is being lost. Disappearing with this diversity are the unexplored genes and traits that are key to overcoming the myriad biotic and abiotic stresses faced by global agrifood systems now and in the future. Business as usual or only modest incremental change will not be sufficient to adequately address the scale and urgency of the problems faced by humanity.

But what exactly should we do?

We need crop diversity to transform agrifood systems

Considerable changes to agrifood systems are clearly needed, but transformation will be difficult. Many different actions will be required across all sectors of society to effect serious, lasting change for the better. However, there is one guiding principle that will be absolutely necessary for any truly meaningful transformation: the global good of plant diversity needs to be at the heart of future agrifood systems. Greater crop diversity in agrifood systems will enable greater productivity, improved sustainability and increased resilience, while also improving global health and social equity. Diversifying the plants we grow and eat, including in agroforestry systems that incorporate productive tree species alongside annual crops and other forms of intercropping, will build resilience, enhance nutrition, preserve traditions, and sustain livelihoods. With a more biodiverse, climate-resilient agriculture centred around a rich combination of cereals, vegetables, pulses, fodders, fruits and nuts (both cultivated and wild-harvested) our agrifood systems can be transformed to be abundantly productive and health-sustaining, while also regenerating the environment.

1. Food and nutrition security. Plant diversity, at both the species and variety level, is a prerequisite for food and nutritional security, and broader positive outcomes for human health. Crop diversity is important over time and over space. Over time, as pests and diseases wax and wane, as temperature and precipitation patterns change, and as markets shift, farmers need to adjust to work with new crops and better adapted varieties of familiar crops. Genetic diversity within crops allows plant breeders – in both the public and private sectors – to develop more productive, more resilient, more nutritious varieties, providing wider, better choices to farmers[6]. Spatial variety is also beneficial: farmers that cultivate a wider range of annual, perennial and tree crops, in rotation or at the same time, and multiple varieties of individual crop species, face lower risks of harvest failures, while also stabilizing crop productivity, their own incomes and everyone's food supply. Diverse crops in diverse agricultural landscapes also offer a broader range of nutrients that contribute to balanced and nutritious diets[7]. Enhancing awareness of neglected and underutilized species will help to broaden crop diversity with highly adapted species of proven resilience and nutritional quality. To effectively address hunger and malnutrition in all its forms, agrifood systems

need a greater focus on increasing the availability of diverse, nutrient-dense foods and ensuring their availability to deliver balanced nutrition for all.

2. Environmental sustainability and resource efficiency. Agrifood systems that are diversified over time and space are more economically and environmentally sustainable. Extensive monocultures supported by large external inputs of water, fertilizers, pesticides, and herbicides, increase the overall vulnerability of our agrifood systems and push us to exceed planetary boundaries[8]. Biocultural and agroecological approaches can enhance the sustainability and resilience of food producing habitats. Agroforestry systems that integrate trees into agricultural landscapes can help to reduce erosion, conserve water, sequester carbon, restore degraded landscapes and reduce the need for chemical inputs. Multi-strata agroforests and home-gardens enriched with food trees that yield diverse edible fruits, seeds and leaves are resilient and enhance food and nutritional security[9]. Nitrogen-fixing plants, including nutritious pulses, increase soil fertility without the use of synthetic fertilizer. At the same time, crop breeding is critical to developing varieties that are better adapted to local conditions, that are more efficient in their use of soil nutrients, irrigation water, and other scarce resources, and that minimize the emission of greenhouse gases. New varieties are being developed that can store carbon in deep root systems and that can better cope with hot, dry or saline conditions. Many of these valuable traits are present in the genetic diversity of landraces and wild relatives, and will be vital to improve crops for the future. Breeding for more productive crops that are resilient and have other beneficial attributes can reduce the pressure for agricultural expansion and can help protect biodiversity-rich habitats that provide vital ecosystem services[10].

3. Climate change adaptation. As our planet faces the impacts of climate change, including rising temperatures, changing precipitation patterns, changes in the distribution and load of pests and diseases, as well as more extreme weather events, crop diversity becomes ever more critical. Different crops, and different varieties within crops, exhibit different tolerances to climate-induced stresses. Crop breeders are accelerating the availability of a wider choice of adapted crops for farmers, from heat-tolerant beans, to short-season vegetables, to drought-tolerant cereals. Trees and other food-producing woody perennials may also be more resilient than annual crops to climate change, as their more extensive root systems allow them to better withstand dramatic swings in temperature or water stress. To navigate challenging times, and to adapt to significant changes in real world conditions, we can benefit from the accumulated wisdom of Indigenous peoples and traditional farmers by continuing to conserve crop diversity through cultivation. Farmers can more easily adapt to new climate conditions and reduce their vulnerability to climate change if they have a wide diversity of crops and varieties at their disposal that enable them to safeguard and sustain food production under increasingly challenging and uncertain conditions.

4. Resilience and risk mitigation. Diversity is a prerequisite for the resilience and dynamism of any system, and agriculture is no exception. Agrifood systems that are more diverse are less susceptible to pests and diseases, less vulnerable to market fluctuations, and more resilient to climate change. Crop diversity acts as a natural defence mechanism, reducing the risk of large-scale crop losses if a single crop fails. Diversity is an insurance policy and safety net, but also the raw material for innovation.

5. Social equity. The most marginalized individuals in global society are often the most reliant on agriculture. They are also vital guardians of crop and tree diversity. Around the world, roughly half a billion small-scale farmers grapple with limited access to affordable, high-quality seeds, a paucity of essential services, and inadequate access to viable markets[11]. Therefore, enhancing the diversity, quality, and affordability of annual and perennial crops to small-scale farmers is of paramount importance. Access to preferred varieties empowers vulnerable communities by increasing income and bolstering resilience. Currently, persistent gaps in the local availability of appropriately diverse planting-material hinders the realization of this potential. Interventions from a multitude of actors are needed to tackle the bottlenecks on seed and seedling delivery systems and to promote fairer agrifood systems, but empowerment of women and Indigenous communities, so that they have greater autonomy over their agricultural practices and resources, is crucial. By supporting the unique priorities of women and Indigenous communities to conserve, promote and use plant diversity, we simultaneously safeguard and honor their invaluable knowledge and traditions. A more inclusive approach also strengthens and improves their agency in decision-making and delivery within diverse agrifood systems.

Crop diversity is by no means the only thing needed to transform agrifood systems. But across both time and space, and both within and among species, crop diversity is fundamental to setting agrifood systems on a path towards a more sustainable, equitable and climate resilient future. However, this vital resource is being eroded, and can be difficult to access in a timely manner, especially for those who need it most. And when crop diversity is lost, it is lost forever.

That is why we need genebanks.

We need genebanks to transform agrifood systems

Genebanks are the last line of defence against the global erosion of diverse annual, perennial and tree crops, and are also the wellspring from which plant diversity flows to meet our need for food and nutrition in the face of accelerating challenges. Landraces are disappearing daily from farmers' fields, traditional crops are being abandoned, and in many natural habitats forages and crop wild relatives are being pushed towards extinction. Farmers are thus losing the options on which their livelihoods depend, and the raw material needed to develop crop varieties for better nutrition, livelihoods, and resilience are steadily vanishing. In recent comprehensive global reviews, 40% of plant species are considered threatened with extinction[12], and 86% of studies found a decline in crop diversity over time[13]. Genebanks preserve crop diversity for the long term, cheaply and efficiently. But they do more than just conserve: they also provide ready, safe access to diversity to all who wish to use it. Genebanks thus play a pivotal role in the transformation of agrifood systems in two fundamental ways.

The first way genebanks catalyze transformation is by making the diversity they conserve available to plant breeders and also to the researchers who are exploring the variety of plant life for new and valuable traits. The world's crop genebanks house a vast array of older improved cultivars, traditional landraces, and wild relatives for a wide range of cereals, pulses, roots and tubers, vegetables, fruits, nuts, forages, and oil crops[14]. These are the ultimate foundation for crop improvement programs, whether of global staples or of crops of more restricted distribution and importance. Plant breeders and researchers use the diversity stored and documented in genebanks to develop new, better varieties. Many of these breeders are in the public sector, and respond to local demand for the crop varieties needed by small-scale farmers. Such farmers produce up to a third of the world's food but are not always served by the profit-seeking market. However, the landscape for crop improvement is complex and the private sector plays an important role in the improvement of crops with low public investment, such as vegetables. A wide range of international, national, and local seed enterprises provide an extensive network that potentially allows smallholder farmers to purchase affordable and quality seed to diversify their farm systems with nutritious and high-value crops. We need a diversity of breeders and seed suppliers to deliver diverse seeds worldwide, and they all ultimately depend on genebanks for their raw materials.

Breeders search genebank collections for variants that provide greater nutritional value, withstand more extreme drought and heat, store more carbon, and have higher yields without the need for unaffordable inputs of fertilizer and pesticides. Variants that are easier to process, and that are more culturally appropriate, tasty and nutritious are also important goals for selection. These traits are then introduced into the varieties that reach smallholder farmers through national public systems and a broad range of other seed enterprises. By providing the raw material for these breeding efforts, genebanks contribute to the livelihoods and healthy diets of the world's poor, reduce the use of pesticides, irrigation and other unsustainable inputs, and support the adoption of broader agroecological approaches in farming. In particular, the diversity stored in genebanks includes material that is adapted to a wide range of climatic conditions and agroecological zones, and that contains genetic traits that can be used to develop new varieties that are better suited to changing climates. Genebanks provide the indispensable raw materials for plant breeders involved in developing climate-resilient agrifood systems.

The second way that genebanks support farming communities is through the direct provision to them of crop and tree diversity. Genebanks safeguard landraces that have been cultivated by generations of farmers, that are deeply intertwined with local traditions and practices, and that reflect the unique history and customs of individual communities. By ensuring the availability of these landraces, genebanks help maintain the cultural fabric of farming communities. They help farmers to sustain age-old practices and pass on their agricultural heritage to future generations. This is particularly important for so-called neglected and underutilized crops, including many vegetables, fruits and nut trees that receive little research and development investment[15]. Although these crops may not be widely commercialized in mainstream value-chains, they are often disproportionately important in local agrifood systems, possessing valuable nutritional, cultural, and agroecological characteristics that can contribute to diversifying agrifood systems at larger scales. Genebanks can reach more farmers with diversity from their local crop collections by collaborating with NGOs, public-state systems, farmer cooperatives, and local and national seed enterprises.

Genebanks do not provide crop and tree samples at random. The diversity they provide is carefully curated to be well-suited to a great variety of specific needs. Diversity in genebanks is associated with information about where and when it was collected, which is important in anchoring it to local practices and environmental conditions, as well as how it performs. This information is invaluable to breeders developing new varieties, but also to farmers facing the challenges of changing climates and evolving agricultural techniques. Farmers gain access to plant material that has demonstrated resilience and productivity under specific local circumstances. The tailored approach provided by genebanks empowers farmers to optimize their production and reduce their dependence on external inputs, ultimately contributing to sustainable and self-reliant agrifood systems.

Genebanks thus act as a bridge between the past and the future of agriculture, preserving cultural heritage, enhancing adaptation to local conditions, and championing neglected crops, while supporting breeding efforts. By making available to farmers landraces that they have lost, that provide additional production options, and that they can develop further as they have done for generations, genebanks support the preservation of traditional cultural practices, and complement the efforts of public and private sector plant breeders.

Nevertheless, genebanks face significant challenges in fulfilling their vital mission. How can we help them ensure the continued conservation and use of crop and tree diversity for the benefit of present and future generations and for healthy ecosystems?

Unlocking the power of genebanks to transform agrifood systems

Without crop diversity we cannot hope to develop agrifood systems that are more productive, healthy, resilient, sustainable, and equitable. Much crop diversity is available *only* in genebanks, because it has been lost from nature and from farmers' fields, and a vast spectrum of diversity is *most easily and most safely* available for use from genebanks. We therefore cannot transform agrifood systems without well-functioning genebanks that are closely connected to the needs of their users.

Unfortunately, genebanks are frequently taken for granted, or indeed overlooked entirely. Too often, they are caricatured as static museums for old-fashioned heirloom varieties of only sentimental or hobby value. They are not recognized for what they are – high-tech sources of innovation and possibility – and thus they are not given the support they need. To realize their full potential, to make the full spectrum of crop diversity available to all, to create new options for transforming global agrifood systems, they need a transformation themselves. First and foremost, genebanks need sustainable funding, but not only that.

1. Sustainable funding. To empower genebanks to effect meaningful change in agrifood systems, sufficient, guaranteed financial resources are essential. Investments are needed to upgrade and future-proof storage facilities and associated infrastructure, implement robust documentation and information systems, and support research to investigate the genetic potential of genebank holdings to meet user needs now and in the future. Safety back-ups of genebank collections, especially of field collections, are also essential, as real-life experience in Syria and elsewhere has shown. Project cycle funding for genebanks fails to provide the security and long-term planning that long-term institutions such as genebanks need. Putting in place sustainable funding mechanisms is necessary so that genebanks can fulfil their vital role to preserve crop diversity, and to make it available to transform agrifood systems far into the future.

2. Advanced technologies. Genomics[16], cryogenics[17], bioinformatics[18], and information technologies[19] are already allowing genebanks to more efficiently keep alive, store, catalogue and analyse vast and diverse collections of annual, perennial and tree crops. But much more is needed. Digital platforms and open-access databases are essential to enable seamless knowledge-sharing and collaboration among genebanks and researchers worldwide. These platforms facilitate the identification of valuable material for crop improvement and other uses, while also ensuring that the rights of traditional owners are respected and that benefits are equitably shared. At the same time, green technologies can make genebanks less costly to run and decrease their carbon footprint, while biotechnologies can improve the storage of species that cannot be stored as seeds. By continuing to harness and embrace existing and developing technologies, genebanks can further improve their efficiency and accelerate the multiple beneficial uses of crop diversity.

3. Collaboration and knowledge-sharing. Genebanks, whether community-based, national, regional, or global in scope, need to collaborate more among themselves, as well as with their diverse stakeholders. No community, country or region is self-sufficient in crop diversity, and no single genebank can do everything – nor does it need to, if all are ready to specialize and share common burdens. A strategic global system for conserving crop diversity is needed based on strengthening the connective tissue among genebanks from those at the scale of a village all the way through to those that operate globally. Establishing solid, inclusive, equitable platforms for collaboration, as well as knowledge-generation and knowledge-sharing, enhances the use of diversity, encourages innovation, and accelerates crop improvement and sustainable farming practices. The equitable sharing of crop diversity, and its associated data and best practices strengthens the capacity of all genebanks to contribute to agrifood systems transformation.

4. Supportive policies and regulations. An enabling policy environment is critical to empower genebanks and their users to harness crop diversity effectively. Governments should develop supportive laws, policies and regulations that prioritize the conservation and use of annual, perennial and tree crops, and protect natural habitats containing crop wild relatives and other useful wild species. Clear intellectual property rights frameworks, access and benefit-sharing mechanisms, and biosafety regulations that balance commercial interests with the public good are necessary. The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) is particularly relevant in this regard, as it provides the policy infrastructure to elevate the profile of genebanks, for equitable benefit-sharing, for facilitated exchange of crop diversity, and for collaboration across borders in conservation and sustainable use[20]. There needs to be more support for the full, proactive implementation of the ITPGRFA at national and regional levels.

5. Capacity building and research. Empowering genebanks requires building technical and scientific capacities. Training programs should be developed to continuously enhance the skills of genebank staff in areas such as exploration and collecting, complementary conservation techniques (including cryopreservation), diversity assessment, trait discovery, seed and plant health, and data management. Strengthening scientific capabilities through research partnerships and capacity-building programs enables genebanks to fulfil their potential for agrifood systems transformation. Investments in capacity-strengthening should be prioritized based on information about gaps in coverage of the global system for conservation of crop diversity, in terms of both conserved, available genetic diversity and information about collections. Support should be provided for under-resourced organisations that are willing and able to assume new responsibilities, and address those gaps, on behalf of the international community. Several genebanks have played an international role over decades to support countries to conserve and exchange germplasm. Providing increased support to this growing global system is key to strategically enhancing exchanges of capacity and diversity worldwide.

6. Engagement with the plant breeding and research community. The predominant users of genebanks are crop breeders and researchers, including those working on tree crops, perennials, and agroforestry systems. Genebanks grow their capacity to do good in the world when they continually improve the ways that they make their collections accessible to this research community, especially in low-income countries and in the public sector, so that quality seed can be delivered to farmers globally through well-functioning, inclusive seed systems.

7. Engagement with farmers, farmer organizations, local communities, and development organizations. Genebanks must engage directly with individual farmers, local enterprises, and communities and collaborate with development organizations at scale to reach those people and communities that are growing the food that we all need. Farmers, especially small-scale farmers, many of whom are women, possess invaluable knowledge as traditional custodians of on-farm crop diversity. Genebanks, breeders and researchers should collaborate with farmers in participatory breeding programs, on-farm conservation efforts, and decision-making processes. Initiatives that promote farmer-led seed systems, community seedbanks, seed business development, and citizen science projects, including for trees, empower both genebanks and farmers to contribute to the transformation of agrifood systems.

A call for action in support of genebanks

Empowering genebanks to catalyse the transformation of agrifood systems requires a concerted and sustained effort by multiple actors to have an impact across multiple dimensions. Governments, the seed and food processing industries, the research community, civil society, the financial sector, multilateral agencies, and farmers must all work together to achieve a collective vision of an effective and efficient global genebank system that can put the diversity of crops of all kinds at the heart of agrifood systems. Advanced technologies, better collaboration, supportive policies, capacity building, and closer engagement with the users of crop diversity, including especially local communities, are key for unlocking the full potential of genebanks. But all this takes financial resources. Only through adequate investment in genebanks can we ensure the conservation, documentation, and – crucially – the use of crop diversity. By investing in genebanks we can transform agrifood systems to be more productive, healthy, resilient, sustainable, and equitable – for the benefit of all humanity and the planetary systems that sustain us all.

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