Agrobiodiversity and a sustainable food future

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The biodiversity of food plants is vital for humanity's capacity to meet sustainability challenges. This goal requires the rigorous integration of plant, environmental, social and health sciences. It is coalescing around four thematic cornerstones that are both interdisciplinary and policy relevant.

The agricultural and food sciences are leading the way in how food and crop production uses plant biodiversity. However, the world's sustainable food future also depends on the responses of plant biodiversity to global changes that range from climate and environmental impacts to market integration, demographic and nutritional transitions, and human health and disease. The broad scope of these sustainability challenges highlight the need to involve the environmental, social and health sciences in policy- and management-relevant research on the use and conservation of food plant biodiversity.

Integrative approaches to this agrobiodiversity are based around four main themes: (1) genetic resources, ecology and evolution; (2) governance policy, institutions and legal agreements; (3) food, nutrition, health and disease; and (4) global change drivers with social-ecological interactions. These four cornerstones have seen an expansion of scientific research, policy and management activities involving agrobiodiversity, with the rate of scientific and scholarly research increasing significantly in recent years (Fig. 1).

The framework of these four cornerstones and the growing bridges between them promise to advance new integrative scientific approaches. These are needed to identify strategies that can transform the contributions of agrobiodiversity to global food sustainability. They reflect the need for policy- and management-relevant research on the complex roles of smallholder and indigenous people in food biodiversity and security. Their knowledge and management account for the majority of current global production and consumption of food plants. They also form a major segment of the food-insecure, malnourished and impoverished population of the world.

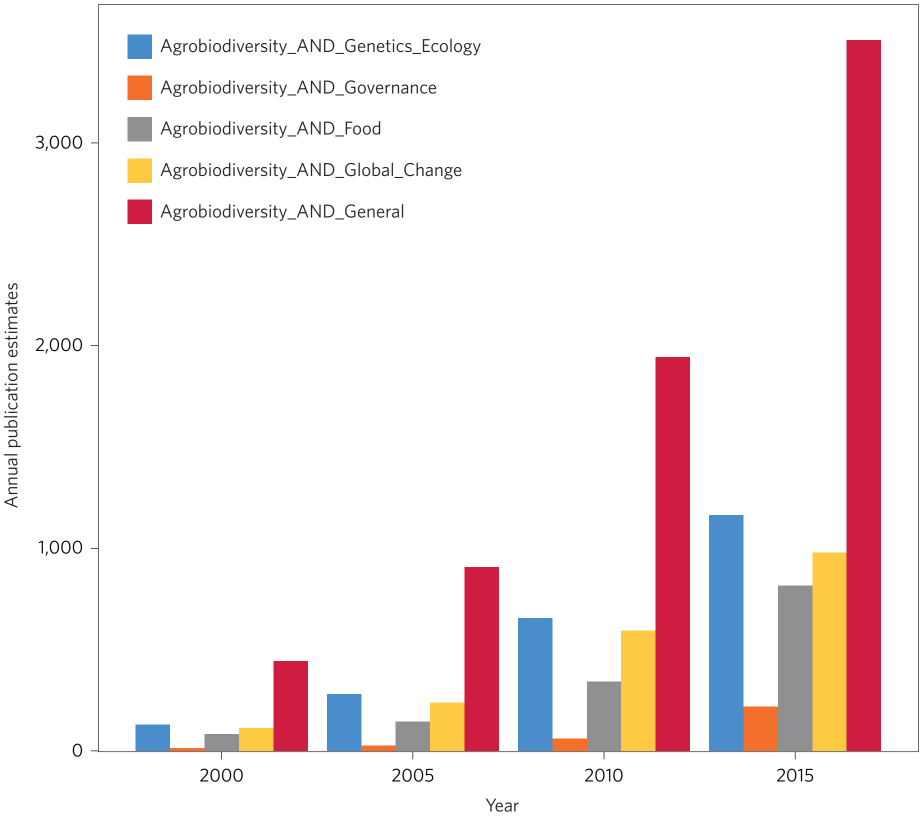

Figure 1 | Publications on the biological diversity of agriculture and food systems. Annual publication estimates in general (red) and cornerstone scientific areas (blue, genetics; orange, governance; grey, food; yellow, global change; see full title and description of each area in the main text). Data taken from https://apps.webofknowledge.com, accessed 30 October 2016.

Genetics, ecology and evolution

Applying genomic, geospatial and ecological tools is yielding new insights into worldwide agrobiodiversity in farming landscapes and food systems, ranging from the gene level to ecosystem- and global-scale synthesis, propelled by the increase of high-quality information on multilevel environmental functionality and cultural interactions[1,2]. These data can support spatial and temporal comparisons of diversity in key hotspots through systematic monitoring of the status and coverage of *in situ* management and *ex situ* genebank collections. Globally, the highest levels of agrobiodiversity occur in farm ecosystems and the surrounding landscapes of smallholder and indigenous populations[3].

Integrated analysis of the history and evolution of plant and animal gene pools amid cultural interactions and knowledge systems are needed to document adaptive population-level shifts of *in situ* agrobiodiversity and use of *ex situ* materials through genetic enhancement and crop improvement[4]. In the case of crop wild relatives, recent scientific advances and improved global-scale geospatial information have enabled high-resolution *ex situ* gap analysis[5]. New genomic tools and systematic monitoring methods are enabling refined baseline knowledge of the genetic diversity patterns of the landrace populations of local crops and crop wild relatives that continue to be managed and conserved *in situ*.

Integrated scientific approaches are needed to understand the natural and cultural dynamics of current agrobiodiversity evolution and ecology. Insights drawing on new research tools and spatially explicit models are being applied to the evolutionary ecology of food plants in environmental and sociocultural spaces subject to climate change and market integration[6,7]. Genetic resources and crop conservation science require a similarly integrative approach. Recent repatriations of genebank accessions to farmers in Peru, Brazil and India, for example, raise questions over whether and how crop biodiversity can be included in production systems subject to climate change, and whether such flows are reaching farmers, including those affected by agrobiodiversity loss. Future research will need the expansion of systematic agrobiodiversity monitoring at benchmark observatories with inter-institutional data networking and citizen science tools.

Governance gaps and gains

The portfolio of policy, legal and institutional mechanisms for the governance of agrobiodiversity has been broadened to involve multiple international arrangements on access and benefit sharing, including the International Treaty on Plant Genetic Resources for Food and Agriculture and the Convention on Biological Diversity, together with the Nagoya Protocol and the FAO's Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture. However, the lagging pace of implementation reflects an overall crisis in this governance. Benefits sharing has been widely touted but sparsely applied. In short, new strides to create governance frameworks belie a significant operational deficit.

At the same time, community, grassroots and civil society organizations, along with the private sector, are experimenting with innovative institutions and actions. Examples include seed associations, celebrity chefs and corporate social responsibility agreements between companies and farmer groups. The informal sector, including farmer seed systems, continues to provide relatively low-cost seed through decentralized pathways[8]. Many regions of food plant biodiversity rely on robust informal seed sharing networks and could benefit from quality improvements that incorporate their strengths. Information on region-scale seed systems is a gap in scientific research, which to date has favoured the more tractable community and national levels.

Advances in new scientific technologies that are largely unattended in current treaties produce increased governance challenges. Genomic, proteomic, metabolomic and resulting 'big data' approaches, particularly those involving information about culturally guided evolution of plant biodiversity, are adding a critical new dimension to governance. These approaches also provide information on selected gene sequences and mutations found in local crops, seed or wild relatives in cultural landscapes. Such complex scientific and social issues require interdisciplinary research extending from the plant sciences to the social sciences.

Food, nutrition and health

Ending hunger, achieving food security and improving nutrition and health are highlighted in sustainability mandates, such as the new United Nation's 2030 Agenda for Sustainable Development, that call for the use of biological diversity in consumer-accessible food systems and dietary diversity. However, scientific findings underscore that while agrobiodiversity is significantly varied among certain consumer groups and regions within countries[9], the overall trend is towards reduced levels at a global scale and within most countries even in the world's industrialized economies[10].

One force promoting agrobiodiversity in healthy diets is the resilient preference for biodiversity-related traits in many local farming and food systems[11]. Food biodiversity at the farm level can support the nutrient and organism, and community levels of dietary diversity, especially when combined with informed food choices and specialization, enabling a role for market-based purchasing power[12,13]. The coupling of plant biodiversity to diet, nutrition and health outcomes demands an expanded scientific focus that encompasses taxonomic, functional group, geographic, whole-diet and food system approaches[14].

Integrative approaches are vital to address the decoupling of agrobiodiversity production from its consumption. This decoupling occurs where growers in regions within the global centres of concentrated agricultural biodiversity (known as Vavilov centres) are not able to access diverse foodstuffs due to insufficient resources and associated dietary changes. Many of the affected cultivators are smallholders and indigenous people. Plant sciences integrated with environmental, social and health sciences are required for policy-relevant research on improving the linkages of agrobiodiversity to nutrition and health in these regions[15].

Global change drivers

Global change can result in loss, enrichment or conservation of biodiversity in agriculture and food. These changes are driven by, for example, climate change, demography, land-use intensification and the large-scale integration of food systems and global markets, as well as urbanization, peri-urban expansion and national planning. In the case of climate change, the modelling of crop yield underscores that the variety- and species-level adaptations[16] will depend on the strategic insertion of biodiversity. Climate change challenges correspond to agrobiodiversity systems, as well as farmer knowledge systems[17].

The integration of commodity markets has led to a national-level decline of farming populations, in addition to the biodiversity of global food systems[18]. The global integration of labour markets is similarly a driver. Countervailing trends occur at the local scales of individuals, households and communities. Such counter-tendencies suggest that favourable conditions, such as farm-level resource availability and resilient cultural preferences, can effectively promote agrobiodiversity use and conservation in these contexts.

The interactions of multiple drivers determine whether agrobiodiversity is conserved and, if so, how evolution is structured. Integrating the plant sciences with the environmental and social sciences is urgently needed to distinguish the specific regions, and corresponding producer and consumer populations, that are vulnerable to the loss and potential extinction of food plant biodiversity[19,20], as well as food insecurity. Conversely, regional conditions enabling the compatibility of agrobiodiversity use with potential sustainable intensification also demand policy-relevant scientific analysis[21,22]. In geographic areas that have maintained significant use of agrobiodiversity, non-static practices of cultural identity and ethnicity in smallholder, indigenous and other groups tend to exert strong positive feedbacks.

Elucidating a diversity of scales

The four research cornerstones that we have identified and their interconnections enhance the use of biological diversity in sustainable agricultural and food systems. Each is interdisciplinary, requiring the integration of the plant sciences with the environmental, social and health sciences. The expanding scientific literature highlights that specific subjects and scales characterize each cornerstone (Fig. 2). Research to date shows characteristic scales, both spatial and temporal, revealing that studies of genetic resources and human health put greater emphasis on molecular and organism-scale processes, with time frames dating back to early agriculture. The shorter time-depth of within-country, regional-scale research exposes a continued gap of research across all cornerstones. Linking across cornerstones is similarly needed to respond to key gaps and challenges facing policy-relevant agrobiodiversity research. One example is the impact of global drivers evident as powerful forces propelling changes in each of the four cornerstones.

Integrating policy- and management-relevant research in the plant sciences with the environmental, social and health sciences is paramount to the current and future initiatives needed to advance the contributions of biodiversity to the sustainability of agriculture and food systems. Future developments will require more integrative scientific approaches and research strategies. Powerful linkages are emerging, such as the influence of genomics research and the increasingly influential role of the drivers of global change. Recognizing the linkages within and among the four principal cornerstones of an integrated co-evolving framework, rather than rigid delimitation of topics, will prove essential. The dynamic roles of smallholders and indigenous groups must be a priority in research on agrobiodiversity and food sustainability amid expanding global change. ❐

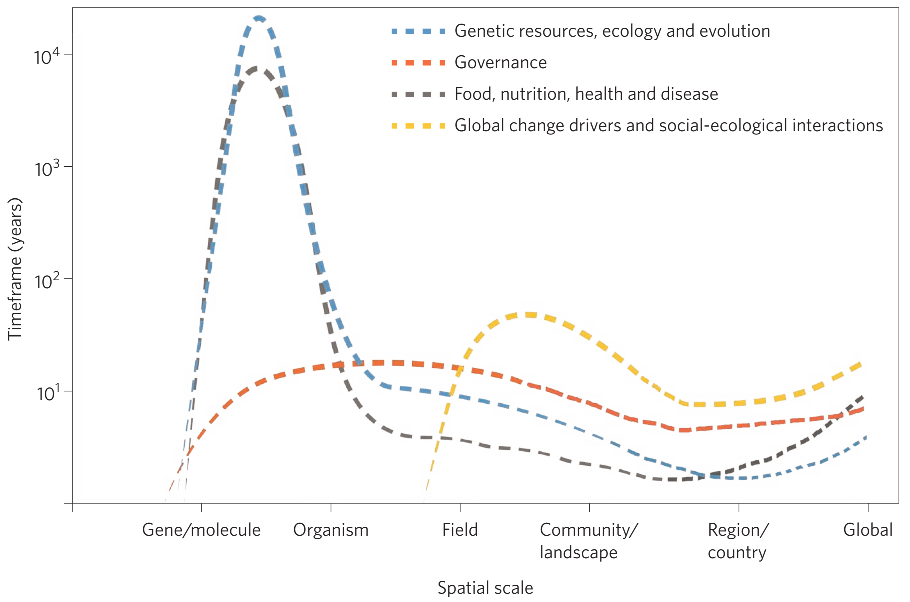

Figure 2 | Characteristics of spatial and temporal scales in research on the biological diversity of agriculture and food systems.

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Competing interests

The authors declare no competing financial interests.