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comment

Expanding the role of botanical gardens in the future of food

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Consistent with their historical focus on the functional utility of plants, botanical gardens have an important opportunity to help ensure global food and ecosystem security by expanding their living collections, research and education programmes to emphasize agriculture and its impacts.

Agricultural land represents both the planet's largest and most rapidly expanding ecosystem, and its single greatest driver of biodiversity loss[1]. Cultivated food plants cover roughly 12% of the world's land surface, with another 20% devoted to pastures[2]. With about 800 million of the world's 7.3 billion people currently malnourished, and roughly 220,000 additional people to feed every day[3,4], we need to cultivate robust and diverse agricultural systems capable of supporting healthy, productive and secure lives for all. Meeting this challenge will require concerted, well-informed societal efforts to address the complex social, environmental and economic issues involved. In an increasingly urbanized world, however, our familiarity with, and knowledge of, food plants and our extensive agricultural system is waning. Efforts to educate society about agriculture, to ensure well-informed decision making, must meet people in the urban locations where most of us now live. Botanical gardens and arboreta constitute an extensive, primarily urban system of institutions dedicated to plant knowledge, research and public education, and are well placed to play a critical role in this area (Fig. 1).

Botanical gardens are living repositories of plant biodiversity that maintain documented collections of plants for display, education, conservation and research. Collectively, the world's more than 3,000 botanical gardens cultivate approximately one-third of known plant species. Many botanical gardens conduct research, contributing valuable information on plant identification, geographic distributions, morphology, reproduction and traditional uses. Furthermore, each year botanical gardens worldwide attract over 250 million visitors who come to gardens in order to experience and learn about plants[5]. Thus, botanical gardens are uniquely situated to advance knowledge of food plants and the impacts of their cultivation, and to help promote an understanding of the relationship between plants, agriculture and the environment.

Rooted in agriculture

Historically, many botanical gardens focused on plants for their utility rather than their aesthetic or diversity value. One of the first botanical gardens in Europe, the Botanical Garden of Padua, Italy, originated in 1545 from a Benedictine collection of medicinal herbs[6]. During the eighteenth and nineteenth centuries, colonial powers founded a number of botanical gardens to investigate the commercial value of local crops and wild plants. These gardens, like Pamplemousses Botanical Garden, Mauritius, became centres for the dispatch, receipt, propagation and establishment of crops[7]. Until the early twentieth century, food plants and their wild relatives played a significant role in many botanical gardens[8], with prominent scientists advocating[9] that they should become "field museums of agriculture".

The utilitarian focus of botanical gardens has, in the past century, shifted to horticultural displays and conservation, rarely emphasizing crops, conservation of crop biodiversity, agricultural ecosystems or their impacts on wild plant biodiversity. As the world's primary repositories of living plant collections, botanical gardens are in an excellent position to expand efforts to document, conserve and make available wild plant diversity in the service of improving agriculture. By highlighting such plants, botanical gardens could also play an enhanced role in educating visitors about the food plants and agricultural systems on which we all depend.

Cultivating research

Together the world's botanical gardens cultivate more than 120,000 species of plants. These valuable living collections, including seed banks, complement germplasm reserves held by major centres of crop research (for example, CGIAR centres and the United States Department of Agriculture National Plant Germplasm System). Some gardens

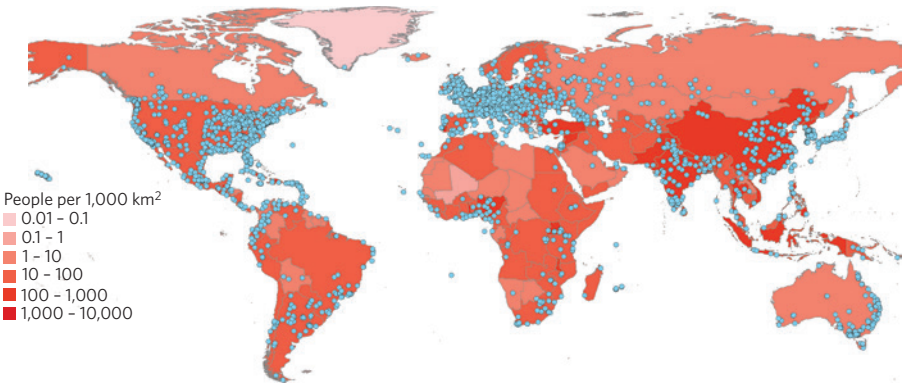

Figure 1 | The global network of botanical gardens. Botanical gardens (blue dots) superimposed on a map of human population density (by country, with darker shading showing increasing population density). Data from the GardenSearch database (www.bgci.org/garden_search.php), accessed October 2013.

have extensive and diverse collections of food plants, often of well-documented origin such as the collection of breadfruits maintained at the National Tropical Botanical Garden in Hawaii. By including local crop varieties, their relatives and less well-known edible species, botanical gardens safeguard genetic diversity that may be under threat in nature. A few botanical gardens undertake research related to food plants, but they are in a position to do more. One important example is a contemporary project being carried out at the Royal Botanic Gardens, Kew, London, in conjunction with the Global Crop Biodiversity Trust, entitled Adapting Agriculture to Climate Change. This is an ambitious effort to identify, collect and preserve seeds from the wild relatives of 29 crops important for global food security. Other botanical gardens can undertake similar programmes and harmonize their efforts with those of agricultural research centres worldwide.

Botanical gardens that are situated near areas where crop wild relatives are endemic (for example, the Fertile Crescent, Central Mexico or the Andes) could play more prominent roles in preserving local diversity and identifying promising crop traits. Many already hold hidden treasures of crop biodiversity, such as the large collection of native and domesticated apples grown by the Almaty Botanical Garden in Kazakhstan which includes several wild forms of *Malus sieversii*[10]. A few botanical gardens have begun using living collections for basic research related to agriculture. The Missouri Botanical Garden is growing multiple genotypes of two North American grape species (*Vitis* spp.) that are used as rootstocks by the global grape industry. These accessions are being used to study comparative gene expression in response to heat and drought conditions with the goal of improving viticulture.

As the need for rapid improvement of our crops increases, living collections of botanical gardens can make crop varieties and their wild relatives more readily available than in nature, where they may even have become extinct. Many living collections are now linked through Botanic Gardens Conservation International's PlantSearch database (www.bgci.org/plant_search), an online tool that allows users to search 1.2 million living collections in more than 1,000 gardens. Preserved plant specimens and associated data (collection date and locality) housed in gardens and other institutions provide an important and increasingly digitized record of natural species distributions and local uses (www.tropicos.org). This information aids in the identification of wild species that have not yet entered the domestication process but that, based on their morphology or known previous uses, may be candidates for crop development. The Missouri Botanical Garden and Saint Louis University recently initiated a collaborative project with The Land Institute (Salina, Kansas) aimed at evaluating the suitability of some wild perennial grain and legume species for domestication and cultivation. Through such initiatives botanical gardens offer important avenues of research and improvement to cropping systems that cannot be easily replicated elsewhere.

Nonetheless, questions about the direction and goals of research remain. Botanical gardens and agriculture are surprisingly disconnected, particularly in relation to large-scale industrial agriculture. Modern agriculture is associated with increasing homogeneity within global agricultural systems[11]: of the approximately 7,000 known edible plant species on the planet[12], 309 were grown in 2010 at measureable scales[13]. Just three crop species: rice, maize and wheat, account for over 60% of the daily crop caloric intake by humans worldwide. However, these and other globally important crops are not commonly cultivated in botanical gardens (Fig. 2). The relationships between wild biodiversity, crop plants and agriculture, both positive and negative, could be presented in garden displays and programming. To this end, botanical gardens might consider partnering with applied researchers, the agricultural industry and land managers working on local and global scales to feed a hungry planet without further imperilling the biodiversity on which we ultimately depend.

Growing understanding

Food and the plants that provide it offer an excellent point of entry into the botanical sciences. Urban and suburban botanical gardens, important centres of gardening information, are well positioned to harness the public's growing enthusiasm for urban agriculture. Over half of the world's population now live in urban areas[4], and many would like to learn more about agriculture and food plants[14]. In response to expanding public interest in food and agriculture, botanical gardens are putting increasing emphasis on connecting people with food plants. For example, in 2013 the Missouri Botanical Garden launched Foodology: Digging into the Roots of Your Food, a programme that attracted more than 90,000 visitors to hands-on, interactive learning stations focused on helping people think about their food. Similarly, in 2014, the United States Botanic Garden presented the exhibit Amber Waves of Grain, which educated over 400,000 visitors about ancient and historic trends in wheat breeding and cultivation. With its Windy City Harvest programme, the Chicago Botanic Garden is one of the few American botanical gardens offering formal education to train adults in sustainable horticulture and urban production agriculture, through a partnership with the City Colleges of Chicago. This programme combines business, marketing, nutrition and urban agronomy courses and leads to a certificate in sustainable urban horticulture and urban agriculture. While becoming more common each year, urban agricultural education programmes like these are still rare in most urban centres.

Botanical gardens have the capacity to take on the task of educating people about agriculture. However, when food plants are displayed at botanical gardens, they are often presented in ways that bear little resemblance to their use in production agriculture. When botanical gardens do present agricultural scenarios, they often choose experimental rather than conventional systems. In addition to presenting forward-thinking, experimental agricultural solutions such as vertical farming, and to promoting values such as local food sheds, scientific institutions such as botanical gardens could accurately present existing agricultural conditions alongside future solutions.

As the primary institutions of public education about plants, botanical gardens have the opportunity to present a full picture of the agricultural landscape, including the positives and negatives of current practices, empowering an informed citizenry to make decisions. Botanical gardens can help do this by presenting crop plants and agricultural technologies that are common on farms — agrochemical use, biotechnology, monoculture cropping, mechanization — but little known and often mistrusted by general audiences. To do so, botanical gardens might expand the number of staff members knowledgeable about agriculture and consider presenting crop plants in an agricultural context, for example in a small model or demonstration farm.

Integrating agricultural displays into public gardens, while preserving their identity as places of serenity, aesthetic beauty and conservation, presents significant design challenges. The rewards of doing so, however, would extend well beyond the hundreds of millions of visitors. Gardens undertaking such programmes will help to depolarize contentious public debates about agriculture. They will create a forum for scientifically sound information about the trade-offs between agricultural products and their possible negative consequences

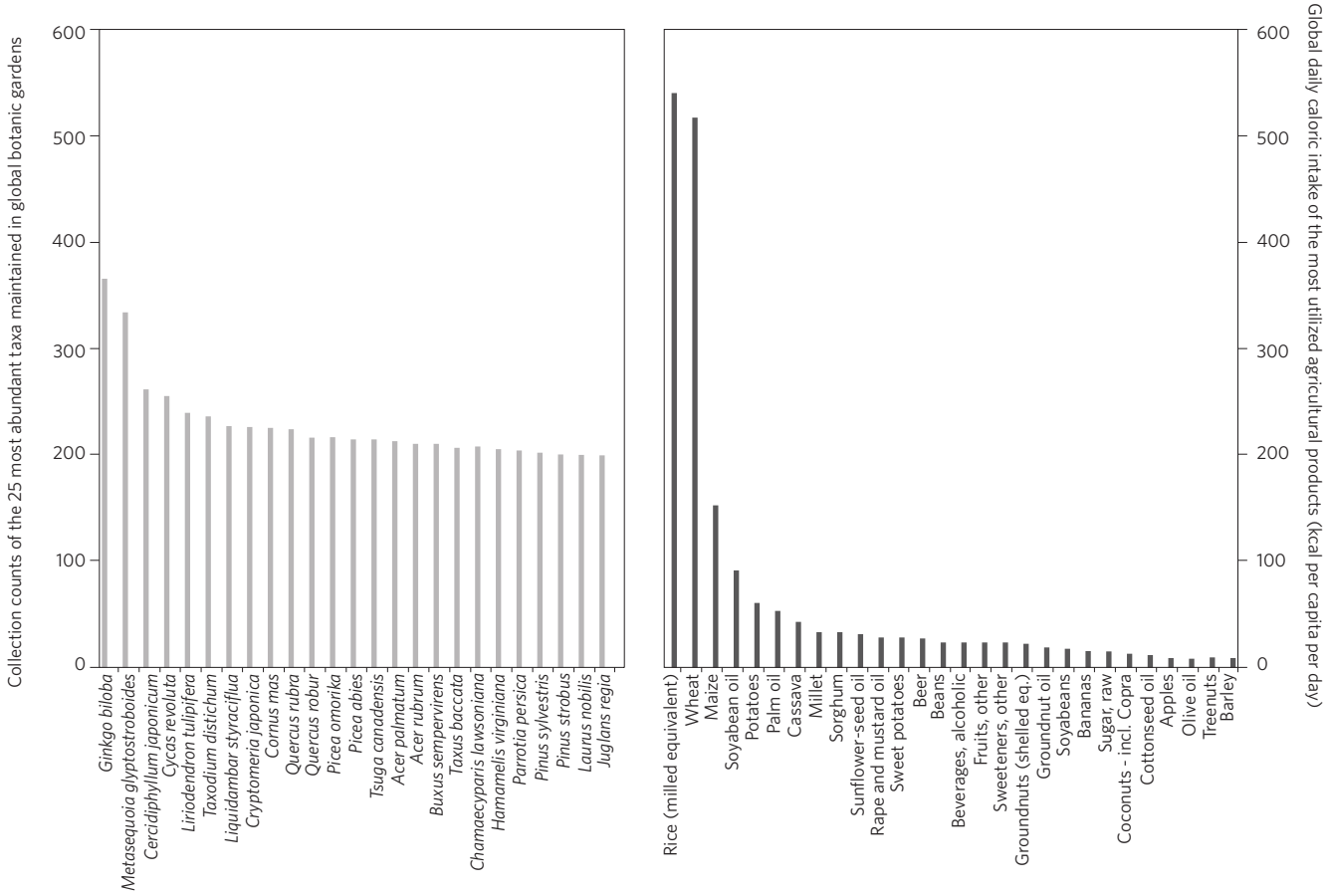

Figure 2 | Ranked abundance of taxa maintained by global botanic gardens and agricultural taxa utilized for human consumption. Grey bars represent the number of individual botanic gardens featuring denoted taxa, black bars represent the global daily caloric intake of agricultural products per capita. Note, there is no overlap of taxa among the 25 most commonly maintained at botanic gardens and the 25 agricultural products that contribute well over 60% of a typical humans daily caloric intake. Also note the skewed distribution of the sources of calories among the agricultural products, suggesting the agricultural sector is depending on just a few taxa to provide the majority of calories required for global demand. Figure adapted from ref. 15, © Oxford Univ. Press; data from ref. 13.

to human and environmental health. From such a solid base, botanical gardens would be well positioned to present the many possible routes to a future of more sustainable agriculture. In the process, they will empower visitors to understand the various systems of growing food so that they can make informed choices about the future of agriculture.

In addition to developing the capacity for presenting plants in an agricultural context, botanical gardens might consider what are the most appropriate goals and priorities for their agricultural education programmes and displays. A framework for developing agricultural educational priorities in botanical gardens is the subject of a current collaboration of the US Botanic Garden, the American Society of Agronomy, the Crop Science Society of America and the Soil Science Society of America, among others. This project has identified broad subject areas that could form the conceptual backbone of botanical garden education programmes on the biology of food plants, the state of production agriculture and the impacts of agriculture on biodiversity. Such comprehensive and inclusive efforts to define informal educational programmes must be prioritized if gardens are to provide much-needed information to their visitors. This will require the explicit cooperation of botanical garden educators with experts in agronomy and multiple related social and natural sciences.

A forward focus

Agriculture must produce sufficient food as sustainably as possible. Botanical gardens present highly suitable venues for the presentation of agricultural displays and educational programmes. In addition, they house germplasm useful for improving existing and future crops. Botanical gardens should consider their roles in presenting crop plants and agricultural activities for their visitors, bringing in new agricultural resources for this purpose. By forming partnerships with appropriate universities and other institutions with active research programmes in agriculture, federal and state departments of agriculture, international agricultural organizations, farmers' organizations and industry groups, gardens will be able to improve their ability to present displays and information concerning agriculture. Potential collaborators will realize the impressive capacity of botanical gardens to educate the public about matters of fundamental importance to them, and will doubtless welcome such partnerships.

Imagine the potential created by a series of museums in virtually every urban centre addressing a primary global challenge of our time. For the issues of agriculture and its impacts, such a system already exists. Botanical gardens currently have well-developed programmes of plant diversity and conservation research, which can easily

be expanded to strengthen sustainable agriculture, address agricultural impacts on natural biodiversity and advance public understanding of both. Given the stakes associated with feeding our crowded planet, there is a tremendous opportunity and a growing global necessity for botanical gardens to play this important role. ❐

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Additional information

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