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COMMENTARY

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Resetting the table for people and plants: Botanic gardens and research organizations collaborate to address food and agricultural plant blindness

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Societal Impact Statement

Food and agricultural plants are integral to human well-being. Due to their universal importance, such plants would appear to represent an ideal entryway by which to address plant blindness. However, with limited opportunities for direct contact with agriculture, many people cannot appreciate the flora that feed us every day. We provide examples of informal education initiatives aimed at increasing public awareness and appreciation of food and agricultural plants, made possible through collaborations between botanic gardens, academic institutions, nonprofits, and agricultural research organizations. We hope these examples encourage and inspire organizations to further utilize food and agricultural plants to tackle plant blindness.

Summary

Of the myriad gifts plants provide to humanity, food is among the most visible, as everyone needs to eat, every single day. Due to their universal importance, food and agricultural plants would appear to represent ideal entryways to address plant blindness. Yet increasing urbanization worldwide and decreasing proportions of the global workforce in agriculture are limiting opportunities for people to have direct, hands-on experiences with food and agricultural plants outside of retail purchasing, meal preparation, and food consumption. This disconnect is troubling, especially as the challenges to the sustainability of our future food supply necessitate that society, and certainly elected decision-makers, have the capacity to understand the potential benefits, risks, and tradeoffs inherent to agriculture and its advancing technologies. We outline opportunities to address agricultural plant blindness with emphasis on current complex issues within the food and agriculture sector. We provide examples of fruitful collaborations between botanic gardens, academic institutions, nonprofits, and agricultural research organizations that engage people around these issues.

KEYWORDS

agricultural education, botanic gardens, informal education, plant blindness, plant conservation, urbanization

1 | INTRODUCTION

If you do not supply nourishment equal to the nourishment departed, life will fail in vigor; and if you take away this nourishment life is utterly destroyed. Leonardo Da Vinci

Over thousands of years, plants have been cultivated, selected, and bred by our ancestors for their nutritional qualities, flavor, productivity, storage ability, and other valued traits (Schaal, 2019). The fate of both people and their cultivated plants have become inextricably linked, with each dependent of the other for survival (Knapp, 2019). Cultural knowledge on food production—from when and how to plant, to how to protect crops from pests and diseases, to when and how to harvest and process plants for consumption—has been central to the adaptation and persistence of human societies for much of the last 10,000 years.

As much as any time in our past, modern societies continue to depend on food and agricultural plants, and these plants in turn depend on people. Yet the daily activities of crop cultivation and processing for consumption are practiced by an ever-decreasing proportion of humanity. In 1910, the U.S. rural population accounted for 54.4% of total population, dropping over a century to 19.3% by 2010 (United States Census Bureau, 2016). In 1880, half of the U.S. population was engaged in agriculture, dropping to just 2% in 2015. The general trend of increasing urbanization and decreasing proportions of the workforce in agriculture has occurred on every continent. More than half of humanity now lives in cities and a much greater proportion are employed in trades unrelated to food and agriculture, and thus have little or no direct experience with the science and art of growing food (FAO, 2018). Compounded with ever more opportunities to consume previously prepared and processed foods, people are becoming blind even to the plants that feed us every day.

The term *plant blindness* was introduced by Wandersee and Schussler in 1998, and since then numerous studies have reported on its negative consequences with regard to plant conservation (Balding & Williams, 2016) and have outlined methods to address it (Balding & Williams, 2016; Frisch, Unwin, & Saunders, 2010; Krosnick, Baker, & Moore, 2018; Pany, 2014; Pany & Heidinger, 2017; Strgar, 2007; Wandersee & Schussler, 1999,2001). Plant blindness has led to the devaluation of plants with regard to their impact on the economy and culture, environmental sustainability, and public health (Krosnick et al., 2018).

Agriculture has inherent tradeoffs with regard to nutrition and sustainability. Humanity needs to grow plants on a massive scale to survive (Foley et al., 2011). At the same time, the alteration of the Earth's forests, grasslands, and other natural areas due to agriculture's expansion and associated land uses represents the single greatest historical driver of plant biodiversity loss (Royal Botanic Garden, Kew, 2016). Impending natural resource limitations and climate change threaten to make future food production more challenging, even while the sector urgently needs to improve soil and water conservation, reduce greenhouse gas emissions, better protect the pollinators and other ecosystem services that bolster crop production, and expand cultivation of vegetables and other nutrient dense foods (Asseng et al., 2015; Cordell, Drangert, & White, 2009; Godfray et al., 2010; Ray, Mueller, West, & Foley, 2013; Tilman, Balzer, Hill, & Befort, 2011). Promising new technologies—from gene editing to plant-based meat alternatives—will need to be evaluated, appropriately integrated, and (where applicable) regulated (Novy & Raven, 2018). In short, the challenge of nourishing the world sustainably in the coming decades is formidable, and complex decisions will need to be made that balance economic growth, cultural values, human nutrition, and environmental sustainability. If such decisions are to be made democratically, society, and certainly elected decision-makers, must have the capacity to understand the potential benefits, risks, and tradeoffs.

In this paper, we outline opportunities to address agricultural plant blindness with emphasis on some current complex issues within the food and agriculture sector. We provide examples of fruitful collaborations between botanic gardens—which have enormous potential to engage society—and academic institutions, nonprofits, and agricultural research organizations—which offer further scientific and outreach expertise—to engage people around these issues to combat the 'out of sight, out of mind' status quo with regard to food and agricultural plants.

2 | BOTANIC GARDEN PARTNERSHIPS CONNECT THE PUBLIC TO PLANTS

The Garden Search database of Botanic Gardens Conservation International (BGCI, 2018) lists 3,534 public gardens globally, which are geographically distributed across every inhabited continent and are located around or within essentially every major metropolis worldwide, as well as across rural areas. Collectively as repositories of plant biodiversity, these gardens conserve about a third of known plant species (Miller et al., 2015), including many crop plants and their wild relatives, in planted outdoor areas, glasshouses and greenhouses, seed banks, DNA banks, and tissue culture labs. The network of botanic gardens is currently being called on to increase its collective impact to ensure that no rare or threatened plant species becomes extinct (Smith, 2019).

As trusted scientific, cultural, and esthetic organizations, botanic gardens employ over 60,000 experts in horticulture, taxonomy, conservation, and public education (BGCI, 2018; Krishnan & Novy, 2016; Moreau & Novy, 2018). These capacities contribute to conservation action and policy, plant research, education, and community engagement with plants.

There are many examples of botanic gardens working to raise awareness of agricultural plants, and particularly with regard to food security, crop diversity, and the importance of agricultural plant genetic resources to the future global food supply (Moreau & Novy, 2018). In many cases, these gardens have collaborated beyond their garden walls with experts in agriculture to increase their intended impact. The following sections showcase examples of collaborations aimed to increase public engagement with food and agriculture. The examples are organized by programmatic areas, including exhibits, demonstration farms, experiential education, community outreach, and collaborative biocultural conservation.

3 | EXHIBITS

Botanic gardens serve as primary conduits for information about plants to public audiences. While gardens are well-regarded for both their formal and informal education programs, the majority of people visit for esthetic purposes, contact with a more natural environment, or to socialize with family and friends, and thus does not participate in active education activities. For visitors roaming through the beauty and diversity of gardens, plant-based exhibits are the main vehicle for educational content. Botanic gardens utilize their permanent living collections, as well as both inanimate and living temporary exhibits, to orient visitors to the wide world of plants, including food and agricultural species. Some institutions conserve internationally significant collections of edible plants and can use these living collections to educate society about food and agriculture. For example, the National Tropical Botanical Garden in Hawaii maintains an extensive collection of breadfruit (*Artocarpus altilis* [Parkinson] Fosberg), a starchy staple of the tropics (Jones, Murch, & Ragone, 2010). Similarly, the Wuhan Botanic Garden in China houses an extensive kiwi fruit (*Actinidia* Lindl. spp.) collection which is noteworthy for its size and accessibility (Huang, Wang, Zhang, Jiang, & Wang, 2004). Visitors are free to walk among hundreds of kiwi cultivars and their wild relatives, providing the opportunity to reflect on the staggering diversity underpinning modern varieties of a well-known fruit.

The United States Botanic Garden (USBG) in Washington, DC, has staged several extensive temporary exhibits focused on food plants, making it a significant theme for many years. In 2014, the USBG created *Food for Thought*, an exhibit of living plants from the Garden's permanent edible collections. Displays included diaspora plants transferred from Africa to the Americas alongside enslaved peoples, food plants deriving from native plants of the eastern U.S. such as blueberries and cranberries (*Vaccinium* L. spp.), and exotic plants used for food in other countries but rarely seen in the U.S., such as konjac (*Amorphophallus konjac* K. Koch).

In 2015, the USBG offered *Amber Waves of Grain*, an exhibit celebrating wheat (*Triticum aestivum* L.) and in particular the Nobel Prize winning efforts of American wheat breeder Norman Borlaug. This exhibit recreated the breeding history of Borlaug's Mexico-based breeding program, which was credited by the Nobel Prize Committee with saving one billion people from starvation. The Garden grew the six main commercial classes of modern wheat alongside ancient wheats—emmer (*Triticum turgidum* L. subsp. *dicoccon* [Schrank] Thell.), einkorn (*Triticum monococcum* L.) and spelt (*Triticum aestivum* L. subsp. *spelta* [L.] Thell.)—to demonstrate the 10,000-year history of wheat breeding. The exhibit also included a 20-foot wooden statue of a wheat plant emerging from a garden bed of common weeds of wheat, to help people recognize the importance of weed management in wheat farming. This exhibit—which was seen by over 600,000 visitors—would not have been possible without significant input and support from a variety of partners in the agricultural research community. Researchers at Cornell University provided seed to grow the ancient wheats, while the USDA National Small Grains Collection in Aberdeen, Idaho provided the Borlaug varieties. Scientists at USDA in Beltsville, Maryland generously lent their time and facilities for vernalization and provided valuable agronomic guidance. In addition, the U.S. Wheat Associates provided key statistics and graphics about the commercial production of wheat in the U.S.

In 2016, the USBG designed *Exposed: The Secret Life of Roots*. This exhibit was fundamentally an effort to bring roots as an essential plant organ out of the soil and into plain view, relying on agricultural subjects to connect the audience with roots' importance. The main display area featured preserved roots of typical annual U.S. farm crops like soybeans (*Glycine max* L.) and wheat alongside native perennial grasses and other plants of U.S. prairies whose habitat has become one of the key breadbaskets of the world. Visitors had the opportunity to learn about the role of plant roots in sustaining both plant and human populations, and to reflect on the importance of perennial root systems in soil conservation. As with the wheat exhibit, *Exposed* would not have been possible without collaboration. The exhibit was largely inspired by work at the Land Institute in Salina, Kansas to breed perennial grain crops and preserve roots growing in prairie soils. Scientists and photographers who develop methods to visualize and preserve the prairie plant roots were integral co-designers and content providers for this wildly popular exhibit.

Worldwide, many gardens are investing their resources and creativity to create exhibits designed to engage visitors on biodiversity, with connections to agriculture and to ecosystem services. At Royal Botanic Gardens, Kew in London, England, a temporary exhibit from the 2015 Milan Expo, themed 'Feeding the Planet, Energy for Life,' called *The Hive* has been reconstructed in the Garden and has become a permanent attraction. *The Hive* is a multisensory artistic representation of a honey bee (*Apis mellifera* L.) hive. Combining visuals, lighting and sound, the exhibit invites the visitor to contemplate the importance of bees to the environment and to food systems, highlighting how the insects communicate. The exhibit aims to create greater public awareness of pollinator activities, which can enable a deeper understanding of the critical importance of pollination for agricultural plant yield, and also draw attention to current issues related to pesticide use and the decline of pollinator populations.

At the Minnesota Landscape Arboretum (MLA) in Minneapolis, a new *Red Barn Garden* will feature sustainable landscaping and horticulture as well as modern agriculture. The MLA includes several important agronomic research programs, including the apple breeding program that gave the world the 'Honeycrisp' variety. Connecting with its active conservation and breeding programs, MLA is pushing the boundaries of innovative agriculture exhibits at botanic gardens.

4 | DEMONSTRATION FARMS

The disconnect of some societies from where its food comes from is even more pronounced for row crops–also called agronomic crops–such as corn/maize (*Zea mays* L.), wheat, and soybean, than for vegetables and fruits. Row crops are often processed into meal, flour, or syrup, and then incorporated into thousands of different end products before reaching the consumer, and are thus less easily recognized in their vegetative form. Fortunately, some agronomic crops can be used as visual examples to build awareness of agriculture, food security, and technological innovation. Corn, one of the most widely grown grain crops in the United States (USDA, 2018a), is a relatively large plant compared to other agronomic crops. It is monoecious, providing great optics for understanding pollination. It is also easy to grow and has a well-researched history that extends back almost 9,000 years (Blake, 2015).

Agriculture crop demonstration plots, where crops are grown in display fields similar in appearance to production farms, have been utilized from the earliest days of extension at land-grant universities as a valuable tool to introduce farmers to technological advances (Nafziger, 1984). Demonstration plots continue to be an important part of agricultural field days for farmers around the world, and are also becoming a tool for botanic gardens to educate about agricultural plants within environments that reflect how food is generally cultivated. At the Louisiana State University (LSU) AgCenter Botanic Gardens, a corn demonstration plot, *Corn Through the Ages*, was planted at the annual Corn Maze event and was used to demonstrate the history, genetic variation, and importance of the plant (Figure 1). Eight lines of ornamental corn were planted in the field in rows to illustrate distinctive characteristics of popcorn, dent corn, flint, Native American, and Mexican varieties. Seed of teosinte (*Zea mays* L. subsp. *parviglumis* H. H. Iltis & Doebley), the grassy wild progenitor, was added to the demonstration plot to show how corn evolved from a very different wild plant. A modern variety of genetically modified corn was also included in the plot to illustrate the full history of corn to the present, and to communicate the importance of technological innovation to agriculture. The development of this demonstration plot was the result of a collaborative effort between the Botanic Gardens staff, LSU AgCenter faculty, graduate students, extension specialists, and seed companies.

FIGURE 1 A demonstration plot at an annual corn maze event showing the history of the domestication of corn (*Zea mays* L.) from its wild ancestor through selection, hybridization, and genetic modification. The demonstration plot is also used to educate about agricultural crops in general and their importance to human nutrition. Photograph: Jeff Kuehny

Planting such variations on a theme in demonstration plots can provide visual platforms for a large number of topics that can be used for educational purposes. Some examples include: the historical importance of a crop to Indigenous peoples and its subsequent dispersal around the world; the diversity of varieties within the crop grown today; the anatomy of the plant and its pollination; the wild progenitor species and other crop wild relatives; how crops were domesticated and improved by farmers; how plant breeders continue to improve crops using technological innovations; the many uses of the crop; and more. By providing interpretive signage, these educational opportunities can be accessible via self-guided interactive experiences as well as within guided tours.

5 | EXPERIENTIAL EDUCATION

Education at botanical gardens takes on a diversity of forms. Seeing plants is not the only way to experience them. Sensory experiences that tap into other senses such as taste, smell, touch, and sound can be used by educators to create fun and meaningful connections to plants. At Cornell Botanic Gardens, staff are drawing connections between the Garden, the University and the community by hosting tasting tours in their vegetable food garden. Biannually changing, themed designs engage guests on a variety of topics. In 2018, the theme *Plants Have Families Too* encouraged visitors to recognize morphological and chemical similarities between members of the same plant families. For example, the structure, smell and tastes of plants from families such as Brassicaceae (mustards, cabbage, broccoli, kale, etc.), Apiaceae (parsley, carrots, celery, etc.), and Liliaceae subf. Allioideae (onions, chives, garlic, etc.) were compared and contrasted to create 'aha' learning moments.

Since 2014, the Sustainable Communities Field School, which includes a food garden component, has been operating out of the University of British Columbia Botanical Garden in Vancouver, Canada (Moreau & Novy, 2018). This program is co-hosted with an environmental nonprofit called SPEC (Society Promoting Environmental Conservation) which has extensive experience with urban agriculture and school food garden programming. The Field School aims to support businesses and organizations in team-building garden tours centered around sustainable food choices, local biodiversity, waste reduction, and water conservation. Complex topics within agriculture, climate change, and global food systems are unpacked through team-building activities that encourage group problem-solving, communication, trust, and connection to nature (Figure 2). While flower tasting, tree walk adventures, and team photos provide easily accessible positive experiences, deeper and more complex questions around food system values, inequalities, poverty, justice, and sustainability can be posed depending on the group and their specific interests. Developing and delivering such a complex

FIGURE 2 Youth learning about water conservation and sustainable food choices in the food garden at University of British Columbia Botanical Garden. Photograph courtesy of University of British Columbia Botanical Garden

and flexible curriculum benefited from the different values and perspectives of the Garden and SPEC staff. An analysis of programmatic impacts found that participants had increased environmental attitudes and showed a greater willingness to engage in specific pro-environmental behaviors compared to visitors that did not participate in tours (Zelenkia, Moreau, Lane, & Zhao, 2018).

Other gardens doing pioneering work in experiential food plant education include the Royal Botanic Gardens, Kew, which celebrated the amazing edible bounty of plants during the festival *IncrEdibles* in 2013, and Missouri Botanical Garden, which invited their visitors to think and interact with the plants on their plate through *Foodology: Dig In* in 2013 (Sharrock, 2013).

6 | COMMUNITY OUTREACH

Botanic gardens among plant organizations are uniquely positioned to engage diverse communities and stakeholders. The Denver Botanic Gardens offers a Veterans Farm Program at its Chatfield Farms location. Some war veterans experience Post Traumatic Stress Disorder (PTSD), depression, and anxiety. The therapeutic effect of cultivating the land is envisioned as one of the ways to re-integrate veterans into society, with many programs emerging in the U.S. in the past decade (Fleming, 2015; USDA, 2018a). The mission of the Veterans Farm Program is 'to connect military veterans to a farming career, specifically in small-scale vegetable production, in a way that engages the mind, body and soul in a holistic approach to sustainable living'. This is achieved by providing veterans education that involves classroom sessions along with hands-on training in small-scale vegetable production, both on a farm and in controlled-environment greenhouses. Trainees are able to diversify their vocational opportunities, engage with community members, and develop relationships with other service members. In addition to acquiring basic agronomic skills, veterans involved in the program receive business planning training, providing critical tools needed for success in the agriculture sector. Once veterans have graduated, efforts are made to connect them with local farms to provide further opportunities to apply the skills acquired through the training program.

BigPicnic, coordinated by BGCI in collaboration with 19 partner organizations spanning 13 European countries and Uganda, is a program aimed at generating greater understanding of food security issues including responsible research and innovation within food and agriculture. This is achieved through traveling exhibitions, science gatherings, and participatory events co-created with local citizens (BigPicnic, 2018). Due to their experience in public engagement and the availability of expertise in the plant sciences, botanic gardens form a majority of the partners involved in the program, alongside other scientists, policy-makers, and industry. The program utilizes a multidisciplinary approach through specially established Food Security Advisory Groups consisting of experts from a wide variety of backgrounds including industry, academia, and NGOs. The BigPicnic website provides many resources that can be adopted by other botanic gardens or organizations to deliver their own programs (https://www.bigpicnic.net/resources/).

Established in 1818, the Royal Tasmanian Botanical Gardens (RTBG) has one of the first recorded vegetable gardens in Australia. The RTBG along with 25 other community-based organizations formed the Tasmanian Community Food Garden Coalition, which established the Tasmanian Community Food Garden (TCFG). The objectives of TCFG are to establish a center of excellence in food production, perform community engagement to provide skills and inspiration for individuals and communities, and provide demonstrations of uses of plants in innovative ways that can be replicated in other communities (Ragus, Reid, & Grosvener, 2013). Other botanic garden outreach initiatives focused around community gardens include *Windy City Harvest* at Chicago Botanic Garden (Chicago Botanic Garden, 2019), and the *Edible Garden Project* at the Royal Botanic Garden, Edinburgh (Royal Botanic Garden Edinburgh, 2019).

7 | COLLABORATIVE BIOCULTURAL CONSERVATION

Botanic gardens in agricultural biodiversity-rich regions are uniquely poised to help conserve regionally important foods in partnership with local communities. In these regions, communities have traditionally been the keepers of botanical knowledge, and engaging them in participatory conservation is essential to preserving both the plant diversity and its associated traditional information. The M.S. Swaminathan Botanical Garden (MSSBG) is located in the Western Ghats of India, one of the agricultural biodiversity hotspots of the world (Khoury et al., 2016). MSSBG is situated in the valley of a natural hillock in an agrarian village traversed with shade grown coffee groves, rice paddies, and banana fields, near Kalpetta, the headquarters of Wayanad district. MSSBG was established to help conserve imperiled agrobiodiversity, including varieties of jackfruit (*Artocarpus heterophyllus* Lam.) and mango (*Mangifera indica* L.), roots and tubers, legumes, medicinal plants, and the diminishing

FIGURE 3 Interpretive signage for the germplasm collection of indigenous tubers at the M.S. Swaminathan Botanical Garden in Wayanad, India. Germplasm is distributed to local farmers for cultivation. Photograph: Sarada Krishnan

non-wood forest products of the region. The garden was also established to support local farming and Indigenous communities, and to serve as an educational facility for youth, teachers, and parents to learn about the native flora and the value of biodiversity and ecosystem services. MSSBG works with local tribal communities to promote the on-farm conservation and sustainable use of indigenous crop varieties (Figure 3), integrating its core values of '4C'—conservation issues, cultivation knowledge, consumption awareness, and commercial aspects (Kumar, Prajeesh, & Smitha, 2017).

The Institute of Botanics and Phytointroductions at the Main Botanical Garden in Almaty, Kazakhstan plays a key role in the preservation and conservation of wild apples (*Malus* Mill. spp.) in their primary region of diversity. With substantial loss of the wild apple populations in the Tien Shan mountains, the Garden is ideally located to undertake conservation. Over the past 40 years, over 200 wild apple accessions have been collected and conserved *ex situ*, while the Garden has also worked to further *in situ* conservation of wild populations (Gregory, 2013). Likewise, the Purwodadi Botanic Garden in Indonesia has focused on *ex situ* conservation of bananas (*Musa* L. spp.), yams (*Dioscorea* L. spp.) and other members of the *Musaceae* and *Dioscoreaceae*. Wild species and local farmer varieties found in low and relatively dry areas have been collected, characterized, and documented (Sharrock, 2013).

8 | BUILDING ON SUCCESSES

The Shenzhen Declaration on Plant Sciences is a call to action for the global community of plant scientists to develop collaborative solutions for environmental degradation, unsustainable resource use, and biodiversity loss (Crane et al., 2019). The final priority of the declaration calls us 'to engage the power of the public with the power of plants through greater participation and outreach, innovative education, and citizen science.' Botanic gardens attract over 250 million visitors annually worldwide and are well positioned to engage society through programs that highlight food and agricultural plants. Many activities led by gardens, in collaboration with other food and agriculture-focused organizations, are providing an evidence base for effective ways to connect people to the plants that nourish them. The examples are culturally and geographically diverse, showing that attempts to deepen peoples' understanding of food and agriculture can be widely applied. While more examples of success are needed, it is the obligation of botanic gardens, academic institutions, nonprofits, and agricultural research organizations to expand current efforts to help people see clearly the critical importance of plants through the lens of the history, present, and future of their food.

AUTHOR CONTRIBUTIONS

All authors contributed to the writing and editing of this article.

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