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Review

Pursuing the potential of heirloom cultivars to improve adaptation, nutritional and culinary features in a changing climate

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Abstract: The burdens of malnutrition, protein and micronutrient deficiency, and obesity cause enormous costs to society. Crop nutritional quality has been compromised by the emphasis on edible yield and through the loss of biodiversity due to the introduction of high-yielding uniform cultivars. Heirloom crop cultivars are traditional cultivars grown for a long time (> 50 years), and whose heritage has been preserved by regional, ethnic or family groups. Heirlooms are recognized for their unique appearance, names, uses and historical significance. They are gaining in popularity because of their unique flavors and cultural significance to local cuisine, and their role in sustainable food production for small-scale farmers. As a contrast to modern cultivars, heirlooms may offer a welcome alternative in certain markets. Recently, market channels have emerged for heirloom cultivars in the form of farmer-breeder-chef collaborations and seed savers organizations. There is therefore urgent need to know more about the traits available in heirloom cultivars, particularly for productivity, stress tolerance, proximate composition, sensory quality and flavor. This information is scattered and the intention of this review is to document some of the unique characteristics of heirloom cultivars that may be channeled into breeding programs for developing locally adapted high value cultivars.

Key words: culinary and nutritional traits, farmer-breeder-chef-consumer nexus, folk cultivars, genetic diversity, global warming, heritage seedbank, local food systems, seed savers, stress tolerance

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1. History and survival of heirloom or folk cultivars

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Heirloom cultivars are generally characterized as traditional or older cultivars that are open pollinated, passed down from gardener to gardener or handed down in families, and often not used in large-scale agricultural enterprises. The definition of heirloom varies, and the term does not carry a precise scientific designation. One of the most typical concepts of an heirloom is its open-pollinated, or non-hybrid, nature. Because of this fact, some heirloom cultivars may be quite variable, and it is therefore apparent why heirlooms may not fit as well into modern agricultural systems that place great value on uniformity. Votava and Bosland [1] found that the pepper cultivar 'California Wonder' had substantial amounts of genetic variability compared to a standard modern cultivar. They recommended that this cultivar not be used for genetic analysis because of this variability. This is often the case for heirlooms; they are known to possess more inherent variation compared to modern cultivars. Some of this could be due to their open pollinated nature, and some might be due to the fact that they are often associated with seed saving. The appearance of F_1 hybrids during the 20th century was arguably a tremendous advance in terms of crop productivity and seed commercialization. Some advocates of heirloom cultivars may, however, view the advance of F_1 hybrids as an incursion on traditional cultivars, as they rapidly usurped the use of traditional open pollinated cultivars for crop production purposes. While the open pollinated cultivar became a source for extracting inbred lines that became parents of F_1 hybrid cultivars, the populations themselves were not maintained or advanced as they once had been.

As F_1 hybrid cultivars became more common, gardeners and farmers began to notice the disappearance of heirloom or traditional cultivars. Importantly, many plant breeders and seed companies have invested their time and resources in hybrid cultivars for decades, thereby leaving heirloom, open pollinated cultivars with a lower commercial status. In some parts of Europe, laws were passed that made it illegal to sell cultivars that were not on government-approved lists. Some of these laws also required substantial time and effort in the testing of cultivars before they could be listed. Part of the rationale was to ensure that cultivars were distinct, uniform, and stable, but many heirloom cultivars did not fit well into these criteria. Thus, heirloom cultivars were in some cases relegated to the agricultural fringe.

Kingsbury [2] commented that at times of technological and social change, it is common to look back on simpler times. He suggests that the interest in heirloom cultivars may be due in part to this phenomenon, which idealizes the past. Another aspect of this yearning for simplicity is the fact that gardens represent for some a retreat from the stress of modernity. In this way, cultivating heirlooms may offer an opportunity for the gardener or eater to reconnect with a different age.

Additional aspects of the heirloom cultivar experience are the unique flavors and culinary qualities that generations of people had come to know and appreciate. Such qualities may be absent in modern cultivars bred for modern cropping systems, creating a desire for the heirloom. An example of such a quality is the creamy mouthfeel caused by high levels of water-soluble polysaccharides (also described as phytoglycogen) in older, heirloom sweet corn cultivars. The creamy mouthfeel caused by the polysaccharides was an important attribute of the *sugary-1* allele, which reduced starch accumulation in the maize endosperm and increased the amount of sugars. As newer F_1 hybrid cultivars were developed with the *shrunken-2* allele, the *sugary-1* allele was replaced. Cultivars homozygous for *shrunken-2* are noticeably sweeter; perhaps even twice as sweet as those

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carrying *sugary-1*. However, they lack the creamy mouthfeel and some of the aromatics associated with older sweet corn cultivars [3]. Thus, an heirloom may represent flavors and culinary qualities associated with specific, old cultivars and may thus represent an important heritage.

Heirloom cultivars are also associated with seed saving, and in fact the generation to generation transfer of heirloom seed is often one of the defining features of a heirloom. Navazio [4] commented that the post-World War II era in the USA saw a major transition in agriculture where more and more farmers were willing to purchase seed every season from seed companies. Prior to that time, farmers were heavily involved with producing their own seed, and with selecting and maintaining good seed stock. As farmers began purchasing seed annually from seed companies, heirloom cultivars and their systems of maintenance through seed saving gradually diminished. Fortunately, a resurgence of interest in heirlooms has taken place in the last several decades. Several examples may illustrate this point. Today, some seed companies feature and celebrate heirloom cultivars in their catalogues. Gardeners and farmers regularly seek out, save, and preserve heirloom seed in order to continue the traditions of these unique cultivars, and consumers are willing to pay substantially more at the market for their products. The development of “new heirlooms” is also discussed in plant breeding fora, where the breeding program may begin with heirloom populations that are subject to selection for current conditions but under the careful guidance of a seed saver or local plant breeder. The Slow Food movement maintains a catalogue of heritage foods, including heirloom cultivars, run by the Ark of Taste. These foods, which include crop cultivars, are “culturally or historically linked to a specified region, locality, ethnicity, or traditional production practice.”

Heirloom cultivars are a part of the farming system in many regions of the world. For example, southern Appalachia is an area of high crop biodiversity in the USA where many heirloom cultivars remain. Veteto [5] documented 134 heirloom cultivars that were still being grown in the region in a recent survey. He found that even though one or two individuals in a community were usually involved in maintaining significant numbers of heirloom cultivars, many communities had lost their heirloom vegetable cultivars. He found that both the decline of the farming population and the lack of cultural continuance in family seed-saving traditions were likely responsible for this loss.

Among the problems associated with heirloom cultivars is their susceptibility to pathogens. In many cases, modern breeding has helped to improve host plant resistance; thus, it is not surprising that heirloom cultivars may lack resistance to important pests. Heirloom tomato production can be limited by soilborne diseases such as bacterial wilt and fusarium, caused by the pathogens *Ralstonia solanacearum* and *Fusarium oxysporum* f.sp. *lycopersici*, respectively. One of the creative approaches to this problem was discussed by Rivard and Louws [6], who grafted heirloom scions onto resistant rootstock. In naturally infested soil, bacterial wilt incidence for nongrafted 'German Johnson' was 79% and 75%, but had no symptoms of bacterial when grafted onto the resistant genotypes CRA 66 or Hawaii 7996. Fusarium wilt incidence was 46% and 50%, respectively, in nongrafted and self-grafted 'German Johnson' controls, but no symptoms of fusarium wilt were seen when plants were grafted onto resistant genotypes. Thus, grafting may be an appropriate approach for heirloom production in infected soils.

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A debate is occurring as to whether modern cultivars are less nutritious than their heirloom counterparts. Barker et al. [7] examined differences in mineral nutrient concentrations between modern F_1 hybrids and heirloom cultivars of cabbage, and also looked at fertilization practices with either organic fertilizer and compost or conventional fertilizers. Crop production increased with conventional or organic fertilizers compared to compost. Mineral nutrient composition did not vary between modern or heirloom cultivars or among different fertility practices; however, the authors did find cultivar differences for nutrient concentration. The fact that mineral nutrient content did not vary between modern and heirloom cultivars is important in that it runs counter to popular press articles that suggest the nutritional quality of our food supply is decreasing. Flores et al. [8] examined carotenoid levels of traditional tomato cultivars. They found substantial amounts of variation for many carotenoids in colored fruit from these traditional cultivars, suggesting new opportunities for breeding. There is little doubt that heirloom cultivars contain reservoirs of useful traits, including those that might be able to contribute to improved human nutrition.

van der Knaap and Tanksley [9] examined the genetic basis of the unique phenotype of the heirloom tomato cultivar 'Yellow Stuffer' which looks more like a bell pepper than a traditional tomato. Their analysis was based on a segregating population derived from a cross between 'Yellow Stuffer' and a wild species of tomato. They found three QTL that influenced fruit shape and seven QTL that influenced fruit mass; many of which had already been identified in other tomato mapping research. They were able to pinpoint an allele at fs8.1 that caused convex locule walls that were responsible for the extended, bumpy shape characteristics of the pepper fruit in 'Yellow Stuffer.' They surmised that the evolution of bell pepper-shaped tomato fruit may have proceeded through mutations of some of the same genes that led to bell pepper-type fruit in garden pepper.

Heirloom potatoes offer unique flavors and qualities that are sought by consumers. Production of these heirloom types is, however, not well understood in the context of modern farming systems. Fandika et al. [10] investigated how irrigation and nitrogen management might be best employed in heirloom potatoes. They found that modern cultivars were more responsive to irrigation and nitrogen than heirloom potatoes. Interestingly, they found that higher applications of nitrogen decreased the yield of heirloom potato cultivars whereas yields of modern cultivars were increased. Heirloom cultivars were more drought tolerant, but required larger water inputs because of later maturities. Overall conclusions of this study suggested that production of heirloom types could be more expensive than modern cultivars.

Interest in seed saving continues to grow in many parts of the developed world, perhaps as a response to the increasing consolidation of the global seed industry and a desire for more local control of plant genetic resources. Interest in heirloom cultivars goes hand in hand with this expanded interest in seed saving. For the most part, these efforts are celebrated by communities who wish to build closer relationships with their seed sources. However, not everyone is celebrating. In the last five years, efforts have been made to close seed lending libraries, which allow gardeners to check out packets of seed and return the seeds they save from the crop grown. The cultivars made available by lending libraries are typically open pollinated and often heirloom. Efforts to close lending libraries were based on an interpretation of the US federal Seed Act, which would have required seed lending libraries to test seeds for germination and purity. In 2016, a state department

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of agriculture in Pennsylvania determined that such seed libraries are noncommercial seed exchanges and therefore not subject to the Seed Act. And a number of efforts have been initiated to resume breeding and seed saving of open pollinated cultivars. The Open Source Seed Initiative (www.osseeds.org) is a clearinghouse for primarily open pollinated cultivars that have been released into a "protected" commons. The protected nature of this commons means that anyone can breed with or save seeds of these open source cultivars, but cannot restrict others' use of them. Some of the cultivars contained in this registry include open pollinated types, such as the new carrot cultivar 'Dulcinea' that were bred recently to fill gaps in commercial seed company catalogs. Such open pollinated types might be considered a modern spin on an heirloom cultivar.

Navazio [4] stated that the seed "is a reflection of the farming system as it is grown, cultivated, selected, and fully incorporated into that system." In this way, heirloom cultivars represent a farming system that considers and prizes traits of long-term interest to the farmer and consumer, the incorporation of seed saving, family and community traditions, and the transference of plant genetic resources from generation to generation. Heirloom cultivars long cultivated locally by people around the world may be a critically important tool in creating a more sustainable food supply given the tremendous challenges of climate change, food production, and food security [11].

2. Heirlooms and sustainable agriculture

Local landraces –defined as traditional cultivars developed over time after adapting to both natural and cultural environments– or heirloom cultivars may perform better than modern bred-cultivars, particularly in marginal and climatic vulnerable sites. Heirlooms are known for their great trait diversity, e.g. for, *inter alia*, colour, shape, size, growth, height, phenology, yield and flavor. This wide diversity –which is the main feature capturing the attention from consumers seeking unique, nutritious, local food sources–also plays a key role in the risk management strategy of farmers if modern bred-cultivars are unsuitable for the local context [12]. Both crop heterogeneity and diversity should be therefore included in a national asset strategy by rural development policy makers because such a valuable genetic endowment will be useful for further breeding, particularly when facing the shocks associated with climate change. In this regard, Newton et al. [13] noted that landraces are sources of host plant resistance and abiotic stress tolerance genes, as well as of phytonutrients with desired micronutrient concentration that alleviate human aging-related and chronic diseases, and nutrient-use efficiency traits –which are very important for sustaining agriculture. Indeed, landraces show variation in their response to diverse stress-prone environments and this heritage may be used as genetic resources for breeding future crops [14]. For example, sweetpotato heirlooms exhibit moderate to high host plant resistance to soil insects that are interesting sources for developing new cultivars [15]; Hopi farmers in Arizona in the United States still plant 'Hopi blue maize' because it is adapted to drought and the short growing season and because of cultural significance [16]; native black and yellow maize landraces from Los Tuxtlas, Mexico are efficient phosphorus (P) colonizers and thus adopted to low soil P conditions [17]; farmers from north east India still cultivate and maintain traditional rice cultivars because of their

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adaptation to harsh growing conditions [18–20]; heritage durum wheat cultivars are more tolerant to drought than modern cultivars [21]; Spaniards and Italian farmers in some regions still cultivate tomato landraces that are highly adapted to drought and salinity [22–23].

3. Genetic enhancement using heirlooms and further seed supply of bred-cultivars for organic farming

Crossbreeding –based on controlled crossing, population improvement and family selection– is pursued to develop cultivars showing elasticity for adapting to climate shifts, energy limitations and low-inputs in organic farming. The main traits of an organic cultivar targeting niches outside industrial agriculture are host plant resistance to pathogens (e.g. bacteria, fungi, oomycetes, phytoplasma, viroid or viruses) and pests (birds, insects and nematodes), ability to outcompete weeds, resource-use efficiency, abiotic stress and pollution tolerance, adaptability to soil quality and low plant density, improved nutritious content, and high yield under eco-farming. Moreover, cultivars may be bred under organic husbandry, thus providing suitable germplasm for such farming system and with the desired quality traits for consumers. For example, dry bean consumers may like to buy heirlooms with unique colour patterns, which may be also sold at premium prices [24]. Swergarden et al. [25] further indicated that both yield stability analysis and economic incentives suggest that heirloom dry bean cultivars –although having 44% lower average grain yield than commercial checks– may allow diversifying production, differentiating in the market, and keeping economic returns for their small-scale organic growers.

Seed production begins with the developer of the new cultivar, who often retains the original breeder stock that may be further used as the "golden standard" for such a cultivar and as source for the foundation stock [26]. The next step is producing registered seed for distribution to licensees, who produce certified seed, which is the last stage of large-scale seed production. Organic farming standards asks further for using organically produced seed, unless lacking them for target crop. Certified organic seed should be only grown in certified organic soil using same inputs as per in organic farming, and package in a certified facility. Crop husbandry includes protecting soil fertility, using manure, rotating crops, conserving biodiversity and natural resources, sound plant health management, recycling, while any practices leading to accumulating heavy metals and other pollutants are forbidden.

4. Promoting conservation of heirloom germplasm

4.1. Seed savers and heritage seedbanks: Some studies have estimated that up to 75% of plant genetic diversity has been lost due to rapid expansion of industrial agriculture and large-scale adoption of monoculture farming [27]. Many such studies are based on a reduction in the number of cultivars of particular crops, and as such may be inaccurate estimates of the amount of actual plant genetic diversity present when both genebanks and cultivars are considered. However, it appears

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likely that the homogenization of agricultural environments around the world and the drive towards widely adapted uniform cultivars of a few major crop species have translated into reduced genetic diversity currently deployed in farmer's fields. In addition to a narrowing of diversity of crop germplasm, there are worrying reports of reductions in the global diversity of plant species. The Millennium Ecosystem Assessment Reports state that 60,000 to 100,000 species of plant are currently threatened with extinction [28]. It is apparent that some of these species play critical roles in agricultural and natural ecosystems, and serve as reservoirs of important genes that could play a role in crop breeding. Hence, this reduction in plant biodiversity is a significant global concern.

One traditional practice that may improve the current state of crop genetic diversity is seed saving. Practiced since the beginnings of agriculture itself, the simple act of saving and replanting seed from a crop was an integral part of food production in many parts of the world until the 20th century. The development of an efficient and wide-reaching global seed industry, the convenience and quality enhancement of purchasing seed each year, and the appearance of technologies such as F_1 hybrids and intellectual property rights have played a role in reducing the practice of seed saving. From the point of view of crop genetic diversity, revitalizing the practice of seed saving may be, however, viewed as vital for the world's sustainable food production and nutritional security.

There are several seed-saving projects, in addition to 1700 *ex- situ* genebanks worldwide including CGIAR genebanks and Svalbard Global Seed Vault [29], that are involved in collecting and maintaining heirloom cultivars across the globe to preserve agricultural biodiversity. ASEED Europe, Camino Verde, Hawai'i Public Seed Initiative, Irish Seed Savers Association, Lousiana Native Plant Initiative, Man and the Biosphere Programme, Millenium Seed Bank Project, Native Seed/SEARCH, Navdanya, National Laboratory for Genetic Resources Preservation, New York City Native Plant Conservation Initiative, Australian Plantbank, Seed Savers Exchange, Seesave.org, Slow Food International, USC Canada, Vavilov Research Institute, and The World Vegetable Center houses many traditional and rare cultivars of fruit, vegetable, flower, and grain crops [30]. Native American seed savers are dedicated to on-farm preservation of their agrobiodiversity (heirlooms) but unwilling to share their seed heritage for preservation in *ex- situ* genebanks (for fear of loss of ownership and access) as they believe that community-based *in- situ* conservation will maintain local control and seed viability than *ex- situ* genebanks [29]. One excellent example of a collection of heirloom cultivars is hele at the Heritage Seed Library (HSL) of Garden Organic, UK. They curate and maintain a collection of 800 heirlooms of carrot (*Daucus carota* L.), cucumber (*Cucumis sativus* L.) and Brassica oleracea L. var. *acephala* (DC.) Metzq, faba bean (*Vicia faba* L.), pea (*Pisum sativum* L.), and lettuce (*Lactuca sativa* L.) [31]. Table 1 presents a list of a few websites providing further information on genebanks or seed savers for heirloom cultivars.

Table 1. Some genebanks or seed savers organizations providing heirloom cultivars or related information.

Name	Website

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AVRDC – The World Vegetable Center	https://avrdc.org/seed/
Nature and Nuture Seeds	https://natureandnurtureseeds.com
Organic Seed Producer Directory	https://seedalliance.org/directory/
Seed Savers Exchanges	https://www.seedsavers.org/mission
Sustainable Seed Company	https://sustainableseedco.com/#
The Kerr Center for Sustainable Agriculture	http://kerrcenter.com/publication/heirloom-vegetables-genetic-diversity-and-the-pursuit-of-food-security/

An in-depth literature search noted several heirloom cultivars of grains such as bean, maize and rice (Supplementary Table 1,) or vegetables., e.g. carrot, potato, squash and tomato (Supplementary Table 2). Heirloom apples among fruit crops have amazing diversity that is maintained by seed savers and gardeners' in North America [https://www.epicgardening.com/heirloom-apples/].

4.2. South and Southeast Asia: 'Vrihi', the largest non-governmental *in situ* seed depository of traditional rice cultivars in eastern India, houses 610 rice landraces that withstand a much wider range of fluctuations in temperature and soil nutrient levels as well as water stress than modern rice cultivars. This collection includes numerous unique landraces, for example, the 'Jugal', the doubled-grain rice and 'Sateen', the triple grain rice, long awn and erect flag leaf, or cultivars with distinct aroma, color, and tastes. 'Vrihi Seed Exchange Network' has more than 6,000 indigenous farmers who have received seeds from 'Vrihi' and continue to cultivate and exchange seeds of these folk cultivars (synonymous to heirlooms) among them and to neighboring farmers [19]. At Basudha farm located in Rayagada district of Odisha, India, over 1400 folk rice cultivars and 30 other crops are grown every year, as a model of ecological agriculture, without any external inputs [www.cintdis.org/basudha]. The Philippine's Department of Agriculture in collaboration with the International Rice Research Institute (IRRI, Philippines), has undertaken a project on raising productivity and enhancing the legacy of heirloom/traditional rice through empowering communities in unfavorable rice-based ecosystem in Philippines. This project has collected about 74 variants of 41 heirloom cultivars with distinct characteristics with the sole aim to enhance productivity and livelihood and conserve in situ on-farm genetic resources [32]

4.3. USA: Native American seed saving efforts are underway to preserve culturally significant seeds and knowledge to promote food sovereignty at the local or tribal level in the USA [29]. These consist of farmers and gardeners who share a common interest in keeping traditional and local crop diversity alive. They usually grow traditional crops and local cultivars of fruits and vegetables for cultural reasons, food preference, risk avoidance, local adaptation, and for niche market opportunities. Various groups, including the Indigenous Seed Keepers Network and Seedshed, have

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formed to foster the preservation and repatriation of heirloom strains of Native American crops, particularly of maize, bean, squash, tobacco, and sunflower. The Seed Savers Exchange (SSE), a non-profit heirloom seed genebank based in Decorah, Iowa, saves and sells heirloom fruit, vegetable, and flower seeds in the US. SSE has in its collection 24,000 rare fruit and vegetable cultivars [33]. This heirloom collection has immense variability, for example, its over 500 heirloom potato cultivars differ in tuber shape (round-, oblong-, and fingerling-shaped), skin (white, red, purple, and variegated) and flesh color (white, yellow, purple), including varying skin and flesh color combinations, i.e. white skin-white flesh, white-skin-yellow flesh, red skin-white flesh, red skin-yellow flesh, red skin-red or pink flesh [34]. Seed saving efforts directed at heirloom cultivars are also found in the southern/central Appalachia region, an area of relatively high crop biodiversity in the USA. In this region, a collection of 134 heirloom cultivars grown and saved by home-gardeners was documented, with beans being the most predominant and highly diverse followed by tomatoes, squash, corn, and potatoes. The decline of the farming population combined with a lack of cultural continuance in family seed-saving traditions, however, threatens the ability of communities to maintain this crop biodiversity [5]. Culture and ethnicity also play an important role in preservation of heirloom cultivars [35–38].

4.4. Europe: There are numerous examples of seed saver networks, for example, 'Réseau Semences Paysannes', 'Red de Semillas', and 'Rete Semi Rureli' [39], involved in the organization of regional and local seed fairs, training workshops, participatory plant breeding activities and transmission of farmer's knowledge about the selection and conservation of local cultivars [40]. The 'Réseau Semences Paysannes' in France bring together all who are open to the development of peasant seeds (local cultivar originating from selection, identified as a collective heritage or heirlooms, and reproduced by all men and women who produce foods), and work toward the development of groups for selecting, conserving and distributing peasant seeds. The 'Red de Semillas' is a technical, social and political Spanish organization formed by the people that maintain agricultural biodiversity on peasant farms and on consumers' plates, while the 'Rete Semi Rureli' has enacted regional laws to safeguard local agricultural biodiversity in Italy. The researchers associated with these networks are involved in development of new cultivars shaped by history and coevolved with farmers. The cultivars are considered 'peasant varieties', which is a term meant to encompass the seed and its constituent reproductive ability, linked to the plant's terroir [39].

5. Promoting local food systems

Industrial agriculture, Green Revolution technologies, climate change, civil conflict, and change in market characteristics, including distance have contributed to the erosion of farm-agrobiodiversity. The production and sale of heirloom cultivars are interdependent in local market, suggesting that local food systems help preserve heritage diversity [41]. Modern food production systems based on 'Green Revolution' technologies are neither sustainable nor nutritionally superior. Recent years have brought increased public awareness that the risk to onset of noncommunicable diseases (cancer,

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diabetes, heart diseases, and obesity) can be reduced by making changes in lifestyle and food habits [42–43]. Local food systems may be a critical component of lifestyle and food habits that can contribute to improved public health.

Local food refers to where the food is produced, sold and consumed within a limited geographical area [44]. What drives consumers to buy locally produced food? Health is the main driver of local food purchase [45–46]. People perceive that local foods have direct benefits to their personal health as such products are fresh, nutritious, tasty and safer than non-local food. The consumption of locally produced food is more environmentally sustainable than procuring food from global markets. Attitudes towards supporting local agribusiness and preserving local heritage and tradition, keeping a connectedness with rural life, reducing the carbon footprint (shorter transportation distance, minimizing the needs of packaging, processing and refrigeration, among others), and protecting the environment for sustainable ecosystems, also drive the public to consume locally produced foods [47–49]. Higher prices, accessibility (time constraints to visiting farmers market multiple retail outlets to purchase local food) and availability are, however, the major barriers for consumption of local food [50–51]. Farmers' markets (FMs) refer to "markets where agricultural products are directly sold by producers to consumers through a common marketing channel" [52]. 'Buy-local initiative' and 'Buy local' movements in North America and western Europe have reinforced greater patronage at FMs and belief in people that local food is fresher than food from farther away and that buying local food benefits both local farmers and the local economy as well as improving environmental sustainability [49, 53].

The indigenous farmers in Mesoamerica domesticated bean, maize and squash, famously called the "Three Sisters", which were cultivated together in the same field providing symbiotic benefit to each other. The squash shades the ground from heat and acts as mulch to suppress weeds and to conserve moisture; the maize provide support to beans climb on its stem; while beans fix atmospheric N, which both the corn and the squash benefit from. The farmers continued to select genetic variants with preferred characteristics that they cultivated (for food, seed, gifts, and trade) and passed on the seeds as family heirlooms. The immigrants who carried seeds from Europe grew out the seeds, there upon selected progenies that were best adapted to the local climate and passed the seeds as family heirlooms. The examples include 'Anasazi' 'Four Corners Gold', 'Taos Red', 'Mayflower', 'Hutterite Soup', 'Kentucky Wonder', 'Bolita', 'Kickapoo beans' 'Great Northern', 'Jacob's Cattle' and 'Mortgage Lifter' among beans [54], 'Glass Gem', 'Golden Bantam', 'Painted Mountain', 'Hopi', 'Oaxacan Green', 'Mandan Bride' and 'Cherokee White Flour' among corn [55], and 'Costata Romanesco', 'Cocozelle', 'Ronde de Nice', 'Sugar Pie' and 'New England Pie' among squash [56] heirlooms.

6. Heirlooms nutritional, sensory and culinary characteristics

6.1. Grain Crops

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The literature suggests significant genetic variation for physico-chemical, sensory and culinary characteristics among heirloom cultivars. The unique seed coat colors and patterns as well as seed size and shape differentiate heirlooms from modern bean cultivars. Heirloom beans had relatively higher protein, total fiber and soluble fiber, and greater *in vitro* antioxidant capacity than controls, while took less time to hydrate (4.33 to 5.07 hours compared to 8.1 hours for the control) but with similar cooking time (~ 1 hour). A few heirlooms even after cooking had high flavonoids and differed in softness. 'Hutterite Soup' and 'Jacob's Cattle' showed lower firmness than 'Kornis Purple' and 'Tiger's Eye' whose texture was similar to the control [57–58]. 'Ganxet' heirloom bean, a landrace from northeast of the Iberian Peninsula, Spain, has greater protein, less total dietary fiber, more digestible dietary fiber, a higher proportion of seed coat, more glucose and less starch than controls, which is greatly appreciated for its culinary qualities (i.e., seed coat tenderness and its buttery texture) [59]. Twenty-four heirloom beans from western Washington have been identified with distinct appearance and great culinary value [60]. The Italian heirloom 'Monachine' is famously known as Pellegrini in honor of Seattle's culinary icon Angelo Pellegrini who enjoyed this bean for decades, and it is now featured by a high-end regional restaurant because of its great culinary quality [61].

There is growing demand for maize with blue kernels because of its significant health benefits and unique culinary applications. Blue kernel maize typically produces anthocyanins in aleurone layer of the endosperm, while in purple maize, the anthocyanin is predominantly produced in the pericarp of kernel [62]. The variation in total anthocyanin content among maize heirlooms ranged from 17.6 to 65.1 mg 100 g seed^{-1}, with an average of 49.6 mg 100 g^{-1}. Cyanidin and pelargonidin were the major components, while peonidin and succinyl 3-glucoside, the minor components. Heirlooms with blue kernels had higher anthocyanin than those with purple or red kernels. 'Navajo Blue' and 'Ohio Blue' displayed highest anthocyanin values, while 'Santa Clara Blue and Flor del Rio had highest oil and protein contents [63]. The variants of a pericarp-pigmented heirloom 'Apache Red Purple' showed greater variation on anthocyanin concentrations (210-6183 μg g^{-1} pericarp), with some having greater proportions of either pelargonidin- or cyanidin/peonidin-derived anthocyanins [64].

Several Indian rice folk cultivars are either very nutritious or maintain their distinctive aroma and colors. 'Kalanamak' (black husked and short-grained rice) among non-basmati aromatic rice types, the heritage rice from eastern India in cultivation in the last 4000 years, is famous for its distinct aroma, color and taste [65]. Unpolished brown rice such as 'Bhadoi', 'Kabiraj Sal', 'Shatia' or 'Agniban' are high in iron and antioxidants, while 'Shatia' and 'Kartiksal' are rich in fiber but low on carbohydrates [66]. Many of the traditional cultivars are of immense medicinal significance. For example, 'Pichha vari', 'Karthigai samba', 'Dudhsar', and 'Bhejri' enhance milk production in lactating mothers, 'Kelas' and 'Bhutmoori' cure anemia, 'Paramai-sal' improves child growth, 'Nyavara' treats neurotic disorders, 'Karhainy' alleviates paralysis; and 'Gudna' to treat gastric ailment [20, 67]; 'Karanga' to treat dysenteric complains, 'Bora' to treat jaundice, and 'Pakheru', 'Saraiphool', 'Karia Gora', 'Dani Gora' and 'Punai Gora' traditionally used a tonic; and people

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consuming 'Bhama', 'Danigora'. 'Karhani', 'Ramdi', 'Muru', 'Hindmauri' and 'Punaigora' rice's can work in their field for whole day without feeling hungry [67].

The white-seeded durum wheat landrace 'Aybo' is highly preferred for use in holy communion and for making difo-dabo, while 'Set-Akuri', 'Arndeto', 'Loko', 'Kurkure' and 'Mengesha' are known for their superior baking quality and used for making difo-dabo and injera. Difo-dabo is a traditional homemade bread prepared from flour by fermenting thick dough, while injera is a thin, flat and spongy pancake-like product from fermented dough baked using traditional mitad [68]. Farmers in northeast Ethiopia maintain several landraces for specific-end uses, for example, 'Nechita' for preparing genfo (thick porridge), shorba (semi fluid drink from cracked grain) and kinche (a dish prepared from cracked barley grains), 'Tikur gebs' for beverage, 'Temej' for kolo (roasted grain), and 'Enat gebs', 'Sene gebs' and 'Meher gebs' for injera [69].

6.2. Vegetable crops

The Puglia region in Italy is a rich source of tomato landraces maintained by farmers by repeated selection generation after generation for desired organoleptic quality. Keeping shelf life after harvest is among the most sought-after quality traits in tomato. 'Regina', a landrace adapted to coastal saline soils of the central Puglia, is known for its unique qualitative profile characterized by high concentrations of tocopherols, lycopene and ascorbic acid and long shelf life [70]. 'Corbarino' and 'Lucariello' tomatoes are highly prized by consumers in Italy for superior quality of their fruits and shelf-life. 'Corbarino' produces intense red color and high levels of soluble and total solids, while 'Lucariello' possesses a heart-shaped fruit with a pronounced pointed apex of less intense red and a thick cuticle [23]. 'Criollo' tomatoes from Andean valley in Argentina are highly valued for flavor and taste [71]. Heirloom tomatoes from North America show abundant diversity in fruit weight (5–150 g), shape (elongated, flattened, rounded, heart-shaped, pyriform), color (white ivory, yellow, orange, red, black), firmness and brightness as well as chemical quality characteristics (TSS, total soluble solids), (TA, titratable acidity), TSS:TA ratio, flavor intensity and ascorbic acid [72]. A few populations of heirloom tomatoes from eastern Spain showed high mean values for ascorbic acid (308 mg kg^{-1} fruit weight, fw), lycopene (130 mg kg^{-1} fw), β-carotene (30 mg kg^{-1} fw), total phenolic (89 mg caffeic acid 100 g^{-1} fw), and may therefore be best suited as source of functional compounds [73].

A multicolored landrace of carrot, 'yellow-purple Polignano', included in the 'slow food' list of traditional products (https://www.fondazioneslowfood.com/en/what-we-do/slow-food-presidia/), has been in cultivation for decades by small farmers in Italy's Puglia region. This landrace is greatly appreciated for its multicolored roots (outer core ranges from yellow or deep orange to dark purple, while the inner core from pale yellow to light green), special taste, tenderness, crispness, flavor, and fragrance. On average it contains 22% lower total glucose, fructose and sucrose content but with similar sweetness as a commercial control. Fructose is the major contributor to its distinctive flavor as well as to its glycemic index. The purple variants of this cultivar showed high levels of antioxidant activity, total phenols, carotenoids and β-carotene [70, 74]. Another colored race from the Apulia region of southern Italy, 'Taggiano' (or Saint Ippazio), possesses an outer and inner core

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with purple and yellow-orange color, respectively. This heirloom is known for the popular cult of the Saint Ippazio; i.e., protection from Saint Ippazio against hernias or male impotency. It has high levels of bioactive compounds and antioxidant capacity compared to orange-rooted controls [75].

7. Assessing diversity among heirloom germplasm

Assessment of genetic diversity and population structure of heirloom cultivars will be of great help to identify diverse heirloom germplasm with beneficial traits for further use in breeding or farming. For example, AFLP analysis of 171 heirlooms from the Heritage Seed Library (HSL) of Garden Organic revealed 1.5 to 2-fold differences in heterozygosity within carrot, cucumber and *Brassica* accessions, as well as 3.6 to 9-fold differences within faba bean, pea, and lettuce accessions [31]. Heirloom beans from southern Italy exhibited significant diversity in seed shape (cuboid, kidney, oval, round, truncate), seed coat pattern (absent, bicolor, pattern around hilum, speckled, spotted bicolor, stripped), seed color (black, brown, grey, vine, violet, white), seed weight (21-74 g 100 seed), and phaseolin (C, T, S) [76]. 'Badda', a round large-seeded bean with a partially coloured seed coat, has been in cultivation for more than two centuries by Sicilian farmers. Over the centuries of its cultivation, this landrace has diverged into two easily distinguished morphotypes; i.e., 'Badda bianco' (white badda) and 'Badda nero' (black badda). The 'Badda' morphotypes grouped into three distinct clusters, namely 'Badda bianco' accessions in one cluster and those of 'Badda nero' in two separate well-distinguished clusters [77].

Microsatellite-based genetic diversity analysis of over 100 rice heirlooms from Northeast India detected three genetically distinct groups: most *joha* rice accessions from Assam and *tai* rices from Mizoram and Sikkim were in cluster 1, while *chakhao* rices from Manipur grouped in cluster 2, and aromatic accessions from Nagaland in cluster 3. Pairwise FST between three clusters varied from 0.223 to 0.453 [78].

'Candy Roaster' heirloom squash fruits differs in size (10–250+ lbs), shape (round, cylindrical, teardrop, blocky, etc.), and color (pink, tan, green, blue, gray or orange), yet most have fine-textured orange flesh [79], while variants of 'Cappello da prete', another squash heirloom of 19th century still grown in the Po Valley of northern Italy, differ significantly in fruit weight, pulp thickness, rind thickness, peduncle diameter and seed weight [80].

Italian tomato landraces, 'Coarbrino' and 'Lucariello', are known for adaptation to water deficit, prolonged fruit shelf-life and good fruit quality. Whole-genome sequencing revealed 43,054 and 44,579 gene loci annotated in 'Coarbrino' and 'Lucariello.' Both genomes exhibited novel regions with similarity to *Solanum pimpinellifolium* and *S. pennellii*, and SNPs or candidate genes associated with fruit quality, shelf-life, and stress tolerance in 'Coarbrino' and 'Lucariello' [23]. Heirloom tomatoes, e.g. 'Criollo' from an Andean valley in Argentina, are known for their excellent organoleptic quality, especially flavor and aroma. Aroma and sourness in 'Criollo' fruit correlate with citrate and several volatile organic compounds, such as α-terpeneol, *p*-menth-1-en-9-al, linalool and 3,6-dimethyl-2,3,3a,4,5,7a-hexahydrobenzofuran (DMHEX), which is a novel volatile discovered in this heirloom [71]. The fruit shape among Italian tomato landraces ranged from flattened or

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ribbed through pear or oxheart to round or elongate types. While the round or elongate types were rich in glycoalkaloids, the flattened types are in phenolic compounds [81]. North American heirloom tomatoes varied in fruit color (white, yellow, orange, red or black), shape (elongated, flattened, heart-shaped, pyriform, rounded), weight (4.2 to 265 g), firmness, total soluble solids (TSS) content, titrable acidity (TA), TSS:TA ratio, flavor intensity and ascorbic acid concentration [72, Fig. 1]. Clearly, heirloom cultivars across crops, as noted above, maintain unique diversity, and can serve as a valuable resource for gardeners, farmers and plant breeders.

Figure 1. Diversity in fruit, root, and tuber size and color of heirloom cultivars of capsicum, carrot, potato, and tomato.

8. Retaining culinary and nutritional traits and improving heirlooms productivity

There is wide variation in productivity among heirloom cultivars when grown in organic farming systems. One a few heirlooms can compete with modern cultivars in organic systems, while almost no heirlooms can compete with modern cultivars under intensive production systems [24–25, 82–84]. However, heirlooms cultivars possess great diversity in fruit and seed size, shape and appearance, may often be superior in culinary and nutritional quality, and possess a rich source of many health promoting compounds. Thus, improving the productivity while retaining the culinary, nutritional, and health promoting compounds of heirloom cultivars is a great challenge for future plant breeding efforts [85]. For example, the heritage rice from eastern India ‘Kalanamak’ is a tall, low-yielding, black-husked short grained rice superior to ‘Basmati’ in aroma and taste. Its acreage has gone down (from 50,000 to almost extinction) over years of cultivation due to its low grain yield and deteriorating aroma and taste. A systematic attempt was made to collect and evaluate variants of

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'Kalanamak', collected from farmers, identify accession as most aromatic and true to perceived 'Kalanamak' quality. Using pure line selection, UPCAR-KN-1-5-1-1 was released as 'Kalanamak 3' (KN3) for cultivation in eastern Uttar Pradesh, India. Subsequently, several semi-dwarf breeding lines, developed through hybridization or induced mutation, outyielded 'KN3' by 40% [65]. A first semi-dwarf non-black husk cultivar 'Bauna Kalanamak 102' with comparable cooking quality and aroma as of 'KN3' was also released for cultivation in eastern Uttar Pradesh [86].

Spaniards highly appreciate 'Ganxet' bean, which is a landrace adopted in the Iberian Peninsula due to its culinary values; i.e., seed coat tenderness and buttery texture. Over the years of its cultivation, the original 'Ganxet' bean became contaminated possibly due to cross hybridization with other beans. Several variants (inbred lines) derived from the 'Ganxet' populations were evaluated against commercial controls. These lines showed great variability in protein content, total dietary fiber, digestible dietary fiber, seed coat, glucose and starch contents than controls. An inbred line L67 had many favorable characteristics (greater protein, less total digestible fiber, more digestible dietary fiber, a higher proportion of seed coat, more glucose and less starch than controls) that resulted in commercialization as true to the original 'Ganxet' [64]. 'Caparrona' is another heirloom bean that was largely grown by farmers in Monzón, Italy. The increasing modernization of agriculture at the end of 20th century resulted in its replacement by modern cultivars. Today, only a few local growers continue producing 'Caparrona' beans mainly for family use. A systematic effort was made to recover this landrace from extinction. Seed samples from growers were grown and two progenies true to 'Caparrona' types in morphology, chemical composition, and agronomic performance were identified for commercializing 'Caparrona' beans as a gourmet product by a local producers' association [87].

A major seed company 'Seminis Vegetable Seeds' has released a multiple resistance heirloom type tomato hybrid, 'Purple Boy' with great taste and unique appearance (purple), which are often the characteristics of heirlooms germplasm for US heirloom gardeners [http://www.hortibiz.com/item/news/seminis-releases-first-purple-tomato-hybrid/].

Intensive breeding of crops with a focus on yield and stress tolerance has indirectly led to reduction in nutrition and flavor [88–89]. The environment and agricultural practices also impact the intensity of flavor and aroma [90–92]. Flavor improvement is most difficult to achieve because of the difficulty of assessing the phenotype as well as a lack of basic knowledge about the chemicals driving consumer preferences, the pathways of their synthesis, and genes regulating the output of these pathways [93]. Analyses of consumer preferences together with accurate phenotyping and use of modern genomics and analytical chemistry tools in breeding, as evidenced in case of melon, strawberry and tomato, and participatory farmer-breeder-chef-consumer collaborations may facilitate development of next generation of crops to meet the growing demands of safe and nutritionally enhanced foods with good flavor, color, aroma and texture [84, 94].

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9. Farmer-breeder-chef-consumer partnerships to preserving heirlooms unique cultural and culinary significance

Within the last decade, several organizations began collaborative breeding efforts among farmers, chefs, culinary professionals, and plant breeders. One of those is the Culinary Breeding Network, which is based at Oregon State University in Corvallis. The goal of this organization is to build communities of plant breeders, seed growers, farmers, produce buyers, chefs and other stakeholders to improve quality in vegetables and grains. The Culinary Breeding Network is interested in facilitating communication, collaboration, and participation in selection so that cultivars with superior performance, flavor, texture, and culinary attributes may be developed. They are also trying to promote and expand the awareness of cultivars developed by independent and public sector plant breeders and particularly those that have been selected for organic systems. Similar efforts are being made by another collaborative endeavor formed at the University of Wisconsin in Madison under the direction of Professor Julie Dawson. This effort is known as the Seed to Kitchen Collaborative. In addition, a seed company known as Row 7 has recently been established to foster close cooperation between chefs, farmers, and plant breeders to heighten the focus on culinary trait breeding.

These efforts are not directed solely at heirloom cultivars that possess unique culinary attributes. Instead, they are trying to capitalize on the connection between the cultivar and the user of that cultivar that is celebrated with many heirlooms, but with cultivars that have been selected for modern cropping systems. Thus, the goal is to combine the satisfaction of heirloom cultivars with the modern traits needed for high intensity farming, often in organic systems.

Part of the impetus for these efforts is the realization that many plant breeders must necessarily focus their efforts on commodity markets. In so doing, they often need to place greater emphasis on traits such as postharvest storability, harvestable yield, and host plant resistance to pathogens. There was little question that such traits were of great importance for crop production. But breeders also recognized that improving specific culinary qualities was possible but often may not be as high on the priority list as those traits that deliver the productivity the market requires. Many plant breeders therefore continued a focus on commodity traits and relegated specific culinary objectives to minor parts of their work.

Within the last 10 years, what were once small projects by plant breeders to modify culinary traits have blossomed into full-blown breeding programs. One of the primary thought leaders in this area is the Chef Dan Barber, of Blue Hill and Blue Hill at Stone Barns in New York. Dan was among the first to realize that partnerships among chefs, farmers, and plant breeders were necessary to be able to bring a focus on culinary traits to cultivars that could be grown and enjoyed widely. His efforts with the new seed company Row 7, which are described below, are one of the best examples of how such partnerships have formed in recent years. The Culinary Breeding Network and Seed to Kitchen Collaborative are attempts to bring many professionals together to participate in the development and selection of new vegetable cultivars. As such, it represents a new form of participatory plant breeding that is rapidly gaining interest in many parts of the world.

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The origin of the Culinary Breeding Network was in 2011, when Lane Selman, an agricultural researcher at Oregon State University, observed chefs and plant breeders sharing knowledge during a taste test of nine different sweet pepper cultivars. At that time, Lane was involved in the management of vegetable trials for the Northern Organic Vegetable Improvement Collaborative (NOVIC), a federally funded partnership that uses on-farm trials to identify cultivars of vegetables that will thrive in organic systems. Farmers were trying to find a replacement for a hybrid sweet pepper that was no longer being offered for sale in the seed industry. Among the sweet peppers trialed were several cultivars developed by Frank Morton, breeder and owner of Wild Garden Seed in Philomath, Oregon. In the field, these plants stood out, and the participants in the trial began to discuss the various qualities of these peppers. This discussion was followed by more in-depth discussions among the various stakeholders who could be growing, cooking, eating, and producing seed of these peppers. A participatory network was thus born.

While plant breeders of horticultural crops often taste the breeding lines they are developing, their evaluations typically lack the sort of analysis that may be common for chefs or other culinary professionals. For example, many plant breeders "bite test" their breeding materials in the field, rendering an opinion when comparing among lines but often lacking in the sort of detailed observation that might be helpful in the culinary arts. When chefs and plant breeders finally started coming together in these efforts, the conversations that ensued were eye opening. Chefs often expressed interest in traits breeders had never considered, or would typically throw out. An expansion of the stakeholders involved in selection made for a much more robust selection process. Importantly, this sort of participatory breeding has a better chance of resulting in an adopted cultivar given the involvement of many different stakeholders during cultivar development. And conversely, as culinary specialists come to appreciate the challenges and limitations of the plant breeding process, there is a much better overall understanding of what is possible for the future of our crops. Both the Culinary Breeding Network and the Seed to Kitchen Collaborative combine field trials with tasting events that allow for such conversations to occur.

The goal of the Seed to Kitchen Collaborative (SKC) is to connect farmers, plant breeders and chefs to develop better cultivars for regional food systems in the Upper Midwest. The collaborative uses farmer focus groups and surveys to identify traits of interest, and flavor is consistently one of the top traits from these surveys. Currently, 80 farms are participating in this collaborative undertaking, and the majority of these farms use information gleaned from trials to find cultivars that they use in their production systems. Another important aspect of the collaborative initiative is that it provides an opportunity for independent plant breeders and public sector plant breeders to trial their newest material. For many specialty crops, organized trailing programs do not exist; therefore, the collaborative provides a unique outlet for breeding programs.

The Row 7 seed company began in 2017 as an effort to bring together breeders and chefs who want to make produce with better flavor and culinary characteristics. Founders of the Row 7 seed company, Chef Dan Barber, Professor Michael Mazourek of Cornell University, and Matthew Goldfarb of Fruition Seed Company, are filling a gap in the seed market that is quite unique. Their goal is to promote and sell seeds for new vegetable and grain cultivars that might otherwise not have been sold by any seed company, because their primary characteristics could be their culinary

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attributes. Row 7's focus is to partner chefs and plant breeders with the aim of creating new cultivars that would bring a focus on flavor to what may have otherwise been commodity crops [95].

Chefs may bring a very useful and interesting perspective to breeding efforts [96]. Chefs readily admit that the food they prepare is only as good as the ingredients they use, so cultivars with improved qualities will make their job easier and more satisfying. Sometimes both consumers and chefs can make an impact on cultivar development. Several examples described by [96] include a new tomato cultivar developed by a cross between a modern breeding line and an heirloom that was identified after a taste panel involving 100 consumers, and a squash that was developed by a plant breeder after extensive dialogue between himself and a chef, who trialed the product in restaurants during its development. Such collaborative breeding efforts widen the scope of traditional plant breeding and likely forecast more consumer-friendly cultivars with enhanced culinary qualities.

10. Outlook

Heirlooms often embody particular shapes, colors, textures, flavors, and productivity traits for which they have come to be known and sought by farmers and consumers alike. They are recognized and prized for their specific qualities that have lent uniqueness to the cuisine of many of the world's cultures. Thus, the wealth of genetic variability encoded in heirloom cultivars of our crops is one of the treasures of our shared global food system.

As modern cultivars and the global seed industry have rapidly replaced heirlooms and the practice of seed saving, this unique genetic heritage is, however, in danger of being lost. In recent decades, as our agricultural systems have become even more industrialized, many scientists have come to recognize that the genetic diversity found in heirloom cultivars is of even greater importance for our shared food future. Modern crop breeding has improved agricultural productivity, but simultaneously reduced genetic diversity in our major crops. As our farming systems become more industrialized and our climate becomes more erratic, enhancing, rather than shrinking, our crop genetic diversity will be critical for feeding the world's growing population. Recent efforts to characterize, preserve, and enhance heirlooms abound, bringing these unique types to the forefront of many modern breeding efforts. Participatory breeding approaches with farmers, breeders, and chefs are but one example of modern approaches to expanding the diversity found in heirlooms into modern germplasm pools. Recently molecular research found markers associated with useful variants in heirloom cultivars that may be further used to introgress such traits into modern cultivars.

Heirloom cultivars are also most closely associated with organic and sustainable farming systems, and typically do much better in such conditions compared to modern, industrialized farming systems. As sustainable farming systems gain in popularity in the developed world, the genetic diversity present in heirloom cultivars may become even more important. However, we realize that modern farming systems will continue to dominate many sectors of world agriculture. One of the most important breeding objectives going forward will be therefore to improve the productivity of heirloom types while retaining their unique qualities.

A number of groups have expanded their efforts to preserve traditional heirloom cultivars that were important cultural touchstones for different ethnic groups around the world. One such example is the recent attempt to preserve, maintain, and repatriate germplasm of American crops

domesticated and bred by Native American tribes. These efforts are closely tied to food sovereignty movements, which seek to bring particular heirloom types of staple food crops back under the control of the people who developed them. In such cases, heirloom cultivars represent a vital link to the past as well as a critical bridge to the future.

One of the hallmarks of modern agriculture is the existence of high performing cultivars that are bred for wide-area adaptation and productivity. These cultivars play a key role in feeding the world's growing population; but they may not possess the genetic diversity required to sustain the world's population. Many decades ago, heirloom cultivars appeared to be relics of an earlier age; as older cultivars that had been improved. However, a renewed interest in heirloom cultivars has helped foster the sense that they may play an important role in future crop breeding efforts. New market channels have emerged for heirlooms that have re-energized this unique repository of crop germplasm. As they possess unique flavors, colors, texture, stress tolerances, and forms, heirlooms may represent an important collection of traits that can be of immediate value in crop production and as a source of breeding germplasm for future cultivars. The goal of this review has been to document some of the unique characteristics of heirlooms with the hope that breeders will identify useful traits to bring into breeding programs aimed at developing high value cultivars.

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