In the Footsteps of Vavilov: Plant Diversity Then and Now

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***Abstract*. N.I. Vavilov's theories direct present-day global activities in plant science, breeding, and conservation. His expeditions around the world located centers of diversity of crop evolution. Vavilov was one of the earliest scientists to realize that wild genetic diversity could be lost, through genetic erosion, reducing the possibilities for future crop improvement. To measure genetic erosion, Gary Nabhan and colleagues traveled in 11 countries following routes that Vavilov had taken more than half a century before. The detailed notes concerning the vegetation and flora that Vavilov observed could be used as a baseline in contrast with Nabhan's plant and cultivar inventories to observe changes in plant diversity at specific sites. The objective of this manuscript is to summarize potential genetic erosion at three case study locations, the Pamiri Highlands of Tajikistan, the Ethiopian Highlands, and the Colorado Plateau of Southwestern North America. At these localities Vavilov's notes can be compared with the agricultural activities of the modern day. In each case, significant climatic, environmental, and human-caused changes have affected the local agriculture during the intervening years. Localities that have retained diversity have suffered the least. Reduction of diversity is associated with decreased agricultural stability and productivity. Programs encouraging farmers to manage diversity and promote involvement of local youth in agriculture may reduce or moderate the effect of genetic erosion.**

VAVILOV'S THEORIES

N.I. Vavilov, the Russian botanist and phyto-geographer, and one of the first practical geneticists (Janick, 2015), was a futurist. Three of his significant theories: the law of homologous variation (Vavilov, 1922), the centers of origin (diversity) for cultivated crop plants (Vavilov, 1992), and the concept of genetic erosion, have directed present-day global plant science, breeding, and conservation efforts (Hummer and Hancock, 2015). He realized not only that wild genetic diversity contained the foundation for the development of improved crops for climate and disease challenges, but that a changing environment due either to humanity or nature could erode that genetic base. He observed that genetic erosion meant loss of wild diversity and localized landraces. This he knew would be a threat to food security.

Vavilov's colleague, Dr. Harry Harlan, further explored genetic erosion (Harlan and Martini, 1936). His son, Dr. Jack R. Harlan, took up the cause, particularly after the green revolution of the 1970s. His book *Genetics of Disaster* (1972) described "genetic vulnerability" and "genetic wipeout." During that time new high-yielding cultivars replaced many landraces. Although these improved cultivars saved lives by producing more food, natural plant diversity was eroded in the process. The monocultural planting of new cultivars underscore a need for conservation of wild types for future breeding.

Although genetic erosion was first described in the 1930s, and anecdotally observed in the 1970s, it is hard to quantify. Time-series data may be unavailable for agricultural crops in centers of diversity, and different incompatible measures of biological variability are used at different times (Nabhan, 2009).With that in mind, Nabhan (2009) retraced some key routes that Vavilov had traveled. Comparisons were made with Vavilov's observations of premodern agriculture as a historic baseline in contrast with agriculture at the same sites that have since been subjected to natural and technological changes.

The objective of this manuscript is to determine the extent of genetic erosion in a changing world. Specific data for three case studies of agricultural crops over time is presented. These localities were chosen from Vavilov's centers of diversity, where his original descriptions and inventories could be used as a baseline, against which subsequent reports could be contrasted.

CASE STUDIES

A center of diversity is a location where multiple crop wild relatives exist, where crop species were developed, and likely originated over evolutionary time (Vavilov, 1992). Vavilov's centers can be termed "hotspots" where residual diversity has been protected by cultural forces within certain regions. In such cultural landscapes, food biodiversity remains a dynamic set of resources changing through time and space, in response to many natural and cultural factors (Nabhan, 2009).

Genetic consequences of reticulate evolution include episodes of introgression and isolation with both wild relatives and with local or introduced cultivated land races. Crop diversity is affected by various changes including climate, soils, pathogens, and pests; cropping systems and culinary uses; and cultural management practices.

However, comparing time-series reports for crops at specific localities has complications. The baseline reports on early "folk varieties," contain language ambiguities and inconsistencies that cloud the data. Furthermore, mutation may make correlations with socio-economic and agro-ecological events difficult. Presently analytical tools from genetics, paleoecology, archaeology, and linguistics may help answer these questions, but an integrated approach is needed. In this paper, three agricultural examples are presented: from the Western Pamir (translation: Onion) Highlands, Highland Ethiopia, and the Colorado Plateau. The implication of genetic erosion for these regions will be discussed and approaches for future conservation efforts will be suggested.

Western Pamiri Highlands of Western Tajikistan. Vavilov recognized that the Pamir Highlands of Western Tajikistan were a significant center for crop evolution. When Vavilov traveled there (Fig. 1), glacier-capped ranges of the Onion Mountains, known as "the roof of the world," provided water in gray rivulets that were channeled into canals and ponds. In Vavilov's time, nine wild species of onions grew with many heirloom cultivars grown in fields, gardens, and orchards (Nabhan, 2009). Frequent mudslides down steep mountain sides blocked roads and trails and isolated communities. Isolation fostered self-reliance and promoted many language dialects, such as Rushani, Shugni, Ishkashemi, and Wakhi. Frequently farmers would marry women from other valleys who brought seeds and fruits as part of their dowry to the patriarchal legacy of their new home. Farmers also traded seeds. The introduction of new cultivars fostered crop diversity.

Farmers mixed new varieties with their locally adapted ones, planting heterogeneous plant populations in their fields. Plants with desirable traits were selected, kept, and shared with other farmers. These practices provided seed security against disasters. When a disaster struck, the community would collect and share seeds from neighboring districts.

Vavilov took meticulous notes on the elevation gradients of the crops in the Pamiri Highlands. He realized that while the wheat produced in his homeland was vulnerable to cold dry weather, the hardy, short season

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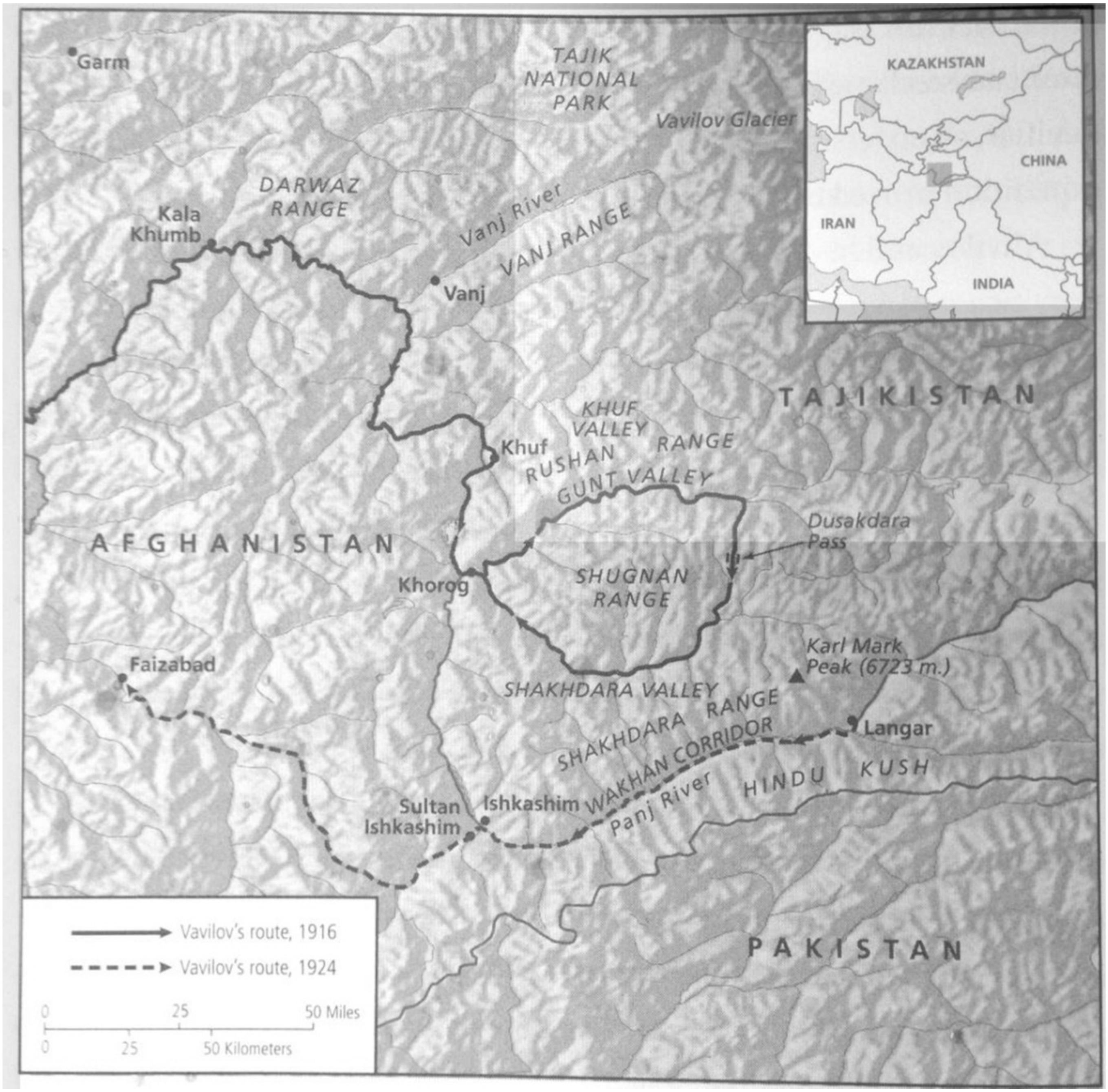

Fig. 1. Expedition of N.I. Vavilov to Pamiri Highlands, Tajikistan, in 1916 and 1924 (after Vavilov, 1997).

grains developed in Tajikistan would be valuable. He suggested they could broaden diversity and provide more hardiness for the difficult Russian climate.

When Nabhan and his group arrived at the Pamir Highlands, the fields of grain were as heterogeneous as they were in Vavilov's time. However, the climate had changed. The glaciers had retreated greatly up the mountains. The frost-free season was longer and wetter. The weather of the valley floor was much colder in the summer than in 1916 when Vavilov was there. Crops matured more slowly at the bottom of the valleys, than previously. In contrast, at the higher elevations above the valley floor, temperatures were much higher and the growing season had become longer. Farmers were dynamically responding. They began to sow grains at higher elevations than their grandparents did, though they planted the same grain crops: wheat, barley, and corn, and vegetables (Table 1). Nabhan (2009) reported that 10 annual crop species were now grown 425 to 525 m higher than in the previous 80 years.

Nabhan examined Vavilov's journals and determined that eight of the field crops Vavilov had recorded were being grown an average of 423 m higher than in 1916. Nine crops had shifted upwards as much as 476 to 506 m from the 1890s. As the climate shifted additional annual crops were also being grown. Growers kept their fields of mixed genotypes, but production had migrated to higher elevation. Additional fruits and nuts, such as walnuts, previously not hardy in these locations were introduced by growers.

Fruit crops were also affected. Mulberry (*Morus nigra*) and apricots (*Prunus armeniaca*) had been traditional and major tree fruit crops for Pamiri families. Trees continued to grow—but did not produce fruit since they no longer receiving sufficient chilling. As a result some traditional foods, such as mulberry bread, were less available.

Highland Ethiopia. In 1926, Vavilov took a major expedition to Abyssinia, the region now called Ethiopia (Fig. 2). During this trip, Vavilov's quest for unusual seeds indicated that this region was one of the more distinctive centers of crop diversification on earth.

Vavilov's route through Ethiopia found a remarkable representation of cereal seed diversity in that region. He realized that durum wheat, which had been thought to have originated in Egypt, had diverged from other wheat relatives in the Ethiopian highlands before moving northward to Egypt and eastward to Oman (Nabhan, 2009). Once again Vavilov observed that each field of ripened grain was not homogeneous, but "displayed such an incredible mixture of varieties."

Worede (1991) noted how Ethiopian studies have confirmed Vavilov's idea about the value of on-farm variation. The farmer's methods of crop selection enhanced landrace diversity because of the many criteria for which they selected. Such mixtures gave field populations considerable capacity to respond to varying conditions from drought to cool wet seasons; from windy to still weather, and from manure-fertilized to nutrient-limited soils.

In 1984–85, famine threatened Ethiopia's food supply and the reserves of farmer's traditional seeds. Many development agencies suggested the introduction of hybrid high-yielding varieties, herbicides, and other technologies to replace the local landraces. Few of the Ethiopian farmers could afford the additional cost of this seed or herbicide. This tactic did not resolve the food issue. In contrast, the Ethiopian Plant Genetic Resources Institute worked for conservation of unique germplasm. Rather than locking diversity away in ex situ genebanks, a collaborative effort was invested in on-farm conservation and improvement of indigenous crops by local communities. In addition, the farmers who had buried cashes of seeds in their fields to weigh against catastrophe, helped maintain crop diversity. Farmers exchanged seeds over the steep elevation gradients of their region. This offered genetic resilience in the face of disaster (Nabhan, 2009).

The Ethiopian tradition of planting mixtures or polycultures of grains helped in a second situation. A strain of black stem rust (*Puccinia graminis* f. sp. *tritici*) was found in Uganda in 1999. This strain (Ug99) spread across East Africa. Most wheat fields that were grown in monoculture were susceptible, leaving the field as a withered mass of seedless stalks.

Table 1. Highest reported elevation for cultivation of several crops in the Western Pamiri Highlands of Tajikistan[z] over time.

		Highest cultivated elevation in:		
Common name	Species	1893–96	1916	2006
Barley	*Hordium vulgare*	3,250 m	3,550 m	3,850 m
Fava bean	*Vicia faba*	2,510 m	2,810 m	2,900 m
Maize	*Zea mays*	1,980 m	2,880 m	3,500 m
Rye	*Secale cereal*	3,250 m	3,550 m	≈2,800 m
Wheat	*Triticum aestivim*	3,250 m	3,550 m	3,860 m

[z]After Vavilov (1997), Nabhan (2009), and (Nabhan, personal communication, 2015).

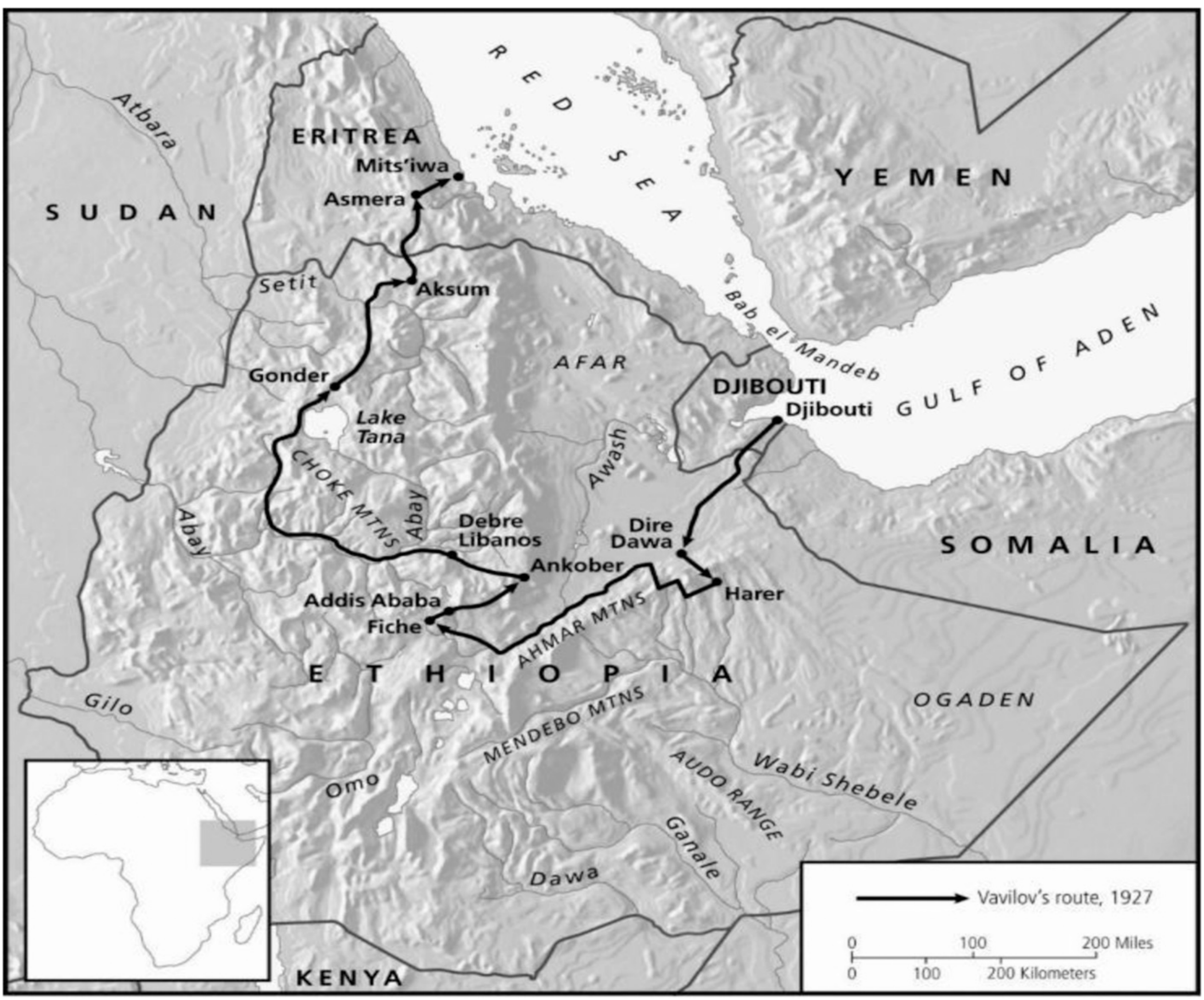

Fig. 2. Expedition of N.I. Vavilov to Abyssinia (Ethiopia), in 1926 (after Vavilov, 1997).

The Ethiopian diverse field mixtures have demonstrated resistance to black stem rust and several viruses thus far (Nabhan, 2009).

Hopi and Navajo, CO Plateau of the Southwestern United States. Vavilov traveled extensively in North America (Fig. 3) and in 1930 he came to Arizona on the invitation of Dr. Homer Shantz, President of the University of Arizona, Tucson. Shantz and Vavilov had both spent years studying the wild native vegetation of Africa. Vavilov lectured at the University on his theories of centers of agricultural diversity. He pleaded with the Americans to become more aware of their valuable genetic resources. Dr. Shantz and Vavilov toured the Hopi and Navajo mesas, some of the oldest continuously managed agricultural areas in the United States, farmed by native peoples for more than 4100 years (Nabhan, 2009) with written records and oral histories that describe a cropping span of 350 years.

Vavilov observed maize, melon, apple, tepary bean, and sunflower production. These field crops were grown on sand dunes that received no added moisture. This production system depended on underground springs that supplied crops with water despite severe drought in the late 1930s. In 1936, at the height of the drought, an amazing diversity of crops were planted and harvested. They managed to grow 4 million pounds of corn, 57,000 pounds of beans in addition to sizeable amounts of melons, squashes, pumpkins, peaches, apricots, pears, apples, grapes, and other vegetables. They grew almost all of the corn that they consumed. They sold surplus crops to their neighbors. Their annual purchase of imported food was less than $25 per capita in 1936 (Nabhan, 2009).

In 1989, Nabhan, with permission of the Office of Hopi Lands, interviewed descendants of the same families present in the 1930s. At that time, the Hopi were growing many of the crops of their grandparent's generation and had added new crop cultivars through commercial seeds brought in and evaluated. The Hopi subsistence strategy maintained traditional and ceremonial crops alongside some newer crops obtained from outside sources.

Unfortunately by 2002, a diminished capacity of production was observed for the Navajo and the Hopi lands. Between 1990 and 2002, the Peabody Energy Company began extracting as much as 1.3 billion gallons of water annually from underground aquifers for mining operations. The net effect

Fig. 3. Expeditions of N.I. Vavilov in North America, 1929–34 (after Vavilov, 1997).

was that fewer spring-fed fields and gardens had sufficient irrigation. This depletion of water deeply concerned the Native Peoples and they successfully lobbied for limited use of aquifer water for this purpose.

Due to additional droughts in the southwest and the shrinking of the aquifer, of 63 named cultivars of specialty crops grown by the Hopi in 1925, only 30 were readily found in gardens, fields and orchards in 2006 (Nabhan, 2009). Only ≈47% of the food needed for self-sufficiency was grown. Many of the drought-sensitive germplasm grown by the Hopi at the time Vavilov visited are now lost. In addition, some of the springs are contaminated with benzene; others have very low flow. Although the fields appeared dry in Vavilov's time, productivity was high due to the water supply from aquifers. Now the same fields were yielding significantly less with lower crop diversity. As a corollary, the younger generation of native people have a declining interest in being farmers and are leaving the area.

CONCLUSIONS

Three case studies demonstrate what has occurred to three centers of diversity from 50 to 80 years prior. In the Pamiri Highlands, the traditional practice of growing fields of diverse genotypes has provided resilience to the changing temperature and climate. The flexibility of planting at higher elevations has allowed for continued crop productivity. In the Ethiopian Highlands, once again, the polyculture of mixed genotypes has allowed the agriculture to continue despite the great and increasing threat of drought and disease. In the Hopi and Navaho lands, where aquifers can no longer support agriculture, genetic erosion has occurred with great losses in plant diversity. Fewer crops, lower productivity, and lower social and cultural esteem for agriculture are the result.

The global focus to conserve genetic diversity should emphasize vulnerable agricultural zones, such as along steep gradients of elevation in mountainous areas, or those along coastlines. The agricultural centers of diversity with high rates of loss where climate change is forcing rapid distributional shifts require immediate attention. The planting of diverse mixed hybrid fields, rather than monocultural planting of the ''best'' cultivar, will be more sustainable in the long term. The initiation of socio-economic programs to revitalize traditional gardening with healthy foods and medicinal plants will bring back productivity to the land. Investing and promoting seed exchange and experimental nurseries or common gardens by local farmers will be a strategy of resilience. Community-based models of conservation based on in situ conservation and on-farm breeding in the face of climate change must be encouraged.

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