RESEARCH BRIEF | Maywa Montenegro, University of California, Berkeley

Banking on Wild Relatives to Feed the World

Abstract: Crop wild relatives, the progenitors and kin of domesticated crop species, promise breeders a potent weapon against climate change. Having evolved outside the pampered environs of farms, wild relatives tend to be more rugged to survive temperature, salt, floods, and drought—all the extremes characteristic of a warming planet. But who will benefit from re-wilded crops? What kinds of agricultural systems will they tend to support? And can wild relatives be protected before they are lost under pavement, desertification, and expanding industrial farms? In this essay, I explore different visions of conservation and use for crop wild relatives. With CWR valued at an estimated $115–120 billion to the global economy annually, many researchers suggest ancient germplasm can be harnessed to feed billions in a warming world. Others look more closely at ancient customs and farmer knowledge that have long promoted conservation of wild species within and around cultivated landscapes. By intentionally planting crops at field borders, farmers also perform "in vivo" breeding. I conclude that wild relatives hold much potential to reinfuse diversity into eroded crop gene pools, providing greater systemic resilience. But unless we consider who controls seeds, intellectual property, and wild and agricultural lands, CWR innovations will only prop up an agriculture that ultimately undercuts crop and wild relative renewal.

Keywords: crop wild relatives, seeds, gene banks, agroecology, indigenous knowledge

NOT LONG AGO, Native Seed Search, a Tucson-based organization dedicated to preserving indigenous crop varieties, was approached by representatives from Monsanto. Did Native Seed have any samples of *teosinte* they were willing to sell? The wild ancestor from which domesticated corn was bred, *teosinte* is scarcely recognizable as a kin of modern corn, the latter with its multiple rows of kernels, plump and sweet. Yet it is in the genes of this wild relative—and those of all the world's major crop species—that modern plant breeders are eager to find a potent weapon against climate change.

Having evolved outside the pampered habitat of a farm, wild relatives are hardier than most domesticated species. Their traits, say researchers, could potentially be bred or engineered into crops to produce climate-hardy varieties. If you have not yet heard that "weeds will feed the world," you soon will.

But who will benefit from such wild relative improvements? What kinds of agricultural systems will they go to support? And how to stanch the loss of wild relatives due to climate change, urbanization, deforestation, pollution—and industrialized agriculture itself?

With such questions still waiting to be satisfyingly addressed, much wild relative work is already underway. Scientists at the United States Department of Agriculture (USDA) are looking to red rice, a weedy relative of domesticated rice (genus *Oryza*), for genes that could make commercially grown varieties more heat-resistant, adapted to saltier soils, and higher yielding even under the driest conditions (Palmer 2014). Other USDA researchers are crossing the countryside in search of wild relatives of sunflower (*Helianthus*), one of the few domesticated plants native to North America (Harvey 2015). Similar research at CIMMYT in Mexico, the cradle of Green Revolution research, focuses on relatives of wheat (*Triticum*), with advances in drought- and heat-resistant traits already resulting in edible grain.

By "capitalizing" on the ancestral germplasm of the world's major food crops, some reports contend, scientists can "feed billions in a warming world" (Palmer 2014). Such language should give us pause, if only because mountains of evidence now suggest that "feeding the world" is the wrong way to think about issues of access, poverty, and concentrated power that configure hunger in the first place.

But it also comes as no surprise. In the United States, the desirable traits of wild sunflowers are worth roughly US$267–$384 million annually to the sunflower industry, according to Bioversity International researchers (Hunter and Heywood 2010: 11). "One wild tomato variety," these experts say, "has contributed to a 2.4 percent increase in solids contents worth US$250 million; and three wild peanuts have provided resistance to the root knot nematode, which cost peanut growers around the world US$100 million each year" (ibid.)

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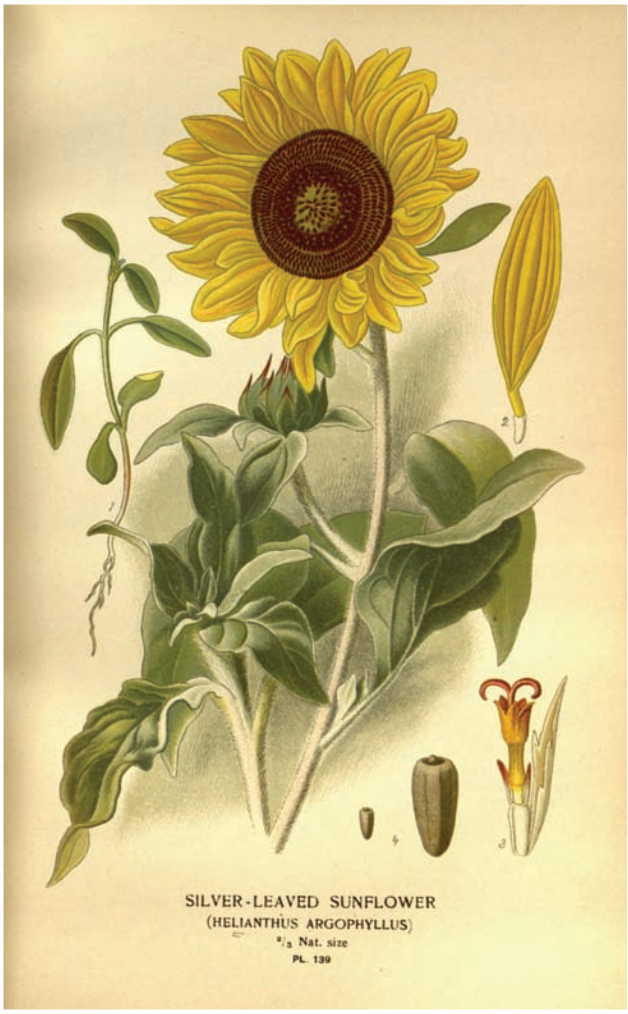


FIGURE 1: *Sunflower Economics. Breeding the sunflower with its close wild relatives, such as this* Helianthus Argophyllus, *could diversify the gene pool but could also reinforce industrial agriculture. One product, marketed as Clearfield, has been bred for resistance to the popular weedkillers imidazolinone and sulfonylurea, and is now estimated to be "worth millions of dollars globally" (Hunter and Heywood 2010).*

"FAVOURITE FLOWERS OF GARDEN AND GREENHOUSE 10574954564.JPG" BY EDWARD STEP (1897) IS LICENSED UNDER CC 2.0.

Other studies have found even greater returns on investment. Using CWR (crop wild relatives) as genetic resources to fend against pests, diseases, and climate stress generates an increase of $20 billion per year in US crop yield and an estimated $115 billion to $120 billion in annual benefits to the world food economy, say scientists at Cornell University and the University of Birmingham (Pimentel et al. 1997; Maxted and Kell 2009; Maxted et al. 2013).

There is money, in other words, in wild relatives, with significant consequences for how an estimated 50,000–60,000 species of CWR will be accessed and used. At present, the inertial tug is to treat wild relatives just as agricultural seeds are often treated: as "genetic resources" that can be exploited to close yield gaps, and which must, in the words of the Global Crop Diversity Trust, be "rescued" from climate change, urbanization, and other drivers of loss. Seed safety, they propose, is best secured in the vaults of a gene bank.

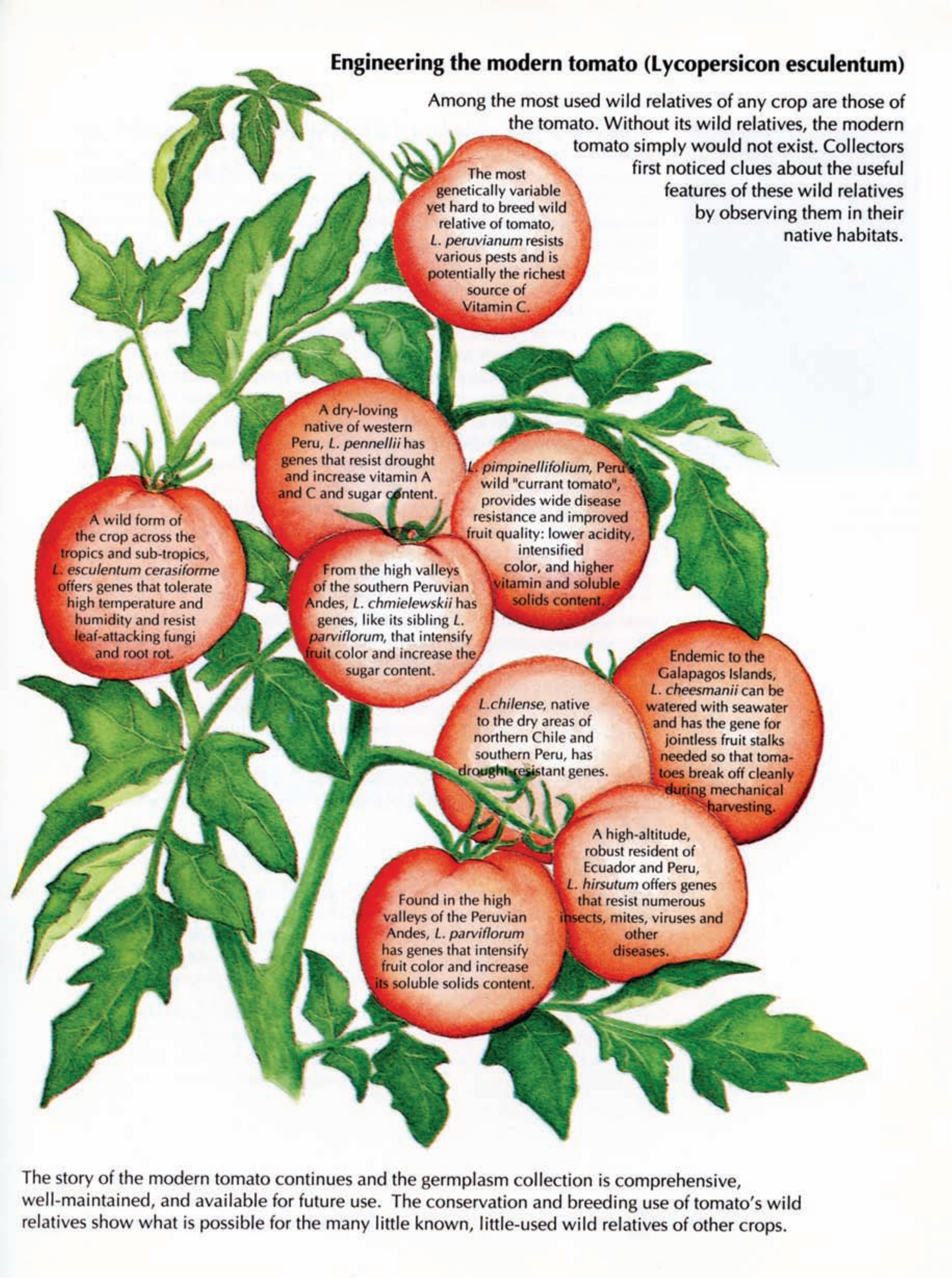
Banking on the Future

This salvation narrative is persuasive, especially at a time when scientists suggest that roughly 39 percent of all monocots—the plant family including most of the world's important food crops—face endangerment, high risk of extinction in the wild, or "critical endangerment" (IUCN 2015),[1] and when studies specific to wild relatives indicate that 16–22 percent of CWR species in three crop gene pools will go extinct by 2055 (Jarvis et al. 2008).

But for those familiar with the long history of colonial and postcolonial seed exploits, these plans provoke caution. For centuries, imperial powers, scientific organizations, and private industry have collected what they considered "raw" and "unworked" germplasm from local farmers and communities without compensation, and without recognition of the knowledge that went into developing such diversity in the first place. At the height of gene and seed banking expansion in the mid-twentieth century, the CGIAR (Consultative Group for International Agricultural Research) established a network of eleven *ex situ* repositories, even while it rolled out Green Revolution intensification technologies across the global south. For many observers, the irony was all too apparent: technologies that simplified landscapes and promoted monoculture cropping endangered the traditional seed varieties that became eligible for "rescue."

Fifty years after the apex of the Green Revolution, the *ex situ* system is still going strong, with more than 1,700 gene banks, the legal support of the International Plant Treaty,[2] and financial backing by numerous sovereign states, private industry, and philanthropy capital. Rescuing seeds, in this context, has effectively configured a "use pipeline" to guide genetic resources away from the farming communities and toward breeders and biotechnologists, whose craft is strongly shaped by private sector interests in sellable seed. The Global Crop Diversity Trust (hereafter the Trust), American University professor Garrett Graddy-Lovelace suggests, has an explicit objective of making crop genes available to private industry and private-industry-affiliated philanthropic plant researchers, so as to "stimulat[e] the flow of conserved genetic diversity down the 'use pipeline' to growers" (in Graddy 2013: 591).

As an example, the Trust recently completed what it describes as "the largest and most successful biological rescue mission ever." With support from the Bill and Melinda Gates Foundation and the Australian Grains Research and



Engineering the modern tomato (Lycopersicon esculentum)

Among the most used wild relatives of any crop are those of the tomato. Without its wild relatives, the modern tomato simply would not exist. Collectors first noticed clues about the useful features of these wild relatives by observing them in their native habitats.

The most genetically variable yet hard to breed wild relative of tomato, *L. peruvianum* resists various pests and is potentially the richest source of Vitamin C.

A dry-loving native of western Peru, *L. pennellii* has genes that resist drought and increase vitamin A and C and sugar content.

L. pimpinellifolium, Peru's wild "currant tomato", provides wide disease resistance and improved fruit quality: lower acidity, intensified color, and higher vitamin and soluble solids content.

A wild form of the crop across the tropics and sub-tropics, *L. esculentum cerasiforme* offers genes that tolerate high temperature and humidity and resist leaf-attacking fungi and root rot.

From the high valleys of the southern Peruvian Andes, *L. chmielewskii* has genes, like its sibling *L. parviflorum*, that intensify fruit color and increase the sugar content.

Endemic to the Galapagos Islands, *L. cheesmanii* can be watered with seawater and has the gene for jointless fruit stalks needed so that tomatoes break off cleanly during mechanical harvesting.

L.chilense, native to the dry areas of northern Chile and southern Peru, has drought-resistant genes.

A high-altitude, robust resident of Ecuador and Peru, *L. hirsutum* offers genes that resist numerous insects, mites, viruses and other diseases.

Found in the high valleys of the Peruvian Andes, *L. parviflorum* has genes that intensify fruit color and increase its soluble solids content.

The story of the modern tomato continues and the germplasm collection is comprehensive, well-maintained, and available for future use. The conservation and breeding use of tomato's wild relatives show what is possible for the many little known, little-used wild relatives of other crops.

FIGURE 2: *The Wild Defenders of Tomato. Appearing in a 1988 pamphlet to raise the public profile of crop wild relatives, this illustration depicts what few people know about the modern tomato: a ubiquity of wild genes have gone into shaping it (Hoyt 1988).*

ILLUSTRATION BY SUSANAH BROWN, COURTESY OF BIOVERSITY INTERNATIONAL.

Development Corporation, it collected nearly 80,000 unique seed and vegetative samples of crops from eighty-eight countries and 143 institutes (GCDT 2015). Germplasm collections in many existing gene banks are at risk of being lost because of poor storage and infrequent grow-outs. To guard against this loss, the Trust safety duplicated seeds for backup storage in the Svalbard Global Seed Vault, helping overcome what the Trust calls "serious constraints to the development of a rational and efficient global system for the conservation of crop diversity in genebanks" (ibid). The terms of the Plant Treaty forbid patenting genetic materials "in the form received," thwarting the commercialization of germplasm obtained directly from the global *ex situ* system. Yet there is no legal block on the patenting of "derived" products, meaning that companies or public institutions that breed or engineer significant changes into genetic materials can then acquire intellectual property rights; the Trust only asks that a portion of the profits be paid back into the global conservation system.

Now, the Trust and its partners hope to expand their work to crop wild relatives.

In 2013, an ambitious new project was launched to put wild relatives at the center of adapting agriculture to climate change. Led by the Trust in partnership with the Millennium Seed Bank, the International Center for Tropical Agriculture (CIAT), and the government of Norway, the effort is premised on the notion that crop wild relatives have "high potential value for food security." Over ten years, researchers will comb the planet to locate and gather relatives of twenty-nine crops—including globally important species such as wheat, rice, and potato as well as crops of major regional importance in the developing world, such as lentils, millets, sweet potatoes, and cowpeas (Dempewolf et al. 2014).

With climate change encroaching, the only viable solution appears to be salvaging seed from farmers and land managers who cannot (or will not) sustain them. Moreover, wild relatives are apparently unavailable for use until collected, frozen, and registered in gene banking databases—from where scientists can unlock their wonders. In the words of prominent Cornell plant geneticist Susan McCouch, "There are still vast reserves of valuable genes and traits hidden in low-performing wild ancestors and long forgotten early farmer varieties that can be coaxed out of these ancient plants by crossing them with higher-yielding modern relatives" (Palmer 2014).

Gone missing from this narrative is the history of wild relatives, and the ingenuity of farmers—both past and present—in continually recycling and recombining ancestral traits into the seeds of edible plants.

Did You Say Farmers?

The cross-fertilization of crops and their wild relatives used to happen frequently and by accident. As long as cultivated species grew in or near their centers of origin—wheat in the Fertile Crescent, potatoes in the Andes, rice on the border of India and Nepal—crops would commonly get pollinated by weedy ancestors nearby. The result was the frequent introduction of wild traits into the agricultural gene pool. Which of these novelties survived, in turn, hinged on farmer selection—as growers considered complex ecological conditions and social needs (for food, fuel, fiber, medicinal, and ritual) when deciding which seed to save and replant.

FIGURE 3: *Peanut Kin, Climate Refugees. Native to Latin America, wild peanuts belonging to the genus Arachis have provided resistance to many devastating crop pests and diseases that affect rural smallholders around the world. Yet a report by the Consultative Group of International Agricultural Research (CGIAR) warns that 61 percent of wild peanut (and 12 percent of wild potato species) could be made extinct over the next half century - largely due to climate change (CABI 2007).*

Over the past thousand years, exploration, trade, travel, and plunder have transported seeds to new frontiers, bringing domesticated crops into contact with new exotic plants, but out of range of the wild relatives with whom they had mingled for millennia. Darwin, Mendel, and the heady science of systematic plant breeding would transform mating possibilities again at the turn of the twentieth century; professional breeders could use seeds and germplasm collected from all corners of the world to make crosses and design "improved" crops.

Wild relatives gathered from the original centers of crop diversity led to several innovations. *Oryza rufipogon* from China gave cold tolerance to rice, *Thinopyrum intermedium* and *Thinopyrum Ponticum* helped immunize wheat against a growth-stunting virus, and an alphabet soup of *Arachis* species provided peanuts in India with resistance to two devastating fungal diseases (Maxted, Magos Brehm, and Kell 2013).

Scientists, however, were far from alone in making intentional use of wild relatives. In their indigenous habitats, where crops grow in close proximity to both wild relatives and traditional farmers, there was much meticulous breeding afoot. Ethiopian and Mexican farmers were known to purposefully plant crops on farm borders so as to encourage cross-fertilization with hardy cereals (Maxted and Kell 2009). Indeed, over the years, ethnobiologists and ethnoecologists have documented numerous cases of peasant successes in maintaining and even enhancing crop and wild relative diversity through applying agroecological principles and practices (Posey 1985; Altieri and Merrick 1987; Oldfield and Alcorn 1987; Meilleur and Hodgkin 1994; Nabhan 1989, 2009).

These contemporary studies are backed up by archaeological evidence suggesting that swidden cultivation – an ancient technique of rotational farming in which land is cleared for cultivation, normally by fire, and then left to regenerate after a few years – brought another potent form of genetic intermixing. As farmers moved plots to new patches in the forest, the interface of domesticated and wild was ever-changing. The abandoned plots, meanwhile, were frequently invaded by wild relatives, which might interbreed with straggling survivors of crop plants. The results were extensive crossing that took place in ex-farmland and continued to affect crops the next time the cycle was repeated (Kingsbury 2011).

Domestication, in this light, was not a one-time event, but an ongoing process of bringing wild into cultivated, with farmers at the center. It depended fundamentally on webs of biological relationships in local ecosystems, on farmer knowledge of crop-environment interactions, and on landscape to provide the context for ecological renewal.

Wild Relatives on the Land

Many grassroots organizations today appreciate the necessity of embedding seed conservation in cultural and ecological contexts. Groups such as Native Seed Search in Arizona, Navdanya in India, Seed Saver Exchange, Arche Noah in Europe, Southern Seed Alliance, ANDES in Peru, IIED in London, and the FAO's Global Important Agricultural Heritage Systems (GIAHS) are just a few organizations working to call attention to on-farm (*in situ*) practices of biodiversity conservation.

As Bill McDorman, former director of Native Seed Search, told a reporter for *Truthout*, the organization is not only saving seeds. They are gathering tribal stories of how to cultivate, when to plant, how to tend plants, and how to store the harvest (Schiffman 2014): "There are fields where Hopi blue corn has been grown successfully every year for the past 60 years, with no external inputs, no fertilizer; they never watered it; that's what they have learned to do over a thousand years, so for us just to take a few of those kernels and say, there are some genes in there that we can use, misses the point." Extending this ethic to wild relatives demands a similar biocultural approach, yet on an even more wide-ranging terrain. Wild relatives must be preserved in forests, marshes, and grasslands where they naturally occur. Outside of protected areas, wild species can grow in and around farms—for example, as herbs, shrubs, and trees in agroforestry systems. They can populate urban gardens and abandoned lots. They thrive along rivers and roads.

An expansive conservation space means an equally complex array of people must participate. Farmers, nature conservationists, foresters, urban planners, and policymakers. Ministries of agriculture, environment, and development; bureaus of wildlife and land management; regional and national universities. Policymakers at local, national, and international scales. In other words, more complicated than the stock-and-freeze approach.

One of the world's leading experts on crop wild relatives, Ehsan Dulloo, suggests that the efforts will be worthwhile, because wild plants are essential to livelihoods of people who live close to the land. In addition to using wild relatives in crop breeding, communities often gather species from the wild and cook them. "Throughout Africa," writes Dulloo, "people eat wild cowpea species (Vigna spp.), while in Madagascar, wild yams (Dioscorea spp.) are a rich source of carbohydrates" (Bioversity International 2015). These can also be sold, he notes, "providing rural households with an additional source of income" (ibid.). Just a few hundred plant species form the basis of all agricultural crops. By contrast, one study estimates that the total number of wild plants used by humans in local agricultural systems, and that are collected from the wild for food, fiber, oil, and medicine, runs into the tens of thousands (Heywood 1999).

Dulloo and colleagues at Bioversity International are now beginning a global-local initiative to protect crop wild relatives *in situ*. Over the next ten years, they aim to develop programs to conserve at least thirty crop wild relatives on smallholders' farms and in the wild. They have launched a new Crop Wild Relatives Portal (www.cropwildrelatives.org/) to share national inventories of wild species, and to disseminate information such as maps, images of wild and weedy species, and training manuals co-developed with local communities.

With these projects just now unfolding, many questions remain. Should we focus on specific target species? On the larger habitats and ecosystems in which they occur? On the viability of communities that support, and depend upon, wild relative persistence? All of the above?

What is clear is that conservation and exploitation—for food, fuel, and especially, as genes for crop improvement—can run at cross-purposes. Monsanto's interest in *teosinte*,

FIGURE 4: *From top to bottom: teosinte, a maize-teosinte hybrid, and domesticated maize*

PHOTOGRAPH BY JOHN DOEBLEY, COURTESY OF THE DOEBLEY LAB, UNIVERSITY OF WISCONSIN-MADISON

Domesticating Teosinte, A Patient Farmer Practice

Native Americans domesticated nine of the world's most important food crops, including corn, more properly called maize (*Zea mays*), which now provides about 21 percent of human nutrition across the globe. Until very recently, however, the biological origin of corn was a mystery. Given that corn does not grow well in the wild anywhere on the planet, many crop researchers were stumped as to its ancestry. Many botanists concluded that corn must have arisen through the domestication of a wild maize that was now extinct, or undiscovered. But, as biologist Sean Caroll explains, that story started to unravel in the early 20th century, when a handful of archaeologists, botanists, and geneticists uncovered evidence linking corn to an unlikely parent, teosinte: "Looking at the skinny ears of teosinte, with just a dozen kernels wrapped inside a stone-hard casing, it is hard to see how they could be the forerunners of corn cobs with their many rows of juicy, naked kernels. Indeed, teosinte was at first classified as a closer relative of rice than of maize" (Carroll 2010). George Beadle famously championed the theory and, in his lab at Cornell University, conducted more than 50,000 maize-teosinte crosses to explore their genetic likenesses. Teosinte was clearly very close kin.

But it was not until 2010 that researchers at the University of Wisconsin were able to provide near-definitive evidence of this parentage and to pinpoint a geographic origin. Rounding up 60 samples of teosinte from across its entire Western Hemisphere range, they compared DNA profiles of these samples with all varieties of maize. Nearly all maize, they discovered, is most similar to a type of teosinte found in the Center Balsas River Valley of southern Mexico, suggesting a likely cradle of maize evolution. Mapping genetic distances between Balsas maize and teosinte, they also estimated that domestication must have occurred about nine thousand years ago. For Caroll, the most impressive aspect of the maize story is "what it tells us about the capabilities of agriculturalists 9,000 years ago. These people were living in small groups and shifting their settlements seasonally. Yet they were able to transform a grass with many inconvenient, unwanted features into a high-yielding, easily harvested food crop." Every August he says, "I thank these pioneer geneticists for their skill and patience" (ibid.)

after all, was not to preserve ancestral maize for posterity. Native Seeds turned the company's request down, "politely," according to McDorman, fearing that the agribusiness giant might claim intellectual property on a plant that farmers recognized and began domesticating some nine thousand years ago.

But exploitations are not all alike, as seen in indigenous communities' sustainable harvesting of wild relatives for medicine, fuel, and sustenance. Even in the realm of crop improvement, a chasm exists between the objectives of Monsanto and groups like the Organic Seed Alliance, who explicitly challenge seed industry concentration. Using *teosinte*, two different breeders supported by OSA are now working on organic corn varieties that will reject pollen from genetically modified crops. The trait, derived from the wild relative, only allows *teosinte* pollen to fertilize *teosinte* flowers. When crossed with modern corn, breeders hope, this wild relative could help prevent the contamination of organic crops with patented, modified genes.

The wild kin of our crops, it appears, can promote monopoly control of the food system, or can help resist it. The folks dedicated to organic and agroecological agriculture are banking on the latter. And though they may not have an explicit objective of *in situ* conservation, in many ways, these missions align. Biodiversity loss—including of crops and their wild relatives—is largely driven by the way we grow, distribute, and consume food today. In moving toward regenerative agricultural systems, and by confronting chemical pollution, habitat loss, soil degradation, IP regimes, and other industrial threats to agricultural diversity, there may be fewer endangered species—less plants to rescue in the first place.

So, will weeds feed the world? Wild relatives do hold great potential to reintroduce genetic diversity into our emaciated crop gene pool. With their hardy traits, they could help adapt agriculture to the vagaries of climate change. But much depends on the particular systems of conservation, who controls seeds, and whose decisions matter. If funneled into the conventional use pipeline of production, CWR innovations will only prop up an agriculture that ultimately undercuts crop and wild relative renewal.

Transforming how we put seed into soil—making *in situ* places of biological and cultural diversification—is surely a wild idea. But it is a very ancient one too, suggesting it may be a good place to start.

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"*In Situ* and *Ex Situ* Seed Saving—Can We Have Both?"

Since the early 1990s, "complementarity" has been widely recognized by academics and researchers in international policy circles, suggesting *in situ* and *ex situ* strategies, far from rivaling one another, can coexist. Complementarity is now enshrined in the Convention on Biological Diversity (1992), the FAO Global Plan of Action for Plant Genetic Resources for Food and Agriculture (1996, 2011), and the International "Plant Treaty" (2004).[3]

As anthropologist Stephen Brush wrote in 1991, the reasons for their synergy are both economic and ecological: "on-site conservation might be an inexpensive complementary strategy to *ex situ* programs"—offering, for example, opportunities to conserve larger amounts of germplasm than off-site storage can manage (more bang for your conservation buck). In addition, he argued, *in situ* strategies protect not only the target species saved in a bank, but ecosystems full of "accidentally" conserved nontarget species. Preserving habitats also means protecting dynamic evolutionary and ecological processes—i.e. the ability to maintain not just existing germplasm but the processes that create new germplasm. However, like numerous other researchers writing at the time, Brush hinted that land-based conservation might not be an end in itself: *in situ* could be "a valuable tool to increase the sustainability of *ex situ* conservation…" (Brush 1991: 154).

When assessing the merits, or demerits, of complementarity, it is vital to consider that not all gene banks are created alike, nor is all *in situ* homogenous (or "good"). In *ex situ* approaches, much depends upon the size (local seed bank versus international mega-genebank); the structure (centralized versus decentralized); and the governance of access and benefits (community governed versus ordained by international law). As for *in situ*, CWR conservation on land can empower local communities to regenerate their own seed resources. But establishing "genetic reserves" and "protected areas" can also veer uncomfortably close to colonial and neocolonial habits, in which conservationists thought little of displacing local peoples on the grounds of saving "wilderness." Moreover, in many ecosystems populated by wild relatives—bushlands, desert scrubs, and forests, to name a few—traditional communities often use territory without formal property designations. *In situ* planning thus demands careful consideration of the complex, informal, and overlapping rights of shifting cultivators, hunter-gatherers, and indigenous peoples who are accustomed to harvesting and using wild plants in place.

These dynamics suggest that it is not simply the existence of either *in situ* or *ex situ* practices that should concern us; rather it is their specific social, legal, and institutional characteristics. Also important is the relationship between *ex situ* and *in situ* strategies. Does the land-based genetic reserve function to populate the off-site gene bank? Is value largely flowing one-way, to be accumulated by external actors and institutions? Or does the flow of genetic resources and value recirculate, returning seed to local habitats, and distributing value among communities with whom wild relatives coexist and coevolve?

NOTES

1. A total of 3,877 Monocotyledons were evaluated in the 2015 IUCN Red List Assessment. Of these, 38.9 percent were classified as "endangered" (EN: 562), facing a high risk of extinction in the wild, aka "vulnerable" (VU: 592) or "critically endangered" (CR: 351)

(see IUCN 2015.2; Table 3b). Although this figure is a notable downward revision from evaluations based on 2008 Red List data (e.g., www.cropwildrelatives.org/cwr/threats/), the earlier assessments included far fewer total monocot species (only 1,115).

2. Often dubbed the "Plant Treaty," the International Treaty on Plant Genetic Resources for Food and Agriculture (IPTGRFA) was adopted in 2004. As of 2014, 130 countries plus the European Union have joined the agreement as "contracting parties." The United States remains only a signatory.

3. One example comes from Mesoamerica, where the milpa-solar system combines the traditional "milpa" field—intercropped with maize, beans, and squash—with the home garden, or "solar," in which campesinos customarily tend a high diversity of animal and plant species. According to FAO research, milpa-solar systems offer a number of environmental services, among them serving as "the world's reservoir of maize genes including Teosinte, the ancient relative of maize" (GIAHS 2015).

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