



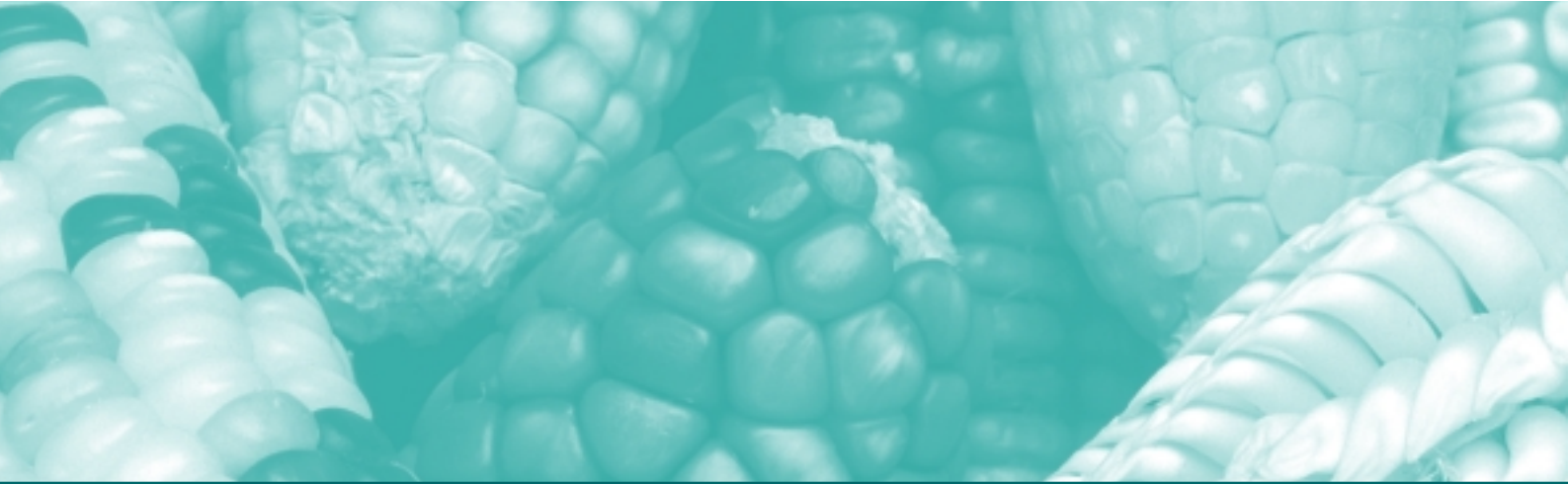
Safeguarding the Future of U.S. Agriculture

THE NEED TO CONSERVE THREATENED
COLLECTIONS OF CROP DIVERSITY WORLDWIDE



Genetic Resources
Conservation Program
University of California
USA

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The international genebank at the International Center for Tropical Agriculture in Cali, Colombia.

Summary

The productivity of US agriculture is legendary, and the value of US agricultural commodities (i.e. food and fiber) exceeds \$191 billion at the farm level—before the considerable added value of processing and marketing. Underlying this impressive output is a little-known resource—collections of seeds and other living plant material stored in crop genebanks around the world. These collections hold thousands of varieties of hundreds of crops. They represent the historic and current diversity of agriculture, without which farming in the US and around the world would stagnate and flounder.

Today, as new and re-emerging pests and diseases threaten to damage or even wipe out entire crop types, and with the market forever demanding new and improved crop varieties, these collections take on added importance to US and world agriculture.

The stakes are high, particularly when it comes to fighting crop diseases. With soybean rust poised to take a \$1 billion bite out of the US soybean market each year, potato blight costing American farmers \$400 million annually, and many other crop species facing costly attacks, plant breeders are under pressure to provide new resistant varieties of crops. To do so they need access to as much genetic variation as possible.

The problem is, despite their value, many crop diversity collections are struggling to survive, particularly in developing countries. And those collections, which can include crops that have been cultivated for centuries and their rare wild relatives, may be the most important ones of all.

For although US industry and government facilities maintain impressive collections of crop varieties grown domestically, the answer to many crop woes may be found in an obscure variety cultivated—or even growing wild—in Asia, Africa, South America or the Middle East. Today, the source pathogen causing a

crop disease in the United States may likewise be traced to a distant region. And the solution may lie in genetic traits contained in a crop variety or wild plant growing there as well.

US agriculture needs the genetic resources of collections of crop diversity around the world to combat pests and diseases and to adapt to environmental changes.

In the United States, pests and plant diseases are conservatively estimated to exact a toll of \$20-\$33 billion each year nationwide. And, while plant pathogens are older than agriculture itself, several recent trends increase the risk that an unforeseen pest or disease will cause widespread damage to US crops:

- **Spreading monocultures and genetic uniformity.** When a few successful crop varieties replace the great diversity of crops and types found in farmers' fields, vast acres of a genetically uniform crop become more vulnerable to pests.
- **Genetic changes within pathogens or insect pests.** Pathogens or insect pests that mutate to overcome a crop's innate resistance or to escape the effects of fungicides and pesticides, together with monoculture conditions, heighten the risk that such novel pests could rapidly spread, causing great losses in crop yield and quality.
- **Increased risk of introduced pests.** The increased volume of global travel and of food imports heightens the risk of accidental introductions of plant pests. In addition, there is growing concern about the threat of intentional introductions.
- **Increasingly volatile weather and climate change.** Prolonged droughts, heavier rainfall, or changes in temperatures may present new challenges to crops and allow pests to expand into new regions.

Overall, a failure to maintain the genetic diversity in crop species could have staggering consequences for both US and global agriculture. Diseases of current and potential concern in major US crops include the following:

- A disease caused by a rust fungus that is now invading US soybean fields. The disease can cause yield losses of up to 80 percent, threatening what was in 2003 an \$18 billion soybean harvest.
- Potato blight of the kind that caused the Irish potato famine has re-emerged to threaten the American potato industry, where it is already destroying \$400 million worth of potatoes each year.
- US corn production, worth \$30 billion annually, is facing multiple assaults from several different diseases, including some that recently have emerged abroad and appear capable of crossing borders with ease.
- A new strain of rice blast disease appears to be emerging with the ability to overcome the resistance that current rice varieties have to this disease.

- Fusarium head blight, or scab, has already caused \$3 billion in damage to the US wheat and barley industries. New sources of resistance are needed to protect these crops.
- The \$1.8 billion US apple industry is vulnerable to destructive bacteria causing the disease called fire blight, which is now showing resistance to pesticides that once controlled it.
- All types of citrus cultivated in the U.S., where they generate \$2 billion annually, are vulnerable to diseases such as citrus canker and citrus blight.

In each of these cases, plant scientists are searching through domestic and international crop diversity collections to find genetic resistance to these diseases. Once those sources are identified, breeders can begin developing new disease-resistant crop varieties.

But the importance of crop diversity to US agriculture goes beyond the fight against disease. Farmers today also must have access to new crops and more diversity within each crop family if they are to stay abreast of a rapidly evolving market.

US agriculture needs global collections of crop diversity to improve the health value of foods and to meet changing consumer demand.

The United States Department of Agriculture (USDA) has noted several major food trends in America today: higher incomes are spurring demand for higher quality foods; an aging population wants healthier foods; increasing numbers of people want organically-grown foods; and an increasingly diverse population desires foods used in ethnic dishes. In each case, satisfying consumer demand will depend on access to the genetic diversity of crops.

For example, consumer interest in health has sent farmers in search of crop varieties that have enhanced nutritional value, and for varieties of newly popular exotic produce that are adaptable to US growing conditions. Maintaining the rapid growth of organic food production in the U.S.—now an \$11 billion industry—is especially dependent on genetic variation. When disease or pests threaten, strict prohibitions on using pesticides or genetically modified varieties make naturally obtained disease resistance one of the few alternatives available to organic farmers.

The United States has a stake in conserving global crop diversity as a means to help solve the related problems of economic development, hunger, and environmental quality in the developing world.

A United Nations (UN) report recently cited the importance of genetically improved crop varieties and native crop genetic resources as a way to boost production on subsistence farms, where half of the world's 800 million chronically hungry people now reside.

Crop varieties stored in genebanks are also playing a prominent role in re-invigorating agricultural production in areas hit by the 2004 tsunami and in post-

war Afghanistan and Iraq, just as they did in Cambodia following the ravages of the Khmer Rouge and in Rwanda following that country's ethnic genocide.

There is clearly a large demand for the services provided by genebanks, whether to maintain the economic vitality of US agriculture, meet constantly evolving market demands, or, by spurring recovery in areas suffering from war or natural disaster, to enhance global security.

But international crop diversity collections are under stress, and global capacity is not keeping pace with demands. For example, of the 1,460 facilities housing collected materials, only 35 meet international standards for long-term storage. In 1996, the UN's Food and Agriculture Organization (FAO) reported that up to 1 million of the 5.4 million samples held in the world's collections are degenerating, and that number has increased in the years since. Many collections are losing vast amounts of genetic material through mundane but devastating events such as power outages, a lack of resources to regenerate decaying seed in old collections, and disease spreading within collections.

Broader recognition of the important role played by crop diversity collections is needed to spur a concerted effort directed toward their conservation and use. With all the modern pressures working to diminish crop diversity, now is also a time of exciting scientific discoveries that can greatly improve the performance of genebanks in assisting global agricultural production. In particular, the molecular tools of plant biotechnology allow scientists to screen plant samples for genes of interest and to then isolate this material and use it to breed new, improved varieties.

Conservation is forever.

Ultimately, the responsibility for safeguarding the world's collections of crop diversity should fall to governments, international organizations, and the private sector acting in partnership to conserve this international public good in perpetuity. The scope of the task, its long-term nature, and the need for genebanks to be easily accessible to researchers and farmers all require strong public involvement.

A solution is at hand. Established in 2004, the Global Crop Diversity Trust is one vehicle for sustaining this partnership. The Trust is an independent international organization with the goal of assuring the long-term security of the world's most important collections of crop diversity. It is the product of a partnership between the FAO and the 15 Future Harvest Centers of the Consultative Group on International Agricultural Research (CGIAR). The Trust is building a \$260 million endowment, through donations from national governments, philanthropic foundations, and private corporations, the interest income of which will be used to fund the costs of crop diversity conservation into perpetuity, as well as to salvage collections at risk and build the capacity of developing countries to manage their collections.

In an age when all agriculture is interconnected—whether by trade, the exchange of genetic resources, or the spread of disease—the economic vitality of US

agriculture and, indeed, of global food security are inextricably linked to the fate of crop genebanks around the world. While crop genebanks may seem to be obscure facilities that are largely invisible to the general public, the effects of their degradation, if allowed to continue, will soon be apparent to us all.

Since crop genebanks around the world are so critical for sustaining the US food supply system and a major sector of the US economy, full support for the Global Crop Diversity Trust and its conservation goals is essential.



Soybeans are grown today on more than half of United States' farmlands. Yet, a hundred years ago, they were virtually unheard of, raised only by a handful of innovative farmers. These seeds, from the National Soybean Germplasm Collection housed at Urbana, Illinois, show a wide range of colors, sizes, and shapes.

Introduction

In November 2004, Louisiana soybean farmers encountered something new in their fields: leaves infected by fungus spores that had blown in on hurricane winds earlier that year. The soybean “rust” raises pustules on the undersides of the leaves and ultimately defoliates the plants. Never before seen in the United States, within months the fungus was identified in ten states. Scientists suspect it is overwintering on roadside weeds in southern states, and will soon spread northward on the moist winds of spring.

Soybean farmers from the Mississippi Delta to Appalachia, from the Great Plains to the Great Lakes are gearing up for what might lie ahead. If undetected and untreated, the rust can ruin a field in two weeks, and farmers can lose up to 80 percent of yield. In 2003, the US soybean harvest was worth \$18 billion. No one knows what it will be worth five years from now. In Brazil, the rust spread to three-quarters of the country’s soy-growing regions in just three years. The US Department of Agriculture (USDA) conservatively estimates that losses in the United States could reach up to \$1 billion annually.

All commercial varieties of soybean are susceptible to the disease. Plant scientists have therefore mounted a massive search for non-commercial soybean varieties that are resistant, and can be used to breed new commercial varieties. Scientists have already screened 16,000 seed samples that are conserved in US crop genebanks by the USDA. While they have identified some varieties with weak resistance, they have found none that are fully immune. So plant scientists are now broadening their search, realizing that the best disease-fighting varieties might well be wild relatives of soybean heralding from China, Taiwan, Australia, or other countries of the region where farmers first domesticated soybean.

The potential crisis for soybean farmers highlights a critical reality: in today’s world: all agriculture is interconnected. And, although the U.S. has among the world’s most extensive collections of crop diversity, there is no guarantee that it



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The National Center for
Genetic Resources
Preservation, Fort Collins

holds the necessary resistant varieties for fighting new or re-emerging pests and plant diseases that lay siege to America's farmlands.

The problem reaches far beyond the vast fields of soybean. Nearly every major US food or fiber crop is battling pests and diseases against which it has no resistance: corn, wheat, potatoes, rice, oranges, apples, grapes, and plums among them. For all of these crops, the difference between devastation—as occurred in the Irish Potato Famine in the mid-1800s—and resilience may be found in crop diversity collections around the world.

However, many of these collections, especially in developing countries, are themselves in dire straits, at times lacking the resources to keep refrigeration running and to keep the crop collections alive. Many are unable to carry out basic functions, such as regenerating seed to ensure its viability, or cataloguing collections to make them useful for farmers and breeders.

Crop genebanks, or “crop diversity collections,” store samples of crops and their thousands of varieties, each one of which has unique genetic traits. In addition to traits for fighting disease, genebank accessions hold the traits for increased yield and nutritional value, and for adjusting to environmental changes such as increased drought or high-salt soils. These collections may be in the form of seeds, cuttings, plant cells in test tubes, or trees and vines planted in a field. Yet they all contain the genetic diversity essential for breeding new crop varieties that sustain and improve food production. Crop diversity collections contain the raw material of agriculture, without which production would catastrophically decline. (See Box 1: Crop Genebanks Around the World.)

Beyond the borders of the United States, crop diversity collections are key to protecting the future food supply for all nations, but especially the developing nations that struggle to overcome hunger and malnutrition. These countries desperately need improved varieties of their native crops, with better yields and higher nutritional value. Many countries would also benefit from high-yielding

Genebanks Around The World

box 1

THE FAO estimates that roughly 1,460 genebanks worldwide together maintain more than 5.4 million samples. Most are government-operated. Below is a brief look at the holdings in some of the world's major genebanks, including: 11 international genebanks coordinated by the Consultative Group on

International Agricultural Research (CGIAR); 15 major national genebanks; and 5 major regional genebanks. (For a detailed profile of the US National Plant Germplasm System see Box 5)

CGIAR Collections*

The CGIAR is a strategic alliance of countries,

international and regional organizations, and private foundations supporting 15 international agricultural centers, which work with national agricultural research systems, civil society organizations, and the private sector. The CGIAR's mission is to achieve sustainable food security and reduce poverty

in developing countries through scientific research and related activities in the fields of agriculture, forestry, fisheries, policy, and environment. CGIAR genebanks hold their accessions in-trust for the world community based on agreements with the FAO.

CENTER	CROP	NUMBER OF ACCESSIONS
International Center for Tropical Agriculture (CIAT), Cali, Colombia	Cassava	5,728
	Forages	18,138
	Bean	31,718
International Maize and Wheat Improvement Center (CIMMYT), Mexico	Maize	20,411
	Wheat	95,113
International Potato Center (CIP), Lima, Peru	Andean Roots & Tubers	1,112
	Sweet Potato	6,413
	Potato	5,057
International Center for Agriculture in the Dry Areas (ICARDA), Aleppo, Syria	Barley	24,218
	Chickpea	9,116
	Faba Bean	9,074
	Wheat	30,270
	Forages	24,581
	Lentil	7,827
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India	Chickpea	16,961
	Groundnut	14,357
	Pearl Millet	21,250
	Pigeonpea	12,698
	Sorghum	35,780
	Minor Millets	9,050
International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria	Bambara groundnut	2,029
	Cassava	2,158
	Cowpea	15,001
	Soybean	1,909
	Wild Vigna	1,634
	Yam	2,878
International Livestock Research Institute (ILRI), Nairobi, Kenya	Forages	11,537
International Plant Genetic Resources Institute (IPGRI) Maccarese, Italy	Musa	931
International Rice Research Institute (IRRI), Los Banos, Philippines	Rice	80,617
Africa Rice Center (WARDA) Cotonou, Benin	Rice	14,917
World Agroforestry Centre (ICRAF), Nairobi, Kenya	Sesbania	25
TOTAL		532,508

*Source: CGIAR

Major National Collections, 1996*

COUNTRY AND INSTITUTE	NUMBER OF ACCESSIONS
USA, National Plant Germplasm System (2005 data)	462,543
China, Institute of Crop Germplasm	300,000
Russian Federation, VIR (N.I. Vavilov Institute)	177,680
Japan, National Institute of Agrobiological Resources	146,091
India, National Bureau of Plant Genetic Resources	144,109
Korea, Rural Development Association	115,639
Germany, Institute for Plant Genetics and Crop Plant Research	103,000
Brazil, National Center for Genetic Resources	60,000
Canada, Plant Genetic Resources Center	100,000
Germany, Federal Research Center of Agriculture	57,000
Italy, Institute of Germplasm	55,806
Ethiopia, Biodiversity Institute	54,000
Hungary, Institute for Agrobotany	45,833
Poland, Plant Breeding and Acclimatization Institute	44,883
Philippines, National Plant Genetic Resources Laboratory	32,446

*Source: FAO

Major Regional Collections, 1996*

CENTER	NUMBER OF ACCESSIONS
Asian Vegetable Research and Development Center, Taiwan Province	37,618
Center for Tropical Agricultural Research, Costa Rica	35,056
Nordic Gene Bank, Sweden	27,308
Southern African Development Community-Plant Genetic Resources Center, Zambia	5,054

*Source: FAO

non-native crops adapted to their own growing conditions. Today, as the United States continues to provide leadership in an international effort to spur development and tackle poverty and disease, the role of a healthful, stable and affordable food supply is abundantly clear. With the world population expected to reach 9.8 billion by 2050, the FAO projects that world food production will need to increase 75 percent in the same time frame. Conserving collections of crop diversity is needed to secure the very base of the food supply.

It is in the domestic and foreign policy interests of the United States—and consonant with American values—to support collections of crop diversity, both

through the US government's National Plant Germplasm System (NPGS), and worldwide, through such institutions as the US Agency for International Development, the CGIAR, FAO, and the Global Crop Diversity Trust.



The strawberry is one of many crops currently susceptible to a number of pathogens. Collections of crop diversity contain the raw material farmers need to stay ahead of pests and diseases.

Fighting Old and New Diseases in Crops

US agriculture needs the collections of crop diversity around the world to combat pests and diseases and to adapt crops to environmental changes.

Global crop losses due to agricultural pests are estimated at 30-40% of potential yield. In the United States, pests and plant diseases are conservatively estimated to exact a toll of \$20-33 billion each year nationwide.¹

While plant pathogens are older than agriculture itself, several recent trends, noted below, increase the risk of an unforeseen pest or disease causing widespread damage to US crops.

- **Spreading monocultures and genetic uniformity.** The advent of monocultures, where a few successful crop varieties replace the great diversity of crops and types found in farmers' fields, means that a particularly virulent pathogen can spread rapidly through a genetically uniform crop, wreaking havoc. While monocultures dominate the agriculture of most developed countries, they are also becoming more common in parts of Latin America, Africa and Asia, leading to an accelerated loss of diversity in the field. Meanwhile, wild relatives of crops are being lost as urbanization and deforestation encroach upon their habitats. This loss of diversity in the field and in the wild means that unless there is a conscious effort to collect and conserve crop diversity in genebanks, it will be permanently lost, robbing future agriculture of invaluable options.
- **Genetic changes within pathogens or pests.** Resistant crop varieties may succumb to new mutant forms that rapidly spread within a crop field and beyond, causing great losses in crop yield and quality. This is not uncommon, especially in monoculture conditions, and thus requires the rapid replacement of a susceptible variety with one that has resistance. That

can only be done with access to gene resources, a vigorous search for new resistance, and transfer of that resistance to an adapted variety.

- **More volatile weather and climate change.** Farmers are concerned about the prospect of an increasingly variable or volatile climate, with possible changes in the frequency and intensity of droughts, flooding, and storms, leading to new levels of erosion and water-logging in some areas, drought or desertification in others. While these changes alone put additional stress on crops, they also open up the possibility that agricultural pests may expand their range, or proliferate in the favorable conditions brought about by changes in climate.
- **Increased risk of introduced pests.** The volume of global travel and of food imports increases each year, heightening the risk of accidental introductions of plant pests. Already today, there are more than 2,000 species of non-indigenous insects and mites in the conterminous U.S., and non-native insects are responsible for an estimated \$14 billion in annual crop losses.² In addition to accidental introductions, there is the threat of intentional introductions. Based on this concern, the US government in 2004 issued a presidential directive that establishes a National Plant Disease Recovery System charged with “responding to a high-consequence plant disease with pest control measures and the use of resistant seed varieties within a single growing season to sustain a reasonable level of production for economically important crops.”

Many crops are especially vulnerable to diseases due to their narrow genetic base—in part a product of their history as introductions from distant areas of crop diversity; in part a result of plant breeding methods and farming practices. Only a handful of crops grown in the US—sunflower and strawberry among them—were domesticated from wild plants native to the United States. The vast majority evolved in far-flung “centers of origin,” where farmers selected them for traits to suit their needs and carried them along as they moved from place to place.

In addition, farmers today tend to rely on a handful of high-yielding varieties at any given time, further narrowing a crop’s genepool. Therefore, the genetic diversity of most major US crops represents only a tiny fraction of the total genetic diversity available in that species.

This is true for soybean and corn, the two largest crops produced in the US. All US soybean varieties can be traced back to a dozen strains from a small area in northeastern China.³ And while the US produces about half of the world’s corn, this vast production is based on using less than 5 percent of the maize diversity available worldwide.

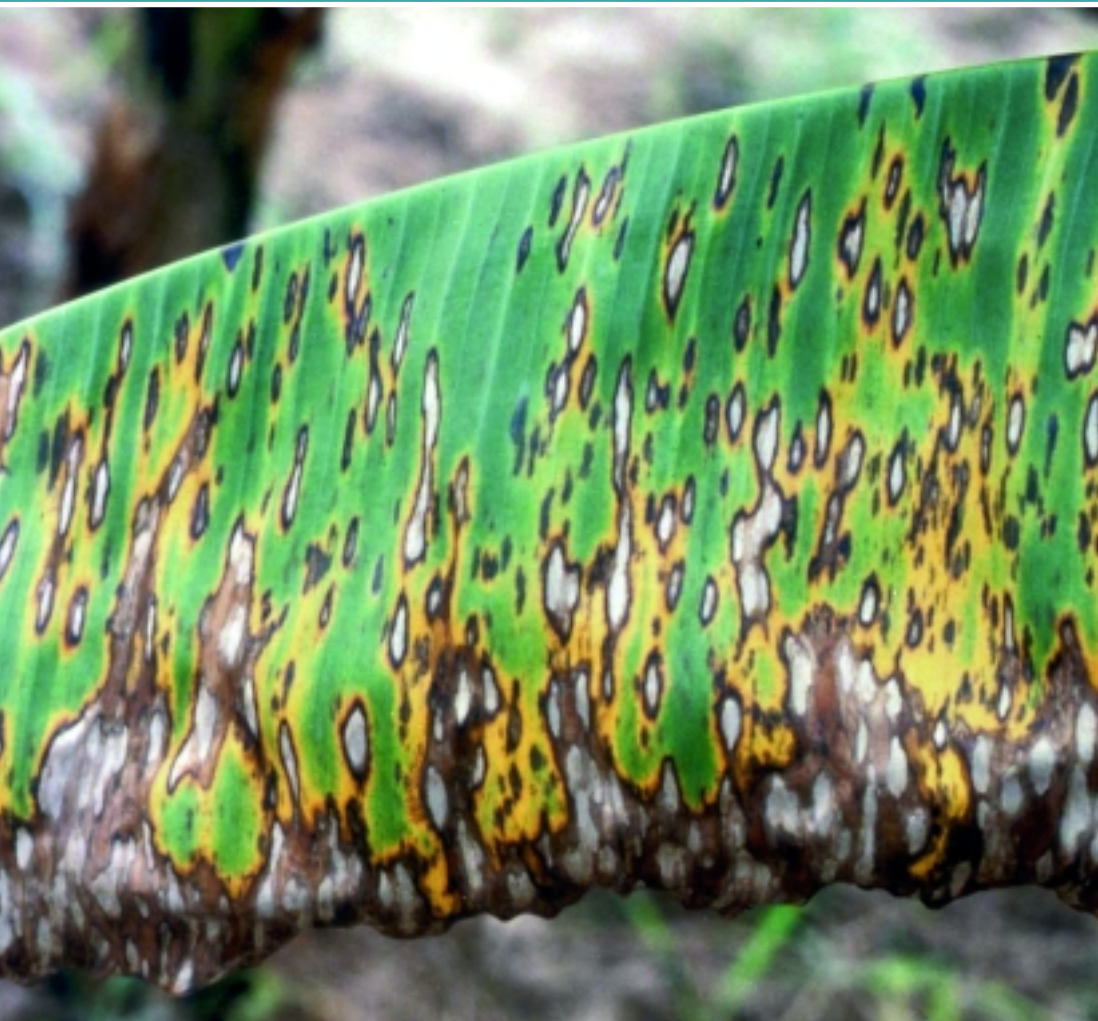
In the past, plant breeders have successfully drawn on genetic variation found in crops grown in all corners of the globe to bolster US and world agriculture, often staving off disaster. Tomato, for example, has benefited from its wild relatives, native to the Andean region of South America. There are at least 44 diseases of tomato to which wild species are resistant. About half of these resistance traits have already been transferred to cultivated tomato. Resistance to a particular disease is

often traced to a small number of plants in a very specific region. As examples, the resistance to barley yellow dwarf virus came from the highlands of Ethiopia, and resistance to the Russian wheat aphid (now a problem in US-grown wheat) hails from Iran and surrounding countries.

During the early 20th century, rapidly mutating wheat stem rust caused widespread devastation in North America. In 1950, a particularly virulent race, 15B, devastated the durum wheat crop, but US and Canadian scientists discovered resistance to that fungus—and by breeding resistant varieties, they have staved off damage for more than 40 years. Working in Mexico during the 1940s, plant pathologist Norman Borlaug and his colleagues painstakingly crossed five established Mexican wheat varieties with a dozen imported ones, ultimately to select many improved wheat varieties that resisted stem rust. That work led to a worldwide wheat production boom. Eventually, Borlaug’s team bred and distributed more than 100 wheat varieties to countries around the world.

But despite all the progress of the past, there is no pause in the pace at which new pest-and-disease-resistant varieties must be developed. Fortunately, the tools of molecular biology offer new technologies to crack the potential of plant varieties around the world. Genetic maps of both crops and their pathogens speed the search for genes that confer resistance, and enable scientists to identify whole areas of chromosomes important to improving yield and other complex traits important to agriculture. Other techniques, such as embryo rescue, make it easier to cross wild species with cultivated ones. These techniques do not require the introduction of recombinant DNA to the plants (i.e. GMOs), and have been used for many years to breed crops with pest resistance.

Regardless of the approach to crop breeding, whether through classical crosses repeated over decades in a field, or by using molecular tools to identify and transfer needed traits, collections of crop diversity allow plant breeders to strategically broaden the genetic base of crops, and to strengthen their resilience and resistance.



A major threat to banana production worldwide is the fungus causing black sigatoka, which can reduce yields by 30 to 50 percent, and causes the fruit to ripen unevenly making it difficult to export.

Select Crops and Diseases of Concern

Today, every major crop grown in the US faces pests and diseases against which it has little to no genetic resistance. In addition, there are a plethora of crop pathogens in various parts of the globe that have not yet affected US crops, but which, like soybean rust, could be just a windstorm away. Below are some examples of diseases and pests that are presently or potentially devastating to crop production and profitability for important crop groups in the US.



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US agriculture needs crop diversity to fight pests and diseases. The maize weevil shown here destroys crops such as corn, wheat, and rice.

Corn

CENTER OF ORIGIN AND DIVERSITY

Corn was first domesticated in Mexico around 3500 B.C., later in the highlands of Peru, and still later in North America.

ECONOMIC VALUE

Annual value of US production: \$30 billion

SELECT DISEASES OF CONCERN

- **Gray Leaf Spot** (caused by *Cercospora zea-maydis*)
This fungus causes one of the most significant yield-limiting diseases of corn worldwide. It poses a serious threat to corn production in portions of the eastern United States and the mid-west Corn Belt. The disease weakens plants and disease lesions can block plants from using the sugars required for ears of corn to develop fully. Changes in tillage practices have led to an increase in disease severity over the past 25 years.

While some hybrids are less susceptible to the disease, no available commercial varieties of corn are immune to gray leaf spot. Plant scientists are still seeking genetic sources of resistance in corn varieties.
- **Anthracnose Leaf Blight** (caused by *Colletotrichum graminicola*)
As this disease progresses, lesions expand to blight entire leaves and finally

cause a devastating stalk rot. The only varieties with known resistance are not high yielding, so plant scientists continue to search for sources of strong resistance that can be bred into US crops. Researchers at North Carolina State University are screening varieties that hail from Central America, Brazil and Thailand for strong resistance. Since resistance to this pathogen is probably conferred by a number of genes, breeding high yielding, resistant varieties will be challenging.

- **Mal de Río Cuarto** (virus family Reoviridae, genus *Fijivirus*)⁴
Not yet present in the United States, this virus is prevalent in Western Argentina and spread by tiny insects called leaf hoppers. US corn varieties have very little resistance to Mal de Río Cuarto, which stunts the plants and reduces the size of corn ears. Although resistance is known to exist in a South African variety, it is a white corn and not suited to the US growing season. Plant biologists fear that the tiny leaf hopper vectors of Mal de Río Cuarto could easily hitch a ride undetected in airplane cargos. In addition, because the climate in the Southern US is similar to that in western Argentina, the disease could become established and thrive. Unsettling evidence of this came when a US corn variety grown in Argentina was decimated by the disease. Finally, Mal de Río Cuarto is of concern because it has the benefit of a wide range of alternate hosts, including the most common lawn grasses grown in the southeastern US.
- **Downy mildew** (caused by multiple species of *Peronosclerospora*)
Two strains of the downy mildew fungus are known. A milder strain is found in Venezuela and the Caribbean, and has been occasionally detected in Louisiana. The second strain, not currently in the US, is a threat across 94 million acres of corn grown in Asia. The fungus covers leaves, blocking photosynthesis. Epidemics simply wipe out the corn they infect. Plant scientists say that US corn lines probably have little resistance to this strain. While farmers in Southeast Asia grow resistant varieties, those varieties are not adapted to the US, and plant scientists expect that it would take a minimum of eight to ten years to breed resistance into varieties that would be suitable to US conditions.⁵



© USDA-ARS, Scott Bauer

Potatoes infected with late blight are purplish and shrunken on the outside and corky and rotted on the inside.

Potato

CENTER OF ORIGIN AND DIVERSITY:

The highlands of South America, Central America, and parts of North America

ECONOMIC VALUE

Value of US production (2002): \$3 billion

SELECT DISEASES OF CONCERN

- **Potato late blight** (caused by *Phytophthora infestans*)
The fungus responsible for the Irish Potato Famine in 1845, which killed one million people and sent emigrants scrambling for distant shores, today is re-emerging as a major problem that costs American farmers roughly \$400 million in lost crops every year. All commercially cultivated potato varieties in the US, across 1.5 million acres, are highly susceptible to late blight, which turns potatoes into a rotting mass of vegetation.

While extensive use of fungicides is temporarily controlling this pest at a cost of up to \$250 per acre, resistant potato varieties are still badly needed. In 2003, scientists discovered a blight resistance gene in a wild Mexican potato. They have since moved the gene into domesticated potatoes, and they are now conducting field experiments to prove its value for US farmers.

- **Numerous cyst nematode (worm) species**

One such species, *Globodera pallida*, is widespread in Europe and parts of South America, but is not currently found in the U.S. Breeding for resistance is ongoing in anticipation of the possible entry of the pest into the U.S.

- **Brown rot or bacterial wilt** (caused by *Ralstonia solanacearum*)

All US potato varieties are likely to be quite susceptible to cool-season adapted races of this pathogen. Thus far breeding for resistance has not been successful.

- **Phytoplasma-like organisms**

These infectious agents lack cell walls of their own, and invade the cells of potatoes, causing tuber disorders and leaf abnormalities. They appear to have spread from Mexico through Texas and into the Pacific Northwest in recent years. Varietal resistance is not yet known.

- **Tobacco rattle virus**

This virus, which causes corky ringspot in tubers, has become more widespread and serious. Screening for resistance is under way in Florida and Idaho.



© USDA-ARS, Keith Weller

US long grain rice. The U.S. is the world's second largest rice exporter, making up about 20 percent of total international trade.

Rice

CENTER OF ORIGIN AND DIVERSITY

A broad arc from eastern India through Myanmar, Thailand, Laos, northern Vietnam, and into southern China. The earliest evidence of domestication comes from a site in Thailand that is at least 6,000 years old.

ECONOMIC VALUE

Value of US production (2002): \$1 billion

SELECT DISEASES OF CONCERN

- **Rice blast** (caused by *Magnaporthe grisea*)

Rice blast, a worldwide fungal disease, has repeatedly struck southern US rice crops. It first came to California's important rice crop in 1996. To fight the fungus, scientists have bred blast-resistant rice varieties with genes transferred from rice obtained from China, the Philippines, and Vietnam. However, there is evidence that a virulent blast strain is already evolving the ability to overcome this resistance. Strategically broadening the genetic base of released cultivars could protect the US rice crop.

- **Rice sheath blight** (caused by *Rhizoctonia solani*)

Sheath blight infection by a fungus can prevent the flow of water and nutrients to the grain, causing premature plant death. In some states, such as Missouri, the severity of the disease has increased in recent years in part due to the use of highly susceptible varieties.

Plant scientists with the USDA and 14 institutions across the US have just launched a project to develop better resistance to sheath blight. The USDA-funded project, called RiceCAP, will screen accessions in the US National Small Grains Collection (94 percent of which originated abroad), and then search for resistance in additional material from Asia and Africa, and wild relatives of rice.

■ **Bakanae** (caused by *Gibberella fujikuroi*)

This scourge, long prevalent in Japan, first arrived in California in 1999. It is also called “Foolish seedling disease,” because it causes infected plants to elongate rapidly, fall over, and die. In Japan, yield losses can be 20 to 50 percent. The fungus is primarily seedborne, so, to protect their crops, southern US rice-producing states have instituted quarantines against rice seed imported from California. For now, California growers treat the disease by immersing seed in household bleach, but plant breeders are searching for sources of genetic resistance.



© USDA-ARS, Jacolyn Morrison

Close-up of wheat head infected with scab, the most devastating disease of wheat and barley to date.

Wheat

CENTER OF ORIGIN AND DIVERSITY

Southwest Asia, near the Fertile Crescent, extending from the Mediterranean coast in the west to the Tigris-Euphrates plain in the east.

ECONOMIC VALUE

Value of US production (2002): \$5.6 billion

SELECT DISEASES OF CONCERN

■ **Fusarium head blight (FHB), also known as scab** (caused by *Fusarium graminearum* and other species)

FHB, the most devastating disease of wheat and barley known, reduces yield and grain quality, and produces toxins that make the grains unfit for milling or malting. Scab infects other small grains, corn, and grasses as well.

Although a known problem for over a century, scab hit the US hard in the 1990s, and now threatens the wheat industry in at least 22 states. Between 1990 and 2002, US wheat and barley farmers in the upper Midwest lost over \$3 billion to the disease. In 2003, during a cool, wet spring, an epidemic crippled the Southeast wheat industry, with yield dropping by nearly 60 percent in Maryland alone. No commercial chemical sprays successfully control wheat scab, and there is little resistance in the common US wheat varieties.

Plant breeders have searched for resistance in Chinese varieties since farmers in China’s Yangtze River Valley first confronted the disease in the 1940s, and have been breeding resistant varieties over many years. The strongest resistance thus far is from the Chinese variety, Sumai 3. In the early 1980s, agricultural company Pioneer Hi-Bred International began a long-term breeding effort to integrate Sumai 3 scab resistance into varieties suited to US conditions. In 2000, Pioneer released the first wheat variety with high scab resistance. Nonetheless, scab remains a very serious problem.

- **Russian wheat aphid** (*Diuraphis noxia*)
The Russian wheat aphid, a major pest of cereal crops, first appeared in US crops in 1986, spurring scientists to develop resistant varieties of wheat and barley. Then, in Colorado in 2003, a possible new biotype of the Russian wheat aphid emerged, which appears to have overcome the genetic defenses of many existing wheat and barley lines. Since the aphid is known to originate in West Asia, scientists are now evaluating large collections of wheat from that region for resistance.
- **Wheat rust** (caused by several *Puccinia* rust pathogens)
Fungal rusts—such as stem, stripe, and leaf—pose ongoing problems for world agriculture. Although the fight against stem rust in the 1950s yielded many disease-resistant varieties of wheat, in 1999, Uganda reported a newly virulent type of stem rust. In the United States, stripe rust (caused by *Puccinia striiformis*) devastated wheat crops in the Pacific Northwest in the 1960s and again in 2003-4. Repeated epidemics in the central Great Plains have occurred since the late 1990s. Fungicide applications may provide control, but at a high cost and with uneven results. Resistant cultivars provide a much better alternative for controlling the stripe rust and other rust diseases. Current wheat varieties offer varying levels of resistance, however, and scientists are actively pursuing new resistance genes from global sources, including collections in Australia, Europe, and the International Maize and Wheat Improvement Center in Mexico (CIMMYT).



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Apple

CENTER OF ORIGIN AND DIVERSITY

Kazakhstan, Central Asia

ECONOMIC VALUE

Annual value of US production: \$1.8 billion

SELECT DISEASES OF CONCERN

- **Fire blight** (caused by *Erwinia amylovora*)
This bacterial disease infects roughly 75 different plant species, including the cultivated apple, pear, and quince. Many favorite apple varieties are highly or moderately susceptible to fire blight, including Golden Delicious, Granny Smith, Gala, and Jonathan.

Growers rely heavily on chemical sprays of antibiotic pesticides to ward off fire blight, and the Environmental Protection Agency (EPA) estimates that over 300,000 pounds of such pesticides are applied to fruit trees and other crops every year in the US. However, in recent years, fire blight has become increasingly resistant to two major antibiotic pesticides used to protect apple crops, streptomycin and oxytetracycline.

To protect commercial apple trees from pesticide-resistant blights and scabs, growers will need to identify and transfer genes from old cultivars and wild apple species into the cultivated apple.

The Environmental Protection Agency estimates that over 300,000 pounds of antibiotic pesticides are applied to fruit trees and other crops every year. Crop diversity can help supply traits that could reduce the need for pesticides.

- **Apple scab** (caused by *Venturia inaequalis*)

This fungal disease occurs throughout the world, especially in cooler apple-growing regions. In the United States, apple scab is a major economic problem for the Mid-Atlantic region, in particular. The fungus blemishes young fruit and leaves. Once established, the fungus can overwinter in orchards, and re-infect apples the following growing season.

Most major apple cultivars are susceptible to apple scab. But USDA-funded expeditions have collected 1,200 apple accessions in Kazakhstan. These varieties are now conserved in genebanks and being grown in the field. Over 40 percent of the seedlings have been found to resist apple scab. Further testing continues on these trees as they mature. Scientists continue hunting for apple scab resistance genes in Kazak collections by screening them both for scab resistance traits and for the presence of DNA markers associated with specific scab resistance genes. Unfortunately, rare apple collections in Kazakhstan are in imminent danger of loss due to insufficient resources to maintain the orchards. (See “A System Under Stress,” below.)

- **Cedar apple rust** (caused by *Gymnosporangium juniperi-virginianae*)

Cedar apple rust fungus requires two hosts: apple or crabapple and an alternate host, such as cedar or juniper trees. Cedar apple rust is of major importance in southern New England, in particular. The fungus blotches leaves and fruit with yellow and orange spots.

In most cases, apple and crabapple trees are not seriously damaged by cedar-apple rust, but severe loss of leaves can shrink fruit size and weaken trees. Cultivar susceptibility varies. Some economically important varieties, such as Golden Delicious, have only intermediate resistance to the fungus. To find resistance to cedar apple rust, scientists are currently evaluating 200 apple accessions from the NPGS collection, as well as 11 species from Central Asia, China, Turkey, Russia, Armenia, and Germany.



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Citrus

CENTER OF ORIGIN AND DIVERSITY

Southeast Asia. Citron, lemon, lime, sweet orange, sour orange, pumello, mandarin, kumquat, and trifoliate orange all originated in this area. Christopher Columbus first brought the orange to America.

ECONOMIC VALUE

Annual value of US production: \$2 billion

In an average year, the U.S. may export 10 times more citrus tonnage than it imports.

SELECT DISEASES OF CONCERN

- **Citrus Canker** (caused by *Xanthomonas axonopodis* pv. *citri*)

In the early 20th century, the agricultural industry worked hard to remove citrus canker, a feared bacterial disease, from the US landscape. Although the disease was declared eradicated from the U.S. in 1947, it has since resurfaced multiple times, and is currently spreading through Florida’s orange groves. Infected trees ultimately produce no fruit at all. Citrus canker is highly contagious and can be spread rapidly by rain.

Citrus are native to southeast Asia (northeastern India, southern China, and the Indochinese peninsula). Christopher Columbus first brought the orange to the United States. US orange production is now the second largest in the world, behind Brazil.

The USDA is spending \$40 million a year in an attempt to eradicate this pathogen once again by destroying infected and exposed trees in orchards and home gardens. As of March 2002, more than 1.56 million commercial trees had been removed or cut back, yet the infected area continued to expand. Citrus species vary in their resistance to the disease, but all commercial orange varieties in Florida are moderately-to-highly susceptible. In a race against time, plant scientists are examining the susceptibility or resistance of various populations of citrus rootstocks and cuttings used for grafting.⁶

- **Citrus variegated chlorosis (CVC)** (caused by *Xylella fastidiosa*)
This bacterial disease was first discovered in Brazil in 1987. It infects almost all sweet orange cultivars. It has not yet reached the United States.
- **Citrus blight** (no causal agent has been identified)
The cause of this disease has never been discovered, yet scientists know it is an infectious agent. Citrus blight sickens and eventually kills trees, and has been an important disease in Florida for over 100 years. It was reported in Brazil in the 1980s and now impels the removal of nearly 10 percent of trees from production annually.

To find citrus varieties resistant to these diseases, researchers are strategically evaluating, coordinating, and building genebank collections. USDA scientists recently have used molecular markers to identify a core collection of 50 accessions in the NPGS system that represent about 90 percent of the genetic diversity identified in citrus. While these plants may hold the promise of a prosperous future, a number of categories of citrus are not represented in the US collection, including wild types that may have valuable genetic variation.⁷



© USDA-ARS, Jack Dykinga

U.S. production of stone fruits—such as peaches, plums, prunes, apricots, cherries, nectarines, and almonds—is worth over \$2 billion.

Plums and Other Stone Fruits

CENTER OF ORIGIN AND DIVERSITY

Origin of plum: Western Asia, in particular the Caucasus Mountains that border the Caspian Sea.

ECONOMIC VALUE

Annual value: US production of stone fruits—such as plums, peaches, apricots, cherries, nectarines, and almonds—is worth over \$2 billion.

SELECT DISEASES OF CONCERN

- **Plum pox or Sharka** (caused by a potyvirus)
This dreaded virus blotches stone fruit and eventually, as the infection develops, prevents trees from bearing any fruit at all. In 1999, growers first discovered that plum pox had arrived in the US, via a Pennsylvania orchard. Since then, efforts to eradicate and quarantine crops struck by plum pox has cost the US over \$20 million.

Unlike fungal or bacterial plant pathogens that can be controlled chemically, antiviral treatments to prevent or control plum pox in the field are

unavailable. Control of aphids has had some, but not total effect. Breeders are attempting to develop plum pox-resistant stone fruits. But progress is slow, both because plum pox virus has several strains and because resistance is a complex trait, involving more than one gene.

Deciphering the genetic code of plum and related species would speed the breeding process, and scientists have made major strides in that direction. In 2004, they published a genetic “reference map” of *Prunus* species, essentially identifying unique genetic characteristics that may indicate the position of 28 major genes, including those that help identify resistance to plum pox, certain nematodes, and powdery mildew. In their work, the researchers called exotic germplasm “an enormous gene pool...available for fruit breeding.”



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The sixteenth of an inch long Silverleaf whitefly, *Bemisia argentifolii*. Criniviruses are transmitted by whiteflies.

Emerging Diseases Affecting Many Crops

■ Criniviruses (Closteroviridae)

Criniviruses are an emerging group of virus species, most of which have been identified within just the past decade.

This group of viruses, transmitted by whiteflies in the greenhouse and field, poses a growing threat to major fruit and vegetable crops, including tomato, strawberry, sweet potato, lettuce, beet, cucumber, pumpkin, and others. When criniviruses strike, a plant’s leaves may turn yellow and brittle, and the plant may grow slowly, be more susceptible to stress, and die early.

Along the west coast of North America, these viruses are exploding as whitefly populations boom on a steady supply of favored crops and weeds, as well as a moderate climate. And the damage is significant, in both greenhouses and fields. When tomato infectious chlorosis virus, or TICV, was first identified in 1993 in Orange County, California, the virus cost the region \$2 million in that year alone.

To manage criniviruses, growers currently spray insecticides to control whitefly populations. But this control method is inefficient. For one thing, whiteflies can transmit viruses before being killed by an insecticide. Secondly, in the greenhouse, plants do not appear sickly until 3-4 weeks after whiteflies transmit a crinivirus—and by that time, spraying cannot prevent widespread damage.

Thriving criniviruses, and their whitefly vector, highlight the need for greater efforts to resist and manage these pathogens. According to USDA researchers, only one good source of genetic resistance to tomato criniviruses has been found, in tomato germplasm of South American origin. They are currently characterizing this genetic resistance and determining whether it would be possible to transfer the resistance into commercial tomato germplasm. In addition, a second source of exotic germplasm appears to reduce whitefly infestation, slowing the rate of crinivirus spread in the field. (See Table: Disease Risks to Major US Crops.)

Disease Risks to Major US Crops

table 1

CROP	ANNUAL US CROP VALUE	CENTER OF ORIGIN	INCIPIENT PESTS AND DISEASES
Corn	\$30 billion	Mexico, Mesoamerica	Gray leaf spot Anthracnose leaf blight Mal de Río Cuarto downy mildew
Potato	\$3 billion	The highlands of South America, Central America, parts of North America	Potato late blight Numerous cyst nematodes (worms) Bacterial wilt Phytoplasma-like organisms Tobacco rattle virus
Rice	\$1 billion	Southeast Asia	Rice blast Rice sheath blight Bakanae, a.k.a. "foolish seedling disease"
Wheat	\$5.6 billion	Southwest Asia, Mediterranean coast to Tigris-Euphrates plain	Scab Russian wheat aphid Wheat rusts
Apple	\$1.8 billion	Kazakhstan, Central Asia	Fire blight Apple scab Cedar apple rust
Citrus	\$2 billion	Southeast Asia	Citrus canker Citrus variegated chlorosis (CVC) Citrus blight
Plums, other Stone Fruits	\$2 billion		Plum pox



Foods like these from around the world are finding a place on American tables. Thousands of potential crops are stored in the USDA Agricultural Research Services' crop diversity collections.



Crop Diversity, Diet and Choice

US agriculture needs global collections of crop diversity to improve the health value of foods and to meet changing consumer demand.

The USDA has noted several major food trends in America today: higher incomes are spurring a demand for higher quality foods; an aging population wants healthier foods; and an increasingly diverse population desires foods used in traditional dishes. In addition, many people are turning to organically grown foods.

The USDA's Economic Research Service (ERS) has noted that by 2020, the Hispanic population in the United States is expected to grow by 1.2 million annually, Africans and Asians by 400,000 annually. Growing ethnic diversity has historically contributed to shifts in food preferences and an expansion of the American food repertoire. The ERS projects that an increasingly diverse population is likely to eat more fruit, nuts and seeds, eggs, and fish. Citrus fruits may see the largest per capita gain, driven by taste preferences of today's Hispanic population. A preference for rice over potatoes is also evident among recent immigrant-based populations. Other less familiar foods favored by different immigrant communities include cassava, plantains, tomatillos, lentils and brassicas, such as Chinese broccoli and bok choy, as well as millet and sorghum.

To adjust to all these trends and satisfy consumer demands, agriculture will require access to genetic traits that add nutritional value, adapt crops to different climates and growing seasons, and offer natural pest resistance needed for organic farming. In addition, industry seeks increased shelf life with improved processing traits that add to convenience while not sacrificing quality or taste. At the same time, consumers will continue to depend on imports for many favorite foods, including the humble banana. (See Box 2: Yes, We Have Bananas, and Plantains Too).

High Expectations for Healthful Foods

Mangoes, papayas, avocados, and kiwi—items rarely seen on grocery shelves 20 years ago—are well stocked today. Imported fresh fruits and vegetables in seasons

YES, We Have Bananas, and Plantains Too

box 2

DESPITE ITS great popularity, the banana teeters on the edge of disaster. Maintaining and making use of genetic diversity in the banana plant family will be key to its survival.

Most people in the US know the banana commonly available in grocery stores, but what they do not know is that these bananas are mostly imported from Latin America, are a single variety—Cavendish, and are susceptible to several diseases, especially black sigatoka to which Cavendish is susceptible, requiring about 50 applications of fungicide each year to harvest a healthy crop. In contrast, approximately 500 different types of bananas are grown locally in the tropics. Some are sweet-

tasting, dessert-types that can be eaten fresh. Others, like plantains, are starchier and need to be cooked before consumption. Bananas and plantains are staple foods in many parts of the developing world, where genetic diversity abounds, but yields are low and varietal improvement for increased production is essential. Since the introduction of new varieties may eliminate native diversity, collection of native types must be conserved in genebanks in all of the banana and plantain-growing countries. This is the key to long-term sustainability of these food crops. Cultivated bananas and plantains, being sterile and producing no seeds, are generally maintained as living plants growing in the

field or in small bottles as tissue culture.

Plantation-grown bananas for US consumption are usually sprayed with fungicide by airplanes, putting local people at risk from spray drift. Breeding disease resistant varieties comparable to the Cavendish should be a high priority for the banana industry. Besides black sigatoka, the root-attacking disease, fusarium wilt is re-emerging as a production threat. *Fusarium* infects the plant's roots, causing the trees to wilt and die. In the 1940s and 1950s, a related strain of *Fusarium* nearly wiped out the then-reigning king of exports, a banana variety called Gros Michel. If the new fungal strain spreads from Asia, the Cavendish

banana may suffer the same fate as its predecessor.

Banana poses serious problems for plant breeders because of the difficulty of identifying stable, but sterile, plants for commercialization. Biotechnology offers good solutions to transfer genetic traits more efficiently from one banana type to another. Ultimately, success will depend on the depth of the banana gene pool. Genetic diversity, or lack thereof, could determine the continued viability of bananas both as a major export crop and as a critical source of nutritious food in the developing world.



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Items like these papaya's, rarely seen on a grocery shelf 20 years ago, are now widely available as consumers diversify their food choices and demand healthier products. Crop diversity can provide the necessary resources to meet the demand for healthier, high quality products.

when there is no US production have been welcomed by consumers, who are willing to pay a higher price. This offers greater diversity in diets—a healthful consequence— and also provides another example of how conserving the genetic diversity of crops in foreign lands would benefit US consumers.

The ERS anticipates that rising incomes will continue to allow Americans to upgrade and diversify their food choices. Economists project that food expenditures will be 26 percent higher in 2020 compared to 2000, based on higher incomes combined with a larger population, with much of that growth attributed to immigration. The US population is expected to grow by 18-28 percent, or 50-80 million people, by 2020. This expenditure increase will have greater implications for issues of quality than quantity, with items such as exotic fruits, mini vegetables, tofu-grade soybeans and vine-ripened tomatoes on consumers' shopping lists.

The trend toward healthier eating is also being fueled by nationwide worries about obesity. With approximately nine million children over the age of six now obese, parents are looking for alternatives to fast foods and soda pops. So pronounced is this trend that the fast food industry is even offering options: last October, for example, McDonald's introduced a new McVeggie Burger, a meatless, soy-based patty, and Wendy's advertises a dish of miniature orange slices, in place of French fries.

In the effort to provide healthier high quality products, plant breeders are producing crop varieties that draw on global crop genetic resources:

- **Potatoes rich in beta-carotene.** USDA researchers at Washington State University are developing a potato high in beta-carotene, a compound that the human body can convert to Vitamin A. While the Irish white potato has barely a trace of beta-carotene, some deep yellow-to-orange potatoes that grow in South America have 40 times as much. Researchers have transferred this super-trait to potatoes that can grow in the Northwest, and they will soon be commercialized. In addition, the International Potato Center in Lima, Peru, is striving to develop and distribute high beta-carotene varieties to poor countries.
- **Health-enhancing compounds in onions.** USDA scientists at Madison, Wisconsin, studied the genetic control of pungency and two major classes of health-enhancing compounds in onions, thiosulfinates and fructans. Both are carbohydrates associated with lower rates of colon/rectal cancers. The genetic information they uncovered will enable plant breeders to select for higher sucrose content in onion bulbs so as to combine a sweeter flavor with relatively high thiosulfinate and fructan concentrations, thus creating more nutritious onions with a pleasant flavor and aroma.
- **Healthier sunflower oil.** Sunflower, one of the few crop species native to the United States, was collected by early European explorers and transported to Europe and Russia, which became the world's largest producer. In the 1970s, sunflower came full circle, when US breeders used a Russian plant introduction to develop sunflowers that produce oil with a high concentration of oleic acid, which can be used as a salad or frying oil—a healthy alternative to hydrogenated oils. This led to the commercial oil “NuSun.” Today, growers continue to need diverse sources of sunflower germplasm to create varieties that lead to innovative new vegetable oils for the frying food industry and to select plants that resist pathogens and insects. Scientists are currently collecting and screening sunflower varieties from Romania, Serbia and Montenegro, France, and wild sunflower from the US.
- **Developing sorghum as a gluten-free alternative to wheat.** For the one to two million people in the US with celiac disease, or gluten intolerance, this grain that hails from Africa could provide a good alternative to wheat in breads, cookies, cereals and other products. Sorghum is an important food in many parts of Africa and India, but has mostly been used in the US as a livestock feed. Now, scientists are testing sorghum varieties to identify those most suitable for good-tasting, finely textured sorghum bread. In addition, sorghum is high in soluble fiber, and some varieties are high in phenols and tannins, both of which are believed to be good antioxidants.



© USDA-ARS, Bruce Fritz

U.S. breeders used a Russian strain of sunflower to develop sunflowers with high-oleic oil - the oil we use on our salads or for frying, as a healthy alternative to hydrogenated oils. Sunflower diversity is needed to continue developing new and potentially healthier oils for the frying industry.

Crop Diversity and Organic Agriculture

The interest in foods for better human health can be seen most clearly in the growth of demand for organically produced food products. When large companies such as Heinz sells organic catsup, and ballparks like St. Louis' Busch

Seminis Seeds: Breeding Health

box 3

SEMINIS SEEDS, the world's largest commercial fruit and vegetable seed company, sells 3,500 fruit and vegetable seed varieties in 150 countries around the world. Seminis promotes a steady stream of new varieties that promise to enhance nutrition and health, deliver better tasting food, and reduce the need for agricultural chemicals.

Seminis could not have gained its reputation for

diversity, variety and health without understanding the fundamental importance of crop diversity. Based in Oxnard, California, Seminis operates 52 research and development stations in 17 countries, breeding varieties suited to climates worldwide. It collects, conserves, and catalogues the hereditary information stored in seeds, and currently maintains 1.5 million breeding lines of seeds. Many of its upscale

and highly nutritional food products are derived from crossing elite lines (established commercial lines) with types obtained from outside the U.S. One current effort includes breeding a cancer-fighting broccoli by crossing plants from the Mediterranean Basin with commercial varieties. The Mediterranean broccoli is rich in glucosinolates, compounds known as naturally occurring cancer-fighters.

In January 2005 the St. Louis-based agriculture company Monsanto announced it would buy Seminis Inc. for at least \$1 billion.

Stadium offer certified organic hot dogs, it is clear that organically certified foods are more than a “niche” market.

In 2003, American consumers sent organic food sales soaring by 20 percent to \$10.8 billion,⁸ and conventional supermarkets and mainstream stores now account for half of the retail sales of organic foods. At the same time, the number of farmers' markets nationwide increased from 1,755 in 1994 to 2,863 in 2000.

But if organic farmers are to produce foods under management practices certified for organic production, they need to follow strict rules regarding reducing or avoiding pesticide and chemical fertilizer use. And to do this, while continuing to meet consumer demand, they need crop varieties with natural disease resistance, as well as those that generally perform well under organic management.

While still miniscule, research into organic farming systems and suitable varieties is growing, and 37 states now have some research land prepared for organic farming.⁹ For instance, the Texas A&M University research station in Beaumont is conducting research to develop rice varieties that perform well under organic management; Washington State University researchers have set up varietal trials for dry beans, asparagus, and peas; Iowa State University researchers are evaluating corn, soybean and barley varieties for certified organic farming; and researchers at the University of Maine are comparing tomato varieties for resistance to early blight, and cucumber varieties for resistance to leaf pathogens.¹⁰

With an eye to marketing seeds to producers who wish to reduce chemical use, Seminis Inc. recently introduced spinach varieties resistant to seven races of downy mildew—caused by a destructive, quickly mutating plant pathogen—as well as tomatoes resistant to tomato yellow leaf curl virus, a highly destructive virus that affects production worldwide.

Beyond organic agriculture, reducing dependence on pesticides in conventional food production systems can reduce or eliminate pesticide residues, which may

have more general benefits. For example, the Environmental Protection Agency (EPA) recently withdrew approvals for many agricultural uses of the pesticide dimethoate, which was popular with conventional fruit and vegetable growers, but was linked to a host of harmful health risks, ranging from headaches to death.¹¹ Meanwhile, strawberry producers in particular continue to search for alternatives to methyl bromide, a highly toxic soil fumigant whose use is being phased out internationally because of its damaging impact on the earth's ozone layer. More pesticide removals could occur as the EPA continues a comprehensive reassessment of a wide variety of approved pesticides.

Seed Savers Exchange	
box 4	<p>GARDENERS and farmers organized to grow, save, and exchange seeds the world over complement government genebank collections—and vice versa. In the U.S, the Seed Savers Exchange based in Decorah, Iowa, makes available seeds of more than 11,000 rare heirloom varieties of vegetables, fruits, and grains to its members. These include a soup bean believed ferried on the Mayflower and a black pole bean carried by the Cherokee over the Trail of Tears.¹²</p> <p>The Exchange aims to save “the world’s diverse, but endangered, garden heritage for future generations.” Its 890-acre Heritage Farm includes a collection of more than 24,000 vegetable varieties, including 4,000 traditional varieties from Eastern Europe and Russia. About 10 percent of the accessions of a crop type are grown at the Heritage Farm every summer, on a 10-year rotation, to update the collections. They multiply up to 2,000 varieties in 35 certified organic gardens (500 varieties of tomatoes, 500 beans, 125 peppers, etc.). An historic orchard maintains about 700 varieties of apple—all that remain of the 8,000 named varieties grown in the US in 1900. According to the National Gardening Association, about one in four American households grow vegetables. Those gardeners have an invaluable resource in the Seed Savers Exchange. For more information see: http://www.seedsavers.org</p>



Providing poor farmers with improved crop varieties can help them in the fight against hunger and poverty.



Global Development Needs Global Genebanks

To help solve the related problems of economic development, hunger, and environmental quality, the world needs the diversity found in crop genebanks.

Of the 800 million people globally who suffer from chronic hunger, half live as farming families in countries where feeble agricultural production is at the root of both malnutrition and poverty.¹³ Therefore, enabling poor farmers to simply grow enough to feed their families would cut in half the stark problem of hunger. Moreover, when farmers can grow enough to market even a small portion of their product, they can begin providing educational opportunities and better health care for family members, and improve the quality of their life as they wish. These changes ultimately fuel economic growth of families, communities and nations.

According to a new report from the United Nations' Millennium Development Project Task Force on Hunger, "over the past 50 years very few countries have tackled mass poverty and hunger without strong economic growth based on increasing agricultural productivity."¹⁴ The report also notes that a key component of effective agricultural aid is improving access to better seeds and other planting materials, and that "genetically superior crop, pasture and tree varieties can enormously increase the productivity of farms in food insecure areas."

Well-maintained genebanks are instrumental to providing the world's poor farmers with access to a rich variety of plant genetic resources. National agricultural systems and non-profit organizations in developing countries are often the biggest requesters of genebank seeds, and they use these seeds to breed crops that offer local farmers hardy, nutritious and disease-resistant varieties of crops adapted to local growing conditions.

Agricultural pests and diseases take an enormous toll in developing nations, where poor farmers lack resources for fertilizers and pesticides, and are often

handicapped by poor soils. Many of the same pests that attack US agriculture are raging through the developing world: rice blast destroys 150 million tons of cultivated rice each year in 85 countries, and costs farmers nearly US\$5 billion; potato late blight costs developing countries an estimated US\$3.25 billion; and epidemics of wheat scab are growing in intensity and frequency in many developing regions. As in the U.S., farmers in poor countries urgently need disease-resistant crop varieties. For this, crop genebanks are essential.

The Green Revolution and the Interdependence of Agriculture

The success stories from the Green Revolution, an international effort that sought to fight hunger some 40 years ago by providing developing countries with high-yielding crop varieties, offers evidence that an arsenal of genetically superior seed stocks can be a potent weapon against hunger and poverty. The Green Revolution brought to poor countries varieties of rice, wheat and corn that helped many farmers to use agriculture as a foundation for economic gain that went beyond mere subsistence.

Genebanks were crucial to this success, beginning with the high-yielding, short-statured wheats that made their way around the world. The origins of these wheats can be traced to a Japanese-US variety wheat called Norin 10, developed in Japan. Later, Orville Vogel, a USDA breeder at Washington State University, crossed Norin 10 wheat with Washington State winter wheats, to create the incredibly high-yielding Gaines variety.

Vogel shared this wheat with plant breeder Norman Borlaug in Mexico, who crossed it with local Mexican wheats, as well as with varieties from other countries. This finally gave rise to the high-yielding, short-statured varieties that transformed wheat farming worldwide. Borlaug and the newly founded Mexico-based International Maize and Wheat Improvement Center (known also by its Spanish acronym CIMMYT), transferred those wheats to India and Pakistan, where their high yield helped to stave off widespread famine. Finally, Borlaug's short-statured spring wheats found their way back to the U.S., and have been widely used in breeding programs to make major strides in US wheat production.

The practice of mining genetic diversity to improve farming is now being put to work to benefit farmers in poor countries that missed the first Green Revolution and will contribute to the hoped-for Ever Green Revolution envisioned by World Food Prize winner, M.S. Swaminathan, in India. For example, a collaborative effort of agricultural research programs from 14 countries in southern Africa, international aid groups, and CIMMYT developed stress-tolerant varieties of maize that offer much higher yields than hybrids available from private companies.¹⁵ To develop the varieties, each year the Southern African Drought and Low Soil Fertility Project (SADLF) works with some 1,000 farmers in 100 farm communities to screen thousands of different maize cultivars for evidence of drought tolerance.

Another CIMMYT-led international breeding effort is providing farmers in sub-Saharan Africa with new “quality protein maize” (QPM) that has twice the amount of the amino acids lysine and tryptophan in its protein than other



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Farmer near Kalomo, Zambia, compares the height of two varieties of maize.



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Rwandan women carry bags of bean seeds through a war-damaged grove of banana trees. Farmers in this Western part of Rwanda fled the fighting and abandoned their crops. Genebanks can provide farmers with the seeds they need to rebuild their lives.

varieties.¹⁶ QPM crops are now planted on 400,000 hectares in sub-Saharan Africa and that number could double by 2007.

Crop Genebanks Healing Wounds

The conservation of genetic variation in agriculture crop species is also emerging as an important element of recovery and redevelopment following wars and natural disasters. Most of the nations that are struggling to recover from the devastation of military conflicts or natural disasters are relatively poor countries where, for most, life still revolves around agriculture. In these countries, some of the most popular and productive crop varieties are “landraces,” varieties that have resulted from generations of selective breeding by local farmers. These varieties are irreplaceable if lost. But invariably, violence, whether caused by humans or nature, takes a heavy toll on farming and can result in the destruction of seed supplies and crop varieties that have sustained people for centuries.

Genebanks have emerged as the foundation of an efficient and effective means of jump-starting a country’s agricultural sector post-conflict or post-disaster. As the examples that follow illustrate, they can serve as repositories for conserving indigenous seed and plant material and as resource centers that can provide seeds that are compatible with a particular ecosystem, diet or culture.

■ After the Tsunami

The tsunami of December 2004 ravished life, destroyed whole villages, and damaged the coastal environments in several nations. Genebanks have since come to aid food production in coastal regions where soil was inundated with sand and salt deposited by the surging seas. Soon after the disaster struck, the International Rice Research Institute (IRRI) began receiving urgent requests from Malaysia and Sri Lanka for salt tolerant varieties of rice. Thanks to its long-term commitment to cataloguing and conserving rice from around the world, IRRI had access to 40 different salt-tolerant varieties. Six varieties have already been sent to Sri Lanka and Malaysia and IRRI is working with local farmers to either plant them immediately or use them in breeding programs to transfer salt-tolerance to local varieties.¹⁷

■ Iraq and the Black Box of Life

Well before the US military’s arrival in Iraq in 2003, plant scientists deposited a duplicate of a valuable Iraqi seed collection in the Syria-based International Center for Agricultural Research in Dry Areas (ICARDA) for safekeeping. The “black box” of seeds held a representative sample of Iraq’s critical crop varieties. So, although the Iraqi gene bank was later ransacked and looted, the rescued seeds were safe in Syria and will be returned to Iraq for planting.¹⁸ ICARDA is also providing Iraq with additional seeds—20 tons of cereal and legume varieties carefully selected for their genetic suitability to Iraq’s growing conditions.¹⁹

■ Bringing Rice Back to Cambodia

Plant varieties maintained by IRRI were instrumental in the dramatic turnaround of Cambodian rice production, which was decimated under the rule of the Khmer Rouge. When the Khmer Rouge murdered one quarter of the population, among their targets was the brain trust of the country’s

agricultural sector. When Khmer agricultural policies destroyed indigenous seed collections and replaced native rice varieties with ill-suited strains imported from China, rice production in Cambodia fell by 84 percent, and the country went from being a major rice exporter to an importer of rice.²⁰

Fortunately, IRRI had amassed a vast library of Cambodian rice varieties. Working in conjunction with the Australian international development agency and IRRI, Cambodians were able to reintroduce the indigenous rice varieties, which were repatriated from the IRRI rice genebank. Cambodians also were provided with new, early-maturing varieties that offered the opportunity for two harvests in one season. These measures contributed significantly to the fact that by 1995, Cambodia was moving back to pre-Khmer production levels.

■ **Aiding Rwanda's Recovery from Genocide**

Prior to the Rwandan genocide of 1994, CGIAR research centers—as part of a project called Seeds of Hope—already were working with local researchers and farmers to establish a collection of some 600 bean varieties cultivated in Rwanda. As violence enveloped the country, this work was completed. Although looters destroyed a number of the research stations, one Rwandan field assistant managed to keep his test plots and seed collections intact throughout the violence. The salvaged stocks have since helped to rejuvenate Rwandan agriculture, providing seeds for farmers and also allowing for the restoration of research programs that can bring future improvements.²¹

A commitment to maintaining genetic diversity in crop species is clearly important to the economic development of countries in both the short and the long run. In the short run, they provide agriculture with resources needed to recover from war or natural disaster; in the long run, they provide the options needed to breed higher yielding, more nutritious crops, and crop varieties suited for tough conditions such as poor soils or dry climates. Ultimately, providing farmers with improved crop varieties will empower poor countries to confront the conjoined problems of hunger, poverty and development.



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Restoring agriculture in Rwanda.



A study has shown that US agriculture has gained up to US \$13.7 billion from the use of CIMMYT wheat varieties in US breeding programs.

Crop Diversity in Demand

The average consumer waiting in the checkout line of a supermarket has little contact with farming and agriculture and all that is involved in producing the goods in her shopping cart. Most people have never heard of crop genebanks, and, if they had, many may question their true importance. But a recent study published by the International Food Policy Research Institute (IFPRI) provides ample evidence of the high demand for genebank resources, and paints a picture of future need.

Distribution and Use of the US Collections

Holding more than 460,000 accessions, the United States National Plant Germplasm System (NPGS) has one of the most comprehensive collections of crop diversity in the world. Practically all of the hundreds of varieties developed and distributed to US agriculture trace to the NPGS collections, which themselves trace to international sources. In addition, NPGS resources are available free of charge to all legitimate requesters, anywhere in the world. Because of this, data on use of NPGS collections generate both a national and an international profile of genebank use.²² The use of the collections also underlines the global interdependence of all agriculture. (See Box 4: Profile of the US National Plant Germplasm System.)

The NPGS provided data to economists Kelley Day Rubenstein of the ERS and Melinda Smale of IFPRI on the distribution of accessions from NPGS. They found that the NPGS distributed over 600,000 samples of 10 major crops between 1990 and 1999: barley, beans, cotton, maize, potato, rice, sorghum, soybeans, squash, and wheat. Seventy-four percent were distributed to requesters in the United States. Of the 26 percent of samples distributed internationally, about 12 percent were sent to developing countries. Another 10 percent went to other developed countries, and about 4 percent went to the transitional economies of the

former Soviet Union and Eastern Europe. In all, the distributed material went to over 200 countries, territories, departments, and commonwealth associations. Private industry in the U.S. makes ample use of NPGS, accounting for almost one-quarter (23 percent) of all samples distributed within the country. In most, cases, this use represents a secondary use of germplasm originally derived from the US breeding programs and other parts of the globe.

Among the international recipients, non-profit, non-governmental organizations received about 80 percent of samples, but only six percent of samples sent abroad went to commercial requesters (however, many other commercial requesters undoubtedly received samples via their cooperators in the U.S.).

The most commonly requested type of material was cultivars that are suitable for planting by farmers and useful to breeding efforts. The second-most requested materials were landraces—varieties of crops that evolved and were improved by farmers over many generations. The authors noted that the use of landraces generally suggests a complex search for traits, given the difficulty of incorporating them into final varieties that are well adapted to grow under a given set of conditions.

This appears to be borne out by the purpose of requests. Within the U.S., 68 percent of requests were made in an effort to find specific traits. In particular, 37 percent of samples were requested for resistance or tolerance to pathogens; 14 percent for resistance to environmental stresses such as drought or salinity; and 17 percent for traits to improve quality (such as oil and sugar content, taste, and nutritional content); while 12 percent were requested for traits for increased yield.

In addition, most respondents (86 percent) said that they expected their use of the NPGS to remain steady or increase. Only 14 percent expected it to decrease. In all the study revealed a widespread distribution of seed collections, in the US and internationally.

Even so, it fails to capture a full measure of usage, which must include an assessment of genes discovered, varieties bred, and the adoption of derivatives in farmers fields.

The Case of the CGIAR

In the search for useful traits, US public and private entities regularly go outside the United States as well, to import an average of 7,500 samples of crop varieties a year through the USDA Animal and Plant Health Inspection Service.²³ Many of these come from CGIAR genebanks, which serve both developed and developing countries.

Developing countries make good use of CGIAR genebanks. Between 1985 and 1995, low income countries received twice as many CGIAR genebank samples than they contributed to the system for some key crops, including chickpea, groundnut, sorghum, and lentils. Indeed, for the same time period, developing

Profile: The US National Plant Germplasm System*

box 5

NPGS HAS one of the most complete germplasm collections worldwide. As of January 2005, NPGS holdings represented 10,768 species, across 1,669 botanical genera and 205 botanical families. Together, these holdings represent 462,543 accessions. The species collections are truly global, for example, the number of nations contributing samples to the NPGS for six of the crops is 58 for apple, 100 for bean, 127 for corn, 39 for potato,

53 for rice, and 119 for wheat. For these same crops, the countries contributing the largest number of accessions were: apple, Kazakhstan, 967; bean, Mexico, 2,423; corn, Mexico, 2,802; potato, Bolivia, 871; rice, India, 1,366; and wheat, Iran, 8,369.

The NPGS has more than 25 sites throughout the U.S for curation and distribution of plant genetic resources of seed and clonally

propagated species. The heart of the NPGS is the National Center for Genetic Resources Preservation located at Fort Collins, Colorado, where backup security seed samples of accessions are maintained. The NPGS is cooperative with state agricultural experiment stations that also have collections of many crops. For example, in a 1986 survey, 47 universities maintained 696 collections of various types. Thirteen of these collections

were assembled to meet specific needs in cooperation with the USDA.²⁴

The following are examples of numbers of accessions held from some major US crops.

GRAINS	ACCESSIONS	VEGETABLES	ACCESSIONS	FRUITS	ACCESSIONS
Barley	31,012	Beans	14,465	Apple	4,134
Corn (Maize)	23,230	Lettuce	1,420	Citrus	897
Oat	21,793	Onion	2,222	Grape	3,996
Rice	21,844	Pea	4,530	Pear	2,293
Sorghum	42,438	Pepper	4,709	Pineapple	160
Soybean	21,118	Potato	6,746	Strawberry	1,733
Wheat	55,516	Tomato	10,473	Watermelon	1,840
Total	216,951	Total	44,565	Total	15,053

*Source: www.ars-grin.gov

countries received the vast majority of rice, wheat, maize, and barley samples from CGIAR genebanks.

Researchers in the U.S. also make good use of these genebanks. Partial data provided by the International Plant Genetic Resources Institute indicated that from five of the CGIAR genebanks nearly 50,000 samples were sent to US researchers over a period of about 25 years, amounting to about 5 percent of the samples sent world-wide from those centers. This is surely an underestimate. Tracking how the samples were used and benefits to US agriculture has not been done. However, there are two outstanding examples of the use of genetic resources developed by the CGIAR centers in the U.S.

The first was an analysis of the economic impact of the introduction of wheat varieties and germplasm from CIMMYT in Mexico to the U.S. The US economy gained at least \$3.4 billion and up to \$13.7 billion during the period of 1970-1993 from the use of CIMMYT's wheat varieties in breeding, or as direct introduction to the U.S. Since US government support of wheat improvement research at CIMMYT amounted to less than \$71 million since 1960, the benefit-cost ratio for US support of CIMMYT was as high as 190 to 1.²⁵

In the same 23-year period, the US economy realized at least \$30 million and up to \$1.0 billion through the use of improved rice varieties developed by the International Rice Research Center in the Philippines. This represented a benefit-cost ratio for US contributions to IRRI as high as 17:1.

Other studies have found that the potential benefits of improving even a single crop type based on genebank materials vastly outweigh all costs of collecting and curating the collections.

A System Under Stress

Despite their value, many critical crop diversity collections around the world are in deep trouble, with collections or parts of collections continually being lost due to lack of resources. Funding for genebanks has not generally kept pace with the costs of maintaining collections. For example, the CGIAR, which operates 11 genebanks housing more than one-tenth of the world's total crop diversity collections, has seen its "unrestricted funding," which funds the genebanks, drop by 50 percent since 1994. However, this loss has recently been mitigated by World Bank funds for upgrading data management and facilities.

Many countries around the world have experienced an insidious, gradual loss of materials from under-funded genebanks that cannot afford to maintain their collections under conditions that guarantee their survival. Such losses are rarely well documented but can have major impacts: important banana diversity has been lost from a collection in Philippines due to viral diseases; a collection of roots and tuber crops in Cameroon was lost due to a power failure over one weekend; samples of beans in collections in Peru and Guatemala, and of chili peppers and tomatoes in Colombia and Costa Rica have been lost because the inability of the collection holders to rejuvenate the samples in time; a yam collection in Togo was destroyed by a brush fire.

Many genebanks lack the ability to regenerate their collections or the resources to build documentation systems that would ensure effective distribution of material from their collections. For example, in Russia, the N.I. Vavilov All Russian Research Institute of Plant Industry (VIR) cannot afford to translate data on its collections into English and to make this available electronically. Although the VIR houses globally important collections of wheat, potato, and many other crops, these resources are thus not readily available to all potential users.

The Indian national collection contains valuable rice diversity, much of which does not exist outside the country, yet the collection is now at risk of being lost due to lack of resources. Important field collections of apple are held in



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Many collections of crop diversity are at risk due to lack of money. In Zimbabwe's national genebank, staff shortages have led to a backlog of seed that still needs to be processed.

Kazakhstan, which is the crop's center of origin. These collections are imperiled by disease and environmental stresses. The collection lacks the funds to secure existing accessions or to duplicate them for safety purposes. Over the years, China's National Citrus Germplasm Repository and regional repositories have lost up to 60 percent of their citrus collections due to factors such as a lack of funds, disease, and freezing weather. India's citrus genebanks have also been declining since the 1950s. Many indigenous varieties, first described in the 1890s and mid 1900s, can no longer be found in the genebanks.²⁶

Other countries have lost important collections in dramatic episodes. These have included the national collection in Afghanistan, which was destroyed in the fighting in 1992; the Iraqi national collection, maintained at a research station at Abu Ghraib near Baghdad, which was destroyed in 2003; and the regional genebank at Gitega in Burundi, which was emptied and the seed bags destroyed during the conflicts that started there in 1993. In many cases it has proven possible to reassemble at least parts of these collections from duplicate samples stored elsewhere, especially those maintained by the Future Harvest Centers of the CGIAR. In other cases, the materials the genebanks held have been lost forever.

A report on the State of the World's Plant Genetic Resources was prepared by the FAO for the International Technical Conference on Plant Genetic Resources, which took place in Leipzig, Germany, in 1996. The report noted that in 1970 there were fewer than 10 genebanks throughout the world. As a result of major collecting efforts in the 1970's and 1980's, by 1995 there were about 1,460 collections in about 150 countries. Approximately 400 of these, in 75 countries, had some medium and/or long-term storage capability, of which only 35 met international standards for long-term storage.

In 1995, more than 5.4 million samples were being maintained in genebanks worldwide. It was estimated that 90 percent of these samples were being held in seedbanks—facilities for species, such as most cereals and food legumes that produce normal seeds. Less than 10 percent of the samples being conserved were of crops that do not produce normal seeds. This includes many fruit and vegetable species that must be maintained either as living collections in the field (called “field genebanks”) or as collections of tissue in special laboratory facilities, either in special glass containers or in liquid nitrogen in cryogenic tanks. Only about 38,000 such samples existed worldwide, indicating that such species were under-represented in collections.

The State of the World Report also indicated that up to 1 million samples of material housed in crop diversity collections were getting old and were in urgent need of regeneration to restore their viability. Adequate data on the source of the— samples and some of their basic characteristics were only available for about 50 percent of samples in national collections.

In 2002, a follow-up study was conducted by Imperial College Wye²⁷ to determine what progress had been made over the 5-year period (1995 - 2000) following the FAO report and the pledges made by governments in Leipzig to



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No country can guarantee its food security unless it can draw on and use crop diversity stored in genebanks around the world.

give more attention to plant genetic resources. Of 98 countries surveyed, there were few major changes in the overall size and distribution of collections. However, approximately 7 percent had lost portions of their collections, and budgets had remained static or declined in 65 percent of countries. Regeneration backlogs had increased in 66 percent of developing countries, indicating that even more material was in urgent need of being regenerated to restore its viability than was the case in 1995. Overall the situation was considerably worse in developing than in developed countries.

The Global Crop Diversity Trust

The future of agriculture in the United States and around the world depends on international cooperation and continued access to the crop diversity that farmers have developed over 10,000 years. No country, be it a rich industrialized nation or an impoverished developing state, can guarantee its food security unless it can draw on and use the rich sources of crop diversity held in genebanks all around the world.

The International Treaty on Plant Genetic Resources for Food and Agriculture, which passed into international law in June 2004, takes a vital step toward ensuring that all people have continued access to crop diversity. By signing onto the Treaty, governments promise to share their resources through the multilateral exchange system laid out in the Treaty.

This multilateral system describes the terms of access and benefit sharing that will apply to the exchange of crop diversity for research and crop improvement. The system initially includes some 35 food and 80 forage crops: the crops that governments have agreed are most important to world's food security.

In late 2004, the Global Crop Diversity Trust was established as an independent international organization, the product of a partnership between the FAO and the International Plant Genetic Resources Institute (IPGRI) acting on behalf of the Future Harvest Centres of the CGIAR. The Trust is an element of the funding strategy of the International Treaty, with the specific goal of supporting the costs of conserving national and international crop diversity collections over the long term. With backing from a growing list of public and private donors, the Trust is building a \$260 million endowment, the proceeds of which will fund basic conservation costs into perpetuity. The Trust also will provide funding to salvage collections at risk and to build the capacity of developing countries to manage their collections. The agreement to establish the Trust has so far been signed by the governments of Cape Verde, Colombia, Ecuador, Egypt, Ethiopia, Jordan, Mali, Mauritius, Morocco, Peru, Samoa, Serbia and Montenegro, Sweden, Syria, Togo, and Tonga.

The establishment of the Trust comes at a pivotal moment in international events. The world faces record losses of plant diversity from farmers' fields and the wild; unpredictable natural disasters, such as the December 2004 tsunami that roiled against the shores of 12 Asian countries; the global threat of terrorism; and growing international concern about diet and health. In each case, a secure, diverse

agricultural base can improve, and sometimes help rebuild, communities and people's lives.



Ensuring that crop diversity is conserved and available is vital for the well being of present and future generations.

Conclusion

Although it is easy to assume that US agriculture is relatively self-sufficient, all agriculture in today's world is interdependent. Crop diversity collections are the lynchpin of this interdependence, and thus central, as well, to the future of US agriculture. Global collections of crop diversity are a long-term public good, and need to be supported in the public interest.

The public good nature of crop diversity collections is not always obvious. For instance, some assume that private sector agricultural firms will maintain enough diversity to ensure food security now and in the future. Although the biggest firms do have impressive genebank collections, as a recent ERS study shows, their work tends to focus on only a handful of major crops. The study found that while private spending on crop variety research and development increased 14-fold between 1960 and 1996, that spending was concentrated on corn, soybeans and cotton. In contrast, public R&D expenditures in the U.S., which remained flat over the same period, were more likely to benefit a greater variety of more “minor” crops.²⁸

Around the globe, agriculture is in the midst of a major transformation, akin in impact to the period of agriculture's origin, when farmers in different parts of the world, at different rates and in their own way, domesticated a myriad of wild crops. That transformation occurred over millennia. Today's transformation is occurring in the course of decades.

Until recently, farmers the world over have themselves developed and selected the best possible varieties to grow in their fields. These homegrown varieties, nurtured over generations, have represented a vast array of genetic diversity. Today, farmers around the world are shifting their focus and switching to new varieties bred by professional plant breeders that may allow them to more rapidly improve their economic condition.

In the U.S., this transformation began in the 1930s, with the development of hybrid corn—varieties with superior yield, but that required farmers to purchase new seed

every year, rather than replant their own best seed. Within two decades, corn farming in the U.S. transitioned from landraces to new hybrids, from on-farm conservation to a focus on production. As farmers cross that threshold, conservation of the diversity in agriculture depends on conscious decisions to collect and conserve. Only by doing so will agriculture the world over avoid the mass extinction of landraces—along with wild relatives of crops that are inevitably being lost to changes in the habitats in which they grow. Such losses in diversity have real, although unpredictable, impacts on the future ability of agriculture to cope with whatever changes lie ahead.

US agriculture needs to anticipate—and be prepared for—the unknown. This may come in the form of a mutated fungus that takes hold across genetically similar fields of wheat or rice, or in the form of pathogens that arrive in the wind or slip through quarantine undetected. Whatever the form taken by such unanticipated events, crop diversity is bound to be an essential component of the response. And while it is not possible to immediately find all the useful genes contained in collections of crop diversity, molecular tools that facilitate targeted genetic searches are increasingly available. The question is not whether we will have the technology to find the genes that are needed, but whether the crop diversity itself will continue to be available for this and future generations.

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