Chapter 3.1

# Crop Genetic Resources

Kelly Day-Rubenstein and Paul Heisey

*Crop genetic resources are essential for agricultural production, and their use results in significant economic benefits. But conservation of crop genetic resources is complicated by their public goods attributes.*

## Contents

## Agriculture's Dependence on Genetic Resources

Agriculture and genetic resources are critically interdependent. All agricultural commodities, even modern varieties, descend from an array of wild and improved genetic resources from around the world. Furthermore, agricultural production depends on continuing infusions of genetic resources for yield stability and growth.

Genetic improvements have arisen in several ways. Before the development of modern varieties, farmers cultivated landraces. Landraces are varieties of crops that evolved and were improved by farmers over many generations. The pace of crop improvement accelerated as modern breeding techniques were developed that facilitated selection of specific desirable traits. Breeders have crossed different parental material and selected traits resulting in higher yields, quality changes, and desirable production traits.

Breeders have also sought resistance to pests and diseases, and tolerance to nonbiological stresses such as drought. Because pests and diseases evolve, breeders continually need new and diverse germplasm from outside the utilized stock, sometimes using wild relatives of cultivated crops and landraces, to find specific traits to maintain or improve yields (Duvick, 1986). USDA has estimated that new varieties are resistant for an average of 5 years, while it generally takes 8-11 years to breed new varieties (USDA, 1990). Plant breeders often rely on landraces or wild relatives as a last resort, because often it is more difficult to incorporate genetic material directly from these sources. Undesirable traits often accompany the trait of interest, and extensive breeding may be needed to produce a final variety. However, when used, genes from these materials have "often had a disproportionately large and beneficial impact on crop production" (Wilkes, 1991).

## Economic Values of Genetic Resources

Attaching a value to genetic resources is hard; describing their benefits is easier (Day-Rubenstein et al., 2005). The simplest value arises from the "direct use" of genetic resources to produce food and fiber or to help create new varieties of crops.

Conserved genetic resources may also have economic value even if they are not being used at the time. The option to exploit resources in the future, for uses not presently known, has considerable value, though this value is difficult to measure. Also, the information about a conserved resource has economic worth. For example, the fact that a species of potato occurring naturally in the Andes has genes adapted for high altitudes may guide breeders toward a set of related germplasm in the future.

Modern molecular biology techniques such as genomics hold promise for reducing the costs of searching for useful traits in conserved material, therefore increasing its value. At present, however, much work would be required to turn raw genetic sequence data into useful information (Attwood, 2000), and neither sequence data nor resources for sequencing are now available for landraces or wild relatives.

Various economic methods have been used to value genetic material, but isolating the contribution made by genetic resources is difficult. Breeders use the genetic material to create new varieties, but the research *effort* by breeders has value as well. Thus, many studies have focused on the value of "genetic enhancement," or the value arising from the *use* of genetic material by breeders.

For example, the Office of Technology Assessment (1987) estimated that genetic improvements have accounted for half the yield gains in major cereal crops since the 1930s. Thirtle (1985) estimated the contributions of biological advances to U.S. crop production, controlling for changes in other inputs such as fertilizers, machinery, and pesticides, and concluded that biological improvements contributed to 50 percent of the yield growth of corn, 85 percent for soybeans, 75 percent for wheat, and 24 percent for cotton. Duvick (2005) estimated that 50 percent of the increases in maize (corn) yields since the early 1930s have been due to breeding. To date, practically all published economic analyses of the collection of genetic material, conservation in gene banks, or use of genetic resources in plant breeding programs have shown significant economic benefits from these activities.

Besides estimating the total value of genetic improvements, it is also possible to estimate the distribution of these benefits. ERS researchers estimated the value of improved crop varieties by modeling the difference in economic welfare for both consumers and producers (crop and livestock) had there not been crop improvements in five major U.S. crops. U.S. producers generally gain as lower production costs outweigh the losses from lower commodity prices. Producer gains are estimated at over $160 million annually. Lower prices benefit consumers by an estimated $223 million per year. Together, the net economic effect from genetic enhancements is estimated at roughly $385 million per year. Economic welfare also rises worldwide. Consumer benefits from lower food prices outweigh producer losses, leading to net welfare gains estimated to exceed $600 million per year (table 3.1.1).

## Genetic Diversity

The loss of genetic diversity in a species, also called genetic erosion, has been identified in many commercially important crops. One reason for this decline in diversity has been the loss of landraces and wild relatives of cultivated crops. The loss of wild relatives occurs mainly through habitat conver-

Table 3.1.1

**Estimates of annual benefits from genetic enhancements in U.S. major crops**

| Region | Change in producer benefits | Change in consumer benefits | Total welfare change |
|---|---|---|---|
| | | *$ million* | |
| United States | 162 | 223 | 385 |
| Canada | -17 | 18 | 1 |
| European Union | -103 | 180 | 77 |
| Other Western Europe | -10 | 16 | 6 |
| Japan | -9 | 66 | 57 |
| Australia/New Zealand | -14 | 8 | -6 |
| China/transitional economies | -171 | 210 | 39 |
| Developing agricultural exporters | -61 | 62 | 1 |
| Developing Asian importers | -5 | 14 | 9 |
| Rest of world | -119 | 157 | 38 |
| Total | -347 | 954 | 607 |

Source: Based on methodology used in Frisvold et al., 2003.

sion. Because the economic values of wild relatives can rarely be appropriated (i.e., captured) by landowners, they may have less incentive to preserve habitats for wild relatives than to devote land to alternative uses such as clearing for agricultural or urban use.

Genetic erosion of crop varieties can be hastened as landraces are displaced by commercially developed varieties. Farmers want high yield potential and desirable consumption attributes, and commercial varieties are often superior in these respects. While maintaining a diverse set of landraces may benefit plant breeding, individual farmers are unlikely to account for this when selecting seed. Landraces, though, become extinct if farmers stop planting and maintaining them.

Widespread adoption of genetically uniform crop varieties makes the crop population more susceptible to a widespread disease or pest infestation. Genetically uniform varieties may initially be more resistant to pests and diseases. But as pests and diseases evolve to overcome host plant resistance, genetic uniformity increases the likelihood that such a mutation will prove harmful to a crop; disease could affect newly vulnerable varieties accounting for a greater proportion of a crop's production. Genetic uniformity contributed to the spread of the Southern corn leaf blight, which reduced the U.S. corn crop by 15 percent in 1970. Since then, the genetic vulnerability of wheat and corn is thought to have lessened (in part because of efforts to breed in greater diversity), but the genetic uniformity of rice, beans, and many minor crops is still a concern (NRC, 1993; FAO, 1998).

Despite concerns that crop yields and production will become more variable (Swanson, 1996), yields for many major crops have been relatively stable. This is probably because temporal diversity (diversity through time) has replaced spatial diversity (diversity across an area) (Duvick, 1984). Modern plant breeding provides a steady release of new varieties with new traits for pest or disease resistance. Keeping ahead of pests and diseases through temporal diversity depends on the quality of germplasm in public gene banks and in private breeder collections. Many of the benefits of raw germplasm cannot be appropriated because genetic material has public good characteristics. As a result, private breeders rely on the public sector to collect, characterize, and perform pre-breeding enhancement of genetic materials to make them available for private use (Duvick, 1991).

## Tools To Conserve Genetic Resources—*In Situ*

Most of the world's genetic diversity is found *in situ*. Species preserved *in situ* remain in their natural habitat. For agriculturally important species, the greatest diversity in landraces and in wild relatives may be found near their centers of origin, i.e., the places in which they were first domesticated (fig. 3.1.1). *In situ* preservation efforts, as well as germplasm collection activities for *ex situ* conservation, are often focused on centers of origin.

Because *in situ* conservation of agricultural genetic resources is carried out within the ecosystems of farmers' fields or wildlands, species continue to evolve with changing environmental conditions. *In situ* preservation can provide valuable knowledge about a species' development and evolutionary processes, as well as how species interact (table 3.1.2).

*In situ* conservation of biodiversity is not more widely practiced because the private costs of doing so often outweigh the private benefits. Many decisions that affect conservation of biodiversity, such as choice of variety or deciding whether to clear land, are made at the individual or local level. To preserve agricultural genetic diversity *in situ*, a farmer may have to forgo a more profitable variety. For wild *in situ* resources, the land may need to be set aside completely.

It is difficult for countries—let alone individual farmers—to capture all of the value from genetic resources. Markets do not exist for most of the other environmental services provided by biological resources, such as benefits provided for wildlife species, and certain genetic resources are easy to transport and replicate.

Figure 3.1.1

**Centers of origin, selected crops**

Source: GAO (1997).

Table 3.1.2

**Advantages and disadvantages of in *situ* and *ex situ* conservation**

| ***In Situ* conservation** | | ***Ex Situ* conservation** | |
|---|---|---|---|
| **Advantages** | **Disadvantages** | **Advantages** | **Disadvantages** |
| Genetic resources used to produce valuable product | Costs borne by farmers | Costs generally centralized | Certain types of germplasm not readily conserved |
| Evolutionary processes continue | May reduce farm productivity | Can preserve large amounts of diverse germplasm | Regeneration can be costly, time-consuming |
| May better meet the needs of certain farms | Requires land | Germplasm can be more readily accessed by more breeders | Potential for genetic "drift" can reduce integrity of collection |
| More efficient for some germplasm, e.g., animals, crops that reproduce vegetatively | Farmer selections may not preserve targeted diversity | High-security storage impervious to most natural disasters | In practice, many collections are insufficiently funded, organized, and documented |
| Existing wild relatives can be preserved without collection | | | |

Developing countries, where many *in situ* genetic resources for major crops are found, often face greater pressures for wildland conversion because of population growth and extensive farming techniques. In contrast, the quantity of agricultural land in the developed world has remained relatively stable or declined.

## Tools To Conserve Genetic Resources—*Ex Situ*

The *ex situ* method of genetic resource conservation removes genetic material from its environment for long-term conservation, most often in gene banks. The world's gene banks presently hold more than 4 million accessions, or specific samples of crop varieties.

However, crop genetic resources must be collected, and only a fraction of the world's germplasm has been collected thus far. Stored plant materials must be kept under controlled conditions, and periodically regenerated (planted and grown) in order to maintain seed viability (table 3.1.2). Not all kinds of plant genetic resources are easily conserved *ex situ*: some plants may need to be kept as living plants, a more costly process that requires additional land and labor. The resources necessary to maintain plant gene banks also face competing demands from other public programs.

## U.S. Policies To Protect Genetic Resources

The United States promotes the conservation and use of genetic resources by (1) funding germplasm preservation efforts here and abroad and (2) pursuing international agreements. U.S. plant preservation is led by the National Plant Germplasm System (NPGS), which is administered by

USDA's Agricultural Research Service. The NPGS, which houses more than 10,000 species, including wild relatives of crops, is one of the world's largest collectors and distributors of germplasm. It focuses on germplasm that may be needed by both public and private breeders, now and in the long term (see box, "Types of Germplasm"). Private incentives to collect and maintain such a collection are small, because any economic returns may not be realized until well into the future. Likewise, collecting exotic germplasm such as landraces and wild relatives can be expensive. However, it is a crucial source of needed traits, particularly resistance traits.

A recent study by the U.S. General Accounting Office found that relatively few wild relatives of domesticated varieties are held in gene banks, and not all collections have sufficient diversity (table 3.1.3). Gene banks also may not be receiving adequate funding to fulfill their mission (Day, 1997). For example, the NPGS lacks sufficient funding to complete evaluation and documentation of its samples, or to perform necessary backups and regeneration of seed accessions (GAO, 1997).

## International Policies on Genetic Resources

Most U.S. farmers produce non-native crops and livestock (NRC, 1993). Access to genetic resources in other countries is therefore critical to maintaining the rate of varietal improvement. Almost every plant species of major economic importance to the United States has been improved with germplasm from elsewhere. Past collection efforts and extensive breeding activities have resulted in the United States' actually being a net supplier of

Table 3.1.3

**Some germplasm collections with insufficient diversity for reducing crop vulnerability**

Collections with insufficient diversity to reduce crop vulnerability:

- Grapes
- Cool-season food legumes
- Sweet potatoes
- Cucurbits (e.g., cucumbers, squash, and pumpkins)
- Tropical fruit and nuts
- Walnuts
- Prunus (peach and cherry trees)
- Herbaceous ornamentals
- Woody ornamentals

Germplasm types with insufficient diversity:

- Wild and weedy relatives: almost 50%, including corn and soybeans.
- Landraces: 12 out of 40 collections, including corn, wheat, cotton, and alfalfa
- Genetic stocks: 50%, including alfalfa, peanuts, grapes
- Obsolete and current cultivars: 5 out of 40 collections

Source: GAO, 1997.

## Types of Germplasm

Germplasm can be categorized into three basic types: (1) elite or modern, (2) landraces, and (3) wild and weedy relatives. Elite or modern germplasm has been improved by plant breeders. It may be a final cultivar (either recently developed or obsolete), or it may be germplasm that has been modified by a breeder for use in creating cultivars. Because landraces and wild or weedy relatives often contain unique traits, they increase the diversity of a germplasm collection. At the same time, elite material also contains diverse genes, which may be less exotic, but are generally easier to use (NRC, 1993). Thus, curators and breeders typically will want all three types of germplasm in a collection. In addition to these three basic types, germplasm collections also may include "genetic stocks," mutants and other germplasm with chromosomal abnormalities that are used by breeders.

plant germplasm to the rest of the world (fig. 3.1.2). The NPGS supplies germplasm, free of charge, to anyone who requests it. Still, the United States continues to rely on other countries for genetic material. So, international agreements that affect the exchange of germplasm are an important tool for both U.S. policymakers and genetic resource managers.

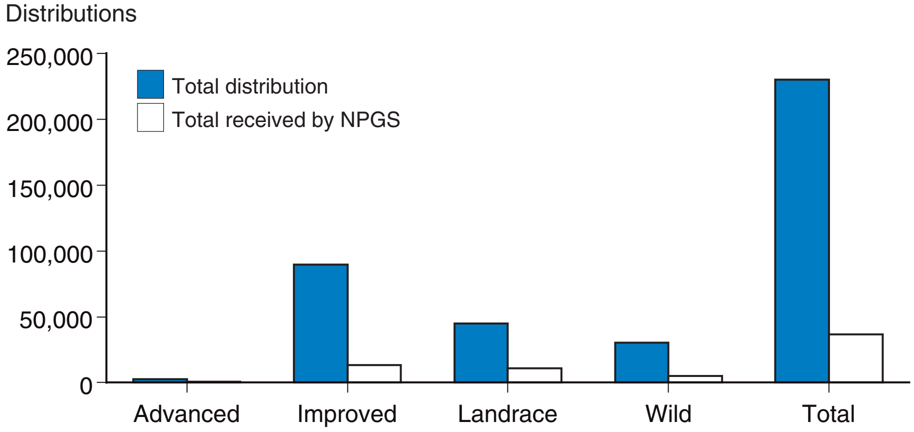
The U.N. Convention on Biological Diversity (CBD), which came into force in 1993, is the most prominent international agreement addressing preservation of genetic resources. Historically, genetic material was regarded as the common heritage of humankind. Developing countries, the centers of origin for many crops, have often provided raw genetic material to public germplasm repositories.

Whether forgone earnings from raw genetic material are compensated for by free access to public genebanks and lower world food prices is an open question (Shands and Stoner, 1997; Fowler, 1991). But the traditional "free flow" of "unimproved" genetic resources and landraces between countries is no longer a given. The CBD is the most well-known in a serious of multilateral agreements to address (among other issues) ongoing disputes over the exchange and use of plant genetic resources. President Clinton signed the Convention in June 1993, but the U.S. Senate has not ratified it yet. The United States attends meetings as a non-voting observer.

In addition to the CBD, the International Treaty on Plant Genetic Resources for Food and Agriculture (IT) came into force in 2004. For parties to the treaty, the IT governs the international exchange of germplasm for specified crops, including wheat, maize, rice, and alfalfa (though not other important crops such as soybeans, tomatoes, and peanuts). It is also intended as a mechanism to fund genetic resource conservation. In June 2006, the governing body adopted a Standard Material Transfer Agreement that defines the terms of germplasm exchange for covered crops. As a result, U.S. policymakers and genetic resource managers face new exchange terms and rules governing benefit sharing, even though the United States has not radified the IT. Uncertainties still surround the valuation of crop genetic resources and the sharing of benefits from germplasm preservation and

Figure 3.1.2

**National Plant Germplasm System: Distribution of germplasm, 1990-95**



Source: National Germplasm Resources Laboratory, USDA.

exchange. Whether funds will be adequate for the preservation provisions of the treaty are also unclear.

The expansion of intellectual property rights may further affect genetic resource conservation and exchange. The CBD and IT establish property rights for plant germplasm in countries that are parties to the treaties, but the effects of these provisions on conservation have not yet been observed.

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