Research & Technology

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Agricultural Genetic Resources: Building Blocks for Future Crops

Agricultural genetic resources—living matter used by plant breeders to develop or enhance desirable traits in crops such as high yields, resistance to disease, and drought tolerance—play a critical role in agricultural production. Genetic improvements from plant breeding account for half the crop yield increases over the past six decades. But continuing evolution of diseases and other pests presents a threat that can quickly undo the gains. Infusions by plant breeders of genetic resources from the wide array of wild and improved plant species found around the world helps maintain and extend the plant characteristics that advance agricultural productivity.

Diverse Genetic Resources Can Improve Cultivated Crops

All agricultural crops descend from wild or weedy ancestors, many of which are still found today. Selecting desirable plants to cultivate began early in human history, and as plants were domesticated for agricultural production, they evolved and were improved by farmers over many generations—before the use of modern breeding techniques. These farmer-improved crop varieties are called *landraces*. Landraces continue to be grown in some parts of the world, and they are generally very diverse because they are adapted to specific environments.

Plant breeding in the modern sense is a relatively new development. Early in the 20th century, modern breeding techniques were developed that relied on the planned crossing of distinct parent plants to facilitate selection of specific desirable traits. At the same time, the disciplines of genetic science and statistics were emerging. Germplasm (genetic material) that has been improved by plant breeding is generally referred to as "modern" germplasm. Modern germplasm includes genetic material in cultivars (varieties) used by farmers, as well as "breeder lines" modified by plant breeders for use in creating new cultivars.

For different types of crops, breeders have developed elite germplasm and selected traits that improved yields, resistance to disease and stress, quality, and other production characteristics. Some of the yield gains from genetic improvements have arisen because of "pure" yield traits, or traits that increase yields in ideal growing environments. Yield gains also result from plants' improved ability to use inputs—e.g., fertilizer and water.

Breeding for resistance—which includes tolerance—has become a primary goal of plant breeders. Resistance traits make plants less vulnerable to pathogens, thereby increasing the level and consistency of crop yields. Because diseases and other pests evolve over time, breeders need continually to incorporate new and diverse germplasm, sometimes drawing on wild relatives and landraces to find specific traits. New varieties are resistant for an average of 5 years, although it generally takes 8-11 years to breed new varieties. Breeders also work on developing varieties that can tolerate nonbiological stresses such as drought. Nonbiological stresses can also change over time, although generally less rapidly than diseases and other pests.

Among the desirable characteristics developed by breeding to enhance crop production efficiency are rapid and simultaneous development during the germination, flowering, and maturation stages, as well as uniform height for easier mechanical harvesting. Varieties of a commodity may also be bred for end-use characteristics—e.g., oranges for processing into juice or for the fresh produce market. Breeding for quality traits also has produced high-oil corn, as well as wheat with improved gluten and golden rice with heightened levels of vitamin A.

The overall genetic diversity of crop varieties that farmers choose to grow can affect the severity of outcome of a disease or other pest infestation. Genetic uniformity does not necessarily mean that a variety is more vulnerable to diseases and other pests. Modern varieties often are bred for superior resistance, hence their popularity. Nonetheless, as diseases and other pests evolve to overcome host-plant resistance, genetic uniformity increases the likelihood that a particular pest mutation, by having a larger susceptible area, will be an evolutionary success. With a larger crop base for an evolved disease or other pest to successfully attack, the potential severity of losses is greater and could even reach epidemic levels.

Although defining and measuring on-field genetic diversity is difficult, many scientists believe that modern breeding techniques have narrowed the genetic base of cropped varieties as increasing percentages of total production are devoted to more genetically uniform products. For example, the U. S. Southern corn blight of 1970—which caused a 15-percent yield loss nationwide—was associated with a gene that was susceptible to a new strain of blight. Because the gene was closely linked to the male sterility gene broadly used in the majority of corn hybrids, its presence made genetically similar hybrids vulnerable.

In the past, farmers as a group often grew many different varieties of a crop in a given geographic area. Today, farmers often grow similar varieties in a given region, but the characteristics of the planted crops change more rapidly over time. Breeders have succeeded in overcoming and mitigating outbreaks of disease or other pests by using the genetic diversity held in gene pools to create new varieties as resistance develops. This kind of genetic diversity (temporal diversity) is found in the succession of varieties that are used across time (e.g., growing seasons) rather than within a given space (spatial diversity).

Storing Germplasm To Protect Biodiversity

In the U.S., most agricultural genetic resources are preserved *ex situ,* by removing genetic material from its normal environment for long-term conservation. Botanical gardens, zoos, and gene banks are examples of *ex situ* biological conservation strategies. Gene banks hold large stores of germplasm, with more than 6 million accessions—or unique samples of crop varieties—at sites around the world. Nevertheless, samples of only a small fraction of the world's plant genetic resources have been collected thus far.

Ex situ conservation includes collection of samples, storage of seeds under controlled conditions, and periodic regeneration (planting and growing the seed to maturity) in order to maintain seed viability. Some plant varieties lose their varietal identity when propagated as seed, so they may need to be kept as living plants, a more costly process that requires additional land and labor.

Germplasm is held by public institutions, private companies, and individuals. In the U.S., the National Plant Germplasm System (NPGS), administered by USDA's Agricultural Research Service, is the primary public-sector institution involved in the effort to secure and utilize germplasm. The NPGS—which collects, develops, and distributes genetic materials—includes centralized facilities as well as a number of collections throughout the country.

Long-term seed storage is the function of the National Seed Storage Laboratory, a high-security NPGS facility that maintains the base collection and backup seed samples for germplasm found in other NPGS facilities. The NPGS maintains close ties with the State Agricultural Experiment Stations, and many of the NPGS facilities are located on or near Land Grant Universities, which facilitates research use of NPGS germplasm. The National Clonal Germplasm Repositories keep germplasm of vegetatively propagated crops.

The NPGS includes collections for more than 85 crop commodities. For each crop, the NPGS seeks both breadth and depth by collecting three types of germplasm: modern, landraces, and wild and weedy relatives. Curators and breeders want all three types of germplasm in a collection. Landraces and wild and weedy relatives often have unique resistance or quality traits, though they can be difficult to incorporate into a modern, high-yielding variety, while modern material may be less exotic but is generally easier to use. The NPGS collections also contain genetic stocks—i.e., mutations, variations, and oddities that are used in genetic research and sometimes in plant breeding.

Germplasm management includes collection, preservation, characterization and evaluation, and enhancement. *Collection* involves gathering germplasm from the field, the wild, or from other gene banks. *Preserving* germplasm includes general maintenance of germplasm and the use and development of technology to improve the preservation process. *Characterization* includes cataloging and studying the general make-up of the species. *Evaluation* involves examining germplasm for traits that are affected by the environment, such as temperature tolerance or pest resistance, and for traits that are relatively independent of the environment, such as size or taste. *Enhancement* involves using germplasm to create superior crops through breeding.

Genebank managers, together with breeders, allocate resources among these five activities. Each activity has benefits, as well as costs. For example, collecting germplasm allows samples to be used in the future, so that the option to use potentially scarce genetic resources could remain open if the samples are sufficiently well-preserved. Evaluation activities provide breeders with needed information about traits. Accurate characterization and evaluation data directs breeders' efforts in their search for traits in germplasm. Enhancement activities are needed for germplasm to translate into benefits related to agricultural production.

The NPGS is one of the world's largest collectors and distributors of germplasm. The germplasm management and enhancement system has yielded considerable economic benefits for U.S. and world agriculture by contributing to increased productivity and greater production.

Most economic studies have focused on benefits embodied in returns to the final products of the germplasm enhancement process—i.e., new crop varieties. Because these benefits arise from a combination of activities, economists have started to examine the components leading to germplasm enhancement. For example, new economic methods have assessed the optimal size of germplasm collections. Other work has estimated the optimal numbers of accessions scientists need to search in order to locate given characteristics. Thus far, economic studies generally find that the benefits associated with additional genebank accessions far outweigh their collection, preservation, and search costs, even in large collections that are not used frequently.

However, it takes time to realize some of these benefits, which helps explain why private-sector germplasm managers have different goals than public-sector managers. Private-sector germplasm collections are focused on activities that enable their breeders to produce successful new varieties.

In the early days of modern plant breeding, private companies did little plant breeding. Instead, they generally commercialized seed varieties created by public-sector breeders. The development of hybrid varieties spurred private companies' interest in varietal development because hybridization offered a natural form of intellectual property protection. Hybrid seed loses considerable genetic purity and yield potential when replanted. Legal mechanisms for protecting varieties and biological inventions have provided further incentives for private breeding activity.

Currently, private-sector breeders outnumber public-sector breeders, and private seed companies now have substantial collections of germplasm. Privately funded germplasm banks place a high priority on germplasm enhancement, in contrast to publicly funded organizations whose goals are more diverse. Private collections generally focus on breeders' working collections of elite germplasm used in the breeding process. Private incentives to collect and maintain a collection for long-term use are small, because economic returns may not be realized until far into the future.

Many forms of germplasm have limited appropriability—i.e., they cannot be protected from use by others because they can be easily reproduced for breeding purposes—and therefore they have little commercial value. The NPGS focuses on germplasm that may be needed by both public and private breeders well into the future. The NPGS has amassed a significant collection of exotic germplasm that, while sometimes difficult and time-consuming to use, can be a crucial source of traits, particularly resistance traits. The NPGS also retains accessions for national security purposes, so that the U.S. has an adequate supply of breeding material, regardless of global political developments.

These accomplishments notwithstanding, the present gene bank system is not without limitations. Gene banks hold relatively few wild relatives of today's domesticated varieties. And many gene banks may not be receiving adequate funding to fulfill their mission. According to a report by the General Accounting Office, the NPGS lacks sufficient funding to complete evaluation and documentation and to perform necessary backups and regeneration of seed accessions.

Biotechnology and Demand For Genetic Resources

The advent of biotechnology, specifically genetic engineering, has launched speculation about the effects of the new techniques on the demand for genetic resources. One goal of genetic engineering is to simplify the process of incorporating desired traits into new varieties, making it easier to use the beneficial characteristics of landraces and wild relatives of agricultural crops. Genetic engineering also can be used to incorporate traits from disparate species. For example, one line of research explores preventing frost damage in plants by utilizing flounder genes.

On the frontier of biotechnology research are efforts to increase breeders' access to genetic material in a plant. Within their DNA, organisms may carry genetic materials that are not actively expressed as traits, although those genes may be of interest to crop breeders. In the future, scientists may be able to determine how these unexpressed genes operate, and to make use of them in the breeding of new varieties.

Thus far, however, it appears that biotechnology has not significantly changed the process of plant breeding. To date, most genetically engineered varieties have incorporated one or two specific traits, such as insect resistance from the *Bacillus thuringiensis* (Bt) gene or herbicide tolerance. An important benefit from biotechnology is the increased speed with which breeders can develop new varieties. New technologies can be used by breeders to better understand the composition of germplasm used in breeding, whether genetically engineered or conventionally bred. And various molecular biology techniques offer a means of incorporating exotic and diverse germplasm.

Biotechnology can improve breeders' ability to find, select, and incorporate resistance, yield, and quality traits from genetic material that would be difficult or impossible to use with purely conventional techniques. But even the most sophisticated techniques cannot manufacture genetic material; they can only increase the efficiency with which breeders use germplasm from conventional sources. Therefore, the general expectation is that use of biotechnology will likely increase the demand for germplasm, at least in the foreseeable future.

Genetic Resources to Meet Diverse Goals

The agricultural sector faces increased expectations regarding the quality and quantity of food supplies, as rising world populations—mostly in relatively poor areas—and increasing incomes raise demand for agricultural products. Farmers must be economically efficient to remain in business, especially when commodity prices weaken or costs rise. At the same time, some natural predators of agricultural pests are in decline, and there is demand for enhanced environmental amenities—especially decreased use of toxic agricultural chemicals—as well as limitations to agricultural land expansion. Continuing improvements through plant breeding—especially adding traits that enhance yields and add resistance to disease or other pests—can help meet these challenges.

Uncertainty about specific resources that plant breeders will need for improving future agricultural production motivates genetic resource managers—especially in the public sector—to collect and accumulate a broad range of germplasm. Even though some conserved crop genetic resources may be used rarely today, it is likely the option to use them will be exercised in the future based on known probabilities of their use in combating diseases and other pests. The quest to increase agricultural production while preserving natural resources may further farmers' reliance on new crop varieties over time. Both factors suggest that breeders' demand for diverse agricultural resources may increase.

Economic research is underway to help genebank managers and breeders direct and distribute their resources. In cooperation with other institutions, USDA's Economic Research Service is working to analyze and quantify demand from both public and private users for biodiversity stored in public crop germplasm collections. Other research explores returns to various germplasm activities and alternatives for collecting diverse types of germplasm. Economic information can help managers make decisions about the allocation of effort among acquisition, assessment, maintenance and enhancement activities related to genetic material, so that genebank managers can get the highest benefit from their resources.

Genetic resources are critical inputs for the agricultural production system. Without continued genetic enhancement that relies on diverse germplasm from wild and improved sources, impressive gains in agricultural yields would soon prove unsustainable. Given the limited incentives for private firms to hold sufficient levels of all types of germplasm, a strong set of publicly held genetic resources is a major asset in meeting society's goals. AO

Kelly Day-Rubenstein (202) 694-5515
kday@ers.usda.gov

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- 13 *Oil Crops Outlook (4 p.m.)***
- 14 *Feed Outlook (9 a.m.)***
- 14 *Wheat Outlook (9 a.m.)***
- 20 *Agricultural Outlook**
- 28 *Livestock, Dairy, & Poultry (4 p.m.)***
- 29 *Rice Yearbook*
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