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RESEARCH AT A GLANCE

Biotechnology and Genetic Resource Policies

What Is a Genebank Worth?

Edited by Melinda Smale and Bonwoo Koo

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Briefs 7–12

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IFPRI was established in 1975 to identify and analyze national and international strategies and policies for meeting the food needs of the developing world on a sustainable basis, with particular emphasis on low-income countries and poor people; to make the results of its research available to all those in a position to use them; and to help strengthen institutions conducting research and applying research results in developing countries.

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The SGRP joins together the international agricultural research centers of the CGIAR in a partnership to contribute to the global effort to conserve genetic resources and promote their use in agriculture, forestry and fisheries for the benefit of current and future generations.

ABOUT RESEARCH AT A GLANCE AND THIS SERIES

Researchers and policy analysts increasingly need concise, comprehensive information on all aspects of complex research issues. IFPRI's Research at a Glance series has been designed to meet this need. This volume contains the second of a series of IFPRI briefs on biotechnology and genetic resource policies. The first set, published in January 2003 and containing Briefs 1 through 6, focuses on intellectual property rights issues, and this second set deals with issues related to the *ex situ* genebank and its collection. The briefs present syntheses and synopses of research conducted by a team from IFPRI's Environment and Production Technology Division and several collaborators. The team focuses on aspects of intellectual property rights, genetic resource management and conservation, biodiversity, and biotechnology.

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Cover photo credits

The collage background represents a Diversity Array Technology (DArT) image, a form of "DNA on a chip" technology developed by CAMBIA for low-cost genome analysis, here being used on rice. The image was generated by Damian Jaccoud. He is a student working under the supervision of CAMBIA's chief scientist, Andrzej Kilian.

RESEARCH AT A GLANCE

Biotechnology and Genetic Resource Policies

What Is a Genebank Worth?

Brief 7

INTRODUCTION: A TAXONOMY OF GENEBANK VALUE

Melinda Smale and Bonwoo Koo

> *"I am awed by how little economics can contribute at present to the valuation of genetic resources. A natural explanation is that since most of the genetic resources of interest do not trade in markets, there are no prices. And it is unlikely that price data will soon appear."*
>
> (Gardner Brown Jr., 1991)

It's Not as Easy as 1, 2, 3…

How much is a collection of plant genetic resources worth? Why do economists hesitate to place a value on it? Plant genetic resources generate economic value with multiple dimensions that are difficult to conceptualize. Only a few of these dimensions can be measured and related to a market price that is a basis for valuation. Scientific nuances complicate measurement. For example, the definition of the genetic unit to be valued depends on the crop and the farming-system context, and whether the units can be added together depends on how closely they resemble one another. Economics research, rather than accounting, is necessary to estimate the costs and benefits of the resources maintained in genebanks. Most genebanks have been publicly financed, and in the past there has been little demand by those who fund them to conduct economics research. Recently, however, demand for assessing the value of such collections appears to have heightened with changing intellectual property regimes and emerging biotechnology applications.

Broadly speaking, plant genetic resources can be conserved *ex situ* (out of their place of origin) by any one of several technical means, or managed *in situ* (in their place of origin), on farms or in wild reserves. The research briefs assembled here highlight published research about the value of *ex situ* collections held in genebanks. This first brief summarizes the way economists approach the topic.

An Economist's Taxonomy of Value

Economics is a utilitarian[1] discipline focusing on human society rather than biological systems. The economic value of plant genetic resources therefore derives from human use, although human use can refer not only to food, fiber, and medicinal production but also to aesthetic, ecosystem, and social-support functions (Brown 1991).

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[1] Relating to utility, or fitness for some purpose such as a product or service.

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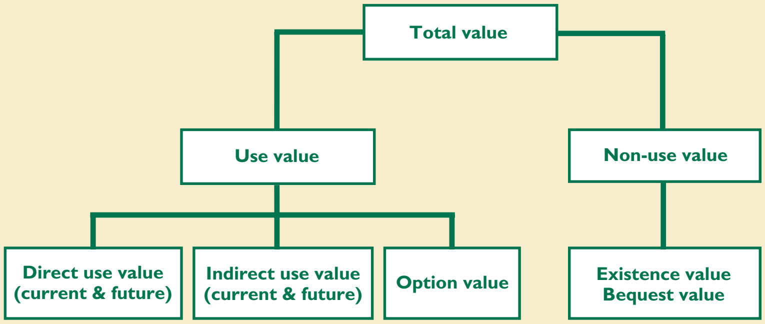
Plant genetic resources are natural resources and physical assets, generating streams of benefits-in-use through crop production and reproduction by farmers and professional plant breeders. Economists who assess the value of natural resources such as wildlife habitats and endangered species have developed a “taxonomy” that may also be used to classify the value of plant genetic resources (Figure 1). Congruent with this taxonomy, the total value derived from plant genetic resources is broadly categorized into *use value* and *non-use value*.

FIGURE 1 **Sources of value from plant genetic resources**



Use value may be direct or indirect. *Direct use value* derives from the food, fiber, and medicinal products to which plant genetic resources contribute, including the amenity value associated with their quality. *Indirect use value* reflects the contribution of plant genetic resources to surrounding habitats or ecosystems. Both direct and indirect use values have current and expected future dimensions. Another use value known as *option value*, implies the flexibility to deal with unexpected future demand for the resources (Fisher and Hanemann 1986).

Non-use value, compared with use value, reflects the satisfaction individuals or societies may derive simply from knowing that something exists, independently of whether or not it is used (Krutilla 1967). For example, *bequest value* refers to the utility individuals gain from knowing that future generations will have the opportunity to enjoy an asset. Endowing a genebank as a trust for future generations is a recognition of bequest value. *Existence value* is another type of non-use value.

It is difficult to imagine, however, that many people (other than a few scientists) take pleasure merely from the assurance that plant genetic resources are housed somewhere in a genebank. Instead, plant genetic resources are conserved precisely because they are thought to embody genes and gene combinations of current and future use to human society. We would argue that, unlike an endangered species or a scenic wonder, most of the value associated with the plant genetic resources in a genebank collection relates to their use rather than their existence.

Can We Measure the Values?

Only some of the dimensions of economic value associated with plant genetic resources are measurable by summing up quantities and prices. We can use methods for imputing the value of component parts or attributes of goods (such as “hedonic analysis”) to ascertain the current value for productivity enhancement of crop genetic resources embodied in crop varieties (Evenson, Gollin, and Santaniello 1998). Yet a genebank collection, in contrast to a breeder’s working collection, exists to a large extent in order to respond to future, often unforeseen challenges. As a consequence, the expected future use value or option value of a genebank collection is an important component of its total value.

We can, with some compromise and a number of caveats, calculate a present value of *expected* future benefits from direct use of germplasm in crop improvement for commercial agricultural systems. We do so by combining the probability of finding useful material with its expected productivity benefit once found and incorporated into new varieties (for example, see Brief 9). Algorithms or numerical rules of thumb can be used to establish upper and lower limits on genetic contribution of any particular progenitor in the pedigree of a commercial variety, and these often serve as best estimates (Pardey et al. 1996). The time required to search for and incorporate useful genes into well-adapted germplasm affects the magnitude of expected benefits in a major way because of the time value of money.

Option value is conceptually distinct from expected future use value and also more challenging to assess empirically. For example, we might use the past incidence of changes in rust disease pathogens or other major pest outbreaks to predict the expected future value of certain types of genebank accessions[2] as new sources of resistance for a known pest. However, there are some pests and other environmental events for which we have no prior knowledge at all. The option value of a genebank accession arises from this uncertainty—but determining its magnitude can be difficult. In any case, option value cannot be negative in sign.

Even if we succeed in counting up the use values that can be approximated through analysis of market prices and quantities, we are likely to underestimate their total value because of their multiple dimensions. Fortunately, we err only on the side of caution. There is another reason, however, why estimates based on market prices underestimate the value of plant genetic resources. Plant genetic resources are public goods, and market prices generally fail to capture the full value of public goods. While recent changes in intellectual property rights may alter the public-good nature of plant genetic resources used in crop improvement, the problem of relying on market prices to assign value to streams of direct use benefits from breeding will persist.

A large body of economic theory has been compiled to guide the estimation of nonmarket values. For example, methods developed by environmental economists can be used to elicit the prices that individuals would be willing to pay if they could trade a nonmarket good on a market. We might conjecture, however, that very few individuals understand plant genetic resources well enough to provide credible responses to such questions. To do this type of economics research properly, an adequate number of responses are needed from those who both consume and produce plant genetic resources. Otherwise, our best estimates may be “glancing blows” that “miss the center of the problem or the potential value of genetic resources” (Brown 1991, 230). Finally, there are many current and future uses of genebank accessions other than their direct use in breeding new crop varieties, and many of these uses are also contributions to other types of public goods, including knowledge (see Brief 11; Dudnik, Thormann, and Hodgkin 2001).

Overviews and surveys discussing the sources of economic value in plant genetic resources are numerous, including Pearce and Moran (1994), Swanson (1996), and Koo and Wright (2000). Alongside conceptual overviews of the sources of value, several theoretical economic models have addressed the value of genetic resources (Brown and Goldstein 1984; Weitzman 1993; Polasky and Solow 1995; Simpson, Sedjo, and Reid 1996; Evenson and Lemarié 1998; Rausser and Small 2000). There are few published examples that use actual data to estimate the economic value of genebank collections. In perhaps the first, Evenson and Gollin (1997) traced the flow of rice germplasm from the collection housed at the International Rice Research Institute into improved varieties grown in the developing world. At that time, they estimated that adding 1,000 catalogued accessions to the collection would generate an annual income stream with a value of $325 million at a 10 percent discount rate. Subsequent studies (Briefs 8 and 9) indicate that benefits to large collections through crop improvement of extensively bred crops are high even when they are rarely used, given that the accessions are viable and distinct.

Can We Count Costs Instead?

The costs of genebank operations are relatively easy to count and estimate compared with the benefits of the collections they house. Methods have been developed to estimate the costs of conserving accession by applying microeconomic principles of production economics (see, in particular, the work by Pardey et al. 2001). If the costs of conserving an accession are shown to be lower than any sensible lower-bound estimate of the corresponding benefits, for many decisions, it may not be necessary to undertake the expensive and challenging exercise of precisely estimating benefits to justify the existence and size of the genebank (Koo, Pardey, and Wright 2003: Brief 6 of this series).

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[2] An accession is a sample of planting material stored in an *ex situ* collection of genetic resources. Because of the way they are sampled and regenerated, accessions may or may not be unique and are not necessarily homogeneous.

How Can Economics Contribute to Management of Genebanks?

In fact, the fundamental economic issue involved is not the absolute magnitude of the benefits from conserving plant genetic resources. A library is a good analogy (Brown 1991). The problem is not in assigning a value to the books we have read, but in deciding which ones to keep from the many we have not yet read, especially given that our descendants will have very different tastes and will live in a very different world.

Given how little we know about the value of the world's plant genetic resources, we can still use economics principles in making decisions. For example, fixed budgets in many genebanks mean that we cannot conserve everything, and there are trade-offs associated with our choices. How do we choose? If all plant genetic resources had equal value, then those that cost the least to preserve would be those that should be preserved (Brown 1991). For the same conservation costs, those more likely to be used sooner rather than later are worth more, because of the time value of money. Those that are close substitutes have less value than those that are rare or genetically distant (Simpson, Sedjo, and Reid 1996). Rich societies and benevolent social decisionmakers tend to value the distant future more than do poor societies and any single decisionmaker. Krutilla (1967) argued that when little is known about the cardinal value of benefits, scientific estimates should be used as proxies for ranking the potential value of candidates for conservation. The decision to manage each original sample of seed or plants as an accession is not necessarily optimal for efficient conservation or utilization, and managers have the option to combine or split accessions based on a combination of genetic and cost criteria (Sackville Hamilton et al. 2002). Some of these pressing management issues can be addressed through the application of economic principles.

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RESEARCH AT A GLANCE

Biotechnology and Genetic Resource Policies

What Is a Genebank Worth?

Brief 8

SEARCH STRATEGIES AND THE VALUE OF A LARGE COLLECTION

Douglas Gollin, Melinda Smale, and Bent Skovmand

While the agricultural productivity benefits of utilizing new germplasm have been widely documented (Evenson 2001; Alston, Norton, and Pardey 1998), some controversy remains about the economic justification for expanding existing collections of crop genetic resources. Concerns persist that germplasm collections are underutilized (Wright 1997) and therefore of questionable economic value. Does infrequent "use" of genebanks in crop breeding programs imply that accessions in genebanks have little economic value? Are seed banks really "seed morgues"?

This study was motivated by criticisms that because plant breeders seldom "use" genebank accessions directly in their breeding programs, there appears to be little justification for maintaining collections. The approach builds on earlier work by Evenson and Gollin (1997), examining more closely the relationship between genebank activities and crop improvement. A search theoretic framework invoked previously for the cases of sugarcane breeding (Evenson and Kislev 1976) and the pharmaceutical industry (Simpson, Sedjo, and Reid 1996) was applied to the analysis of genebank decisions with actual data from searches for new sources of disease and pest resistance. Findings shed some light on the optimal size of collections and on the circumstances in which large genebanks have economic value.

Economic principles dictate that a search should proceed until the expected gains from searching an additional accession are outweighed by the additional costs of the search. The expected gains are defined as the product of two factors: (1) the discounted stream of future benefits from finding the trait and (2) the change in the probability of success from searching one more accession, where the probability of success is the chance of finding an accession with the desired trait in a search of a given size.

Three specific questions on genebank management are answered with numerical experiments on data from past searches and wheat variety diffusion in regions of the developing world.[1] The first case, about the Russian wheat aphid, demonstrates that the probability of finding a targeted trait is extremely sensitive to the frequency distribution of the desired trait among the accessions searched. This distribution in turn depends on the breadth and size of the collection from which the materials are drawn and the distribution of the trait in the underlying plant population. The rarer the source of new resistance, the larger the search needed, and by implication, the larger the collection. A

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Sir Bent Skovmand *is currently director of the Nordic Gene Bank. While conducting this research he was head of the Wheat Genetic Resources Program, International Center for Maize and Wheat Improvement (CIMMYT), Mexico.*

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[1] The sources of data for this analysis include the International Maize and Wheat Improvement Center (CIMMYT) and the Genetic Resource Information Network of the National Small Grains Collection at the U.S. Department of Agriculture.

problem of global importance clearly warrants a large search effort, implying a collection of large size.

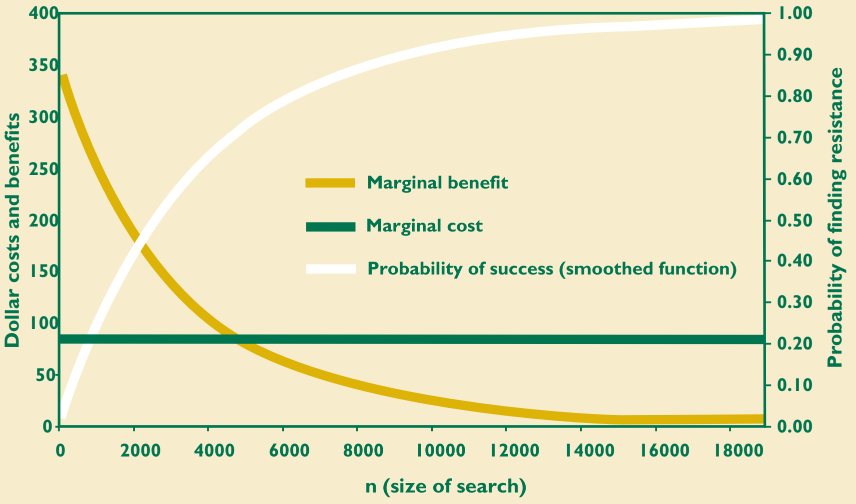
As in any analysis of the benefits from crop improvement, the discounted stream of future benefits depends on how long it takes for plant breeders to transfer the new source of resistance into the variety, the time it takes for the new variety to pass regulatory hurdles, the magnitude of the "problem" to be resolved, and the popularity of the new variety among farmers. The variety's popularity in turn depends on how well adapted it is to local production conditions, how heterogeneous these conditions are, and other constraints farmers face in purchasing seed or related inputs. In the "problem" of coping with yield lost to diseases or pests, the crop breeding process is a race for the development and release of varieties with novel sources of resistance against evolving strains of plant pathogens or pests. The time value of money—or the perspective of the research investor—is a critical parameter in projecting the magnitude of the benefits.

The second experiment illustrates the value of specialized knowledge concerning the "location" of resistance in the collection. The capacity to focus or target a search generally has large payoffs. A priori knowledge that accessions from a given geographical area (in the case of Russian wheat aphid, Iranian landraces[2]) are likely to be more resistant to a pest dramatically reduced the search size required and increased the expected net benefits from the search (Figure 1). What is the basis of this knowledge? It may be held by a few experts or by public databases.

The third experiment indicates why plant breeders avoid tapping categories of genetic resources that are "raw" or unimproved and incompletely characterized. Resistance to Septoria leaf blotch is far more common among accessions of emmer wheat than among elite breeding lines, but the costs of evaluating emmer and transferring resistance into materials that are ready for release to farmers is high. This case shows that it may be efficient not to focus on the accessions known to be more resistant if the relative cost of moving this resistance into varieties that can be rapidly released and adopted by farmers is high.

This study clarifies some essential points about the valuation and utilization of genebanks. First, the empirical examples suggest strongly that large genebanks have substantial economic value for agricultural crops such as wheat. Wheat is an intensively bred, major world cereal crop. There are occasional situations in which the chances of finding a trait are slim and the economic payoff to discovery is great. These are the situations from which large collections derive their value. There are other occasions when the trait of value is found in a tiny subset of the world's collections of genetic resources, such as a set of landraces from a particular geographic location. Although they may be searched rarely, there are reasons for storing them "unused" for years. Most importantly, the casual observation that plant breeders reach into their own collections more frequently than they

FIGURE 1 **Optimal size of search for Russian wheat aphid resistance in a sample of *Triticum aestivum* landraces (optimal size of search = 4,700)**



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[2] The term *landraces* originally referred to livestock breeds, but is now often used to describe traditional or farmers' varieties of crops that are the product of breeding or selection by farmers in their own communities over a number of years. Unlike commercial cultivars that must be recognized as distinct, uniform, and stable, a landrace is typically heterogeneous and may contain rare alleles or gene complexes because of its local adaptation.

demand unimproved materials from genebanks in no way implies that the latter have no value. Certainly survey evidence shows that the crossing blocks of plant breeders themselves hold significant genetic reserves (Brennan et al. 1999; Rejesus, Smale, and Van Ginkel 1996), and Duvick (1984) has argued that the genetic base of elite germplasm provides more useful diversity of traits than is often assumed. For reserves held in banks, however, short-term payoffs may be modest while long-term payoffs are great, especially when considering the multiple traits for which the same accessions can be searched.

While genebank managers can attend to the content of their collections and their management, it is clear that many factors outside their control determine the magnitude of the economic benefits from finding and transferring traits into crop varieties. In some cases, forecasts of future benefits can be grounded on past calculations of benefits and patterns of variety diffusion. As argued in Brief 7, however, the use of economic principles (e.g., marginal benefits equals marginal costs) in deciding which accessions to keep or discard is not so straightforward as it may seem. The range in total discounted net benefits from searching for and finding a new source of resistance to Russian wheat aphid was enormous—more than $165 million—warranting a search that was larger than the total number of wheat landraces in the CIMMYT genebank.

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For a more detailed version of this summary, see

Gollin, D., M. Smale, and B. Skovmand. 2000. Searching an *ex situ* collection of wheat genetic resources. *American Journal of Agricultural Economics* 82 (4): 812–27.

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RESEARCH AT A GLANCE

Biotechnology and Genetic Resource Policies

What Is a Genebank Worth?

Brief 9

THE MARGINAL VALUE OF AN ACCESSION

Armineh Zohrabian, Greg Traxler, Steve Caudill, and Melinda Smale

Ascribing productivity gains to specific genes or accessions is difficult because of the nature of the research process in genetic enhancement, the relationship among genes within a genome, and the interaction of genes with the environment of the crop. Even in commercialized agriculture, the value of unimproved material used for genetic enhancement cannot be measured directly because only finished (or nearly finished) crop varieties are traded in markets (Brief 7).

What is the expected benefit from using an additional, unimproved genebank accession in crop breeding? Typically, plant breeders can deduce little about what these accessions have to offer from the existing data describing them. This study answers this question by combining search theory with a maximum entropy approach, which is particularly suitable for analysis with sparse data. The study estimates the marginal value of utilizing prebreeding materials contained in the U.S. National Plant Germplasm System. Data were drawn from trials to screen 573 recently acquired accessions that test for susceptibility to soybean cyst nematode. The present discounted value of benefit streams in the United States was estimated with areas planted to soybean and its prices.

The present value of the expected gross research benefits is estimated at about $36,000 to $61,000, which implies that the benefit-cost ratio for investing in an additional accession to prevent losses from a single pest is in the range of 36 to 61. The size of benefits is sensitive to changes in area planted to the crop and to the discount rate because of the time lag between investment in the research and the stream of earnings. The magnitude is also affected by the economic value of the crop, the severity of damage caused by the disease, and the likelihood of future outbreaks requiring a new search.

The findings of this study indicate that the lower-bound benefits from utilizing a marginal accession are higher than the upper-bound costs of acquiring and conserving it, justifying the expansion of the U.S. soybean collection. The calculation of the upper-bound costs were based on the costs of screening, the collection costs estimated by the U.S. Plant Introduction Office, and the costs of conserving more expensive crops (Pardey et al. 2001). It should be noted that the estimated benefit reflects the search for a single trait, although any single accession has the potential to be searched for more than one trait. The option value of the accession and other non-use benefits were omitted, as in the cases reported by Evenson and Gollin (1997) and Gollin, Smale, and Skovmand (2000, Brief 8).

How can such a favorable economic return exist in economic equilibrium? Explanations are related to the public-good nature of genetic resources. Even in the publicly funded collection of a rich country, the budget constraint is severe, and much of the budget is consumed as fixed costs with little left over for screening. What about private interests? Despite the fact that private firms are the dominant provider of soybean varieties in some countries, they invest little in the screening and incorporation of

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unimproved genetic resources because incorporating genes from these sources is a long-term, risky prospect. Finally, the benefits reported here include total benefits to both consumers and producers. In fact, suppliers of soybean seed are likely to be able to appropriate less than half of the total benefits through sales (Falck-Zepeda, Traxler, and Nelson 2000).

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RESEARCH AT A GLANCE

Biotechnology and Genetic Resource Policies

What Is a Genebank Worth?

Brief 10

STRATEGIES FOR TIMELY EVALUATION OF GENEBANK ACCESSIONS

Bonwoo Koo and Brian D. Wright

The importance of plant genetic resources as building blocks for crop improvement has grown with recent advances in biotechnology and scientific information. The lack of useful data about accessions is frequently cited as an obstacle to greater utilization of genebanks by plant breeders (Wright 1997). In this context, we can invoke again the analogy to a library for the importance of relevant information, as discussed in Brief 7. If there are no data on the title, keyword, or other relevant information about the books held in the library, they will rarely be used, and the value of the library will be small.

Evaluation data are of the greatest value to plant breeders seeking to improve traits such as resistance to particular pests and diseases. Due in part to financial constraints, it is usually the case that only a small fraction of samples in genebanks are accompanied by evaluation data (Peeters and Williams, 1984). The dearth of supporting data has led some plant breeders to demand more extensive evaluation of genebank materials, although not all agree. The important policy questions for genebank management include when genebank managers should evaluate their materials and how new technological tools should change this decision.

Breeding for disease or pest resistance provides an illustrative example. Some diseases or pests cause chronic losses, and the rate of mutation in the pathogen is high, so that breeders are continually in search of new genetic mechanisms conferring resistance. Other types of diseases or pests occur rarely, with devastating losses. Identifying a novel source of resistance before infestation of a disease incurs significant costs. If the problem of disease infestation is unlikely to occur frequently, then in hindsight it usually becomes clear that the money spent for prior evaluation was wasted. On the other hand, if evaluation is initiated after the disease occurs, excess prior evaluation is avoided, but social losses due to crop damage accumulate during the delay before the release of the new variety. For example, the estimated damages of $670 million caused by Russian wheat aphid in the U.S. during the late 1980s might have been mitigated if the sources of resistance had already been identified (Russian Wheat Aphid Task Force 1991). In contrast, when barley stripe rust fungus devastated barley crops in South America after its arrival from Europe in 1975, plant breeders in the United States worked to identify sources of resistance to the disease and were already breeding resistant varieties when the disease reached the Unites States in 1991.

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Timing of Evaluation

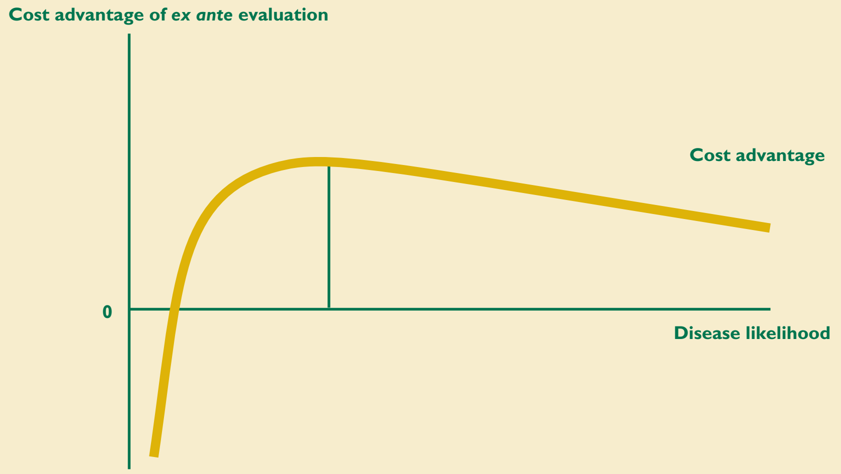
With limited resources and the numerous materials found in a collection, a genebank manager cannot search ahead of time for all possible traits of all genebank collections. Most managers choose to delay evaluation of the collection until after disease infestation (*ex post*), which is justifiable if the trait is expected to be used infrequently in the future. For a rare disease, the cost of searching at present is great relative to the expected present value of the benefits captured later. *Ex ante* evaluation may be preferred for a disease that is more likely to cause an infestation soon, because it reduces the expected social losses associated with the disease during the period of evaluation and variety development. Examples include Australia's development of locally adapted cultivars resistant to wheat stem rust (McIntosh and Brown 1997), and the strategies for breeding nonspecific resistance to stem, leaf, and stripe rusts of wheat at the International Maize and Wheat Improvement Center (Rajaram, Singh, and Torres 1996).

The likelihood of disease infestation provides a signal to a genebank manager regarding evaluation priorities. If a disease occurs rarely, early evaluation is less attractive. If a disease is expected to occur soon, the trait will be evaluated in any case, and the importance of timing the decision is reduced. Figure 1 shows the graph of a cost advantage of *ex ante* evaluation as a function of the likelihood of disease infestation. The size of the cost advantage indicates the degree to which *ex ante* evaluation is preferred to *ex post* evaluation. The advantage of *ex ante* evaluation does not continue to increase after the likelihood of disease infestation reaches a certain point. The benefit from *ex ante* evaluation is largest when the likelihood of disease infestation is at an intermediate rather than a maximum level. A genebank manager should therefore pay greater attention to the timing of evaluation when the likelihood of a disease infestation is in the intermediate range.

The Role of Biotechnology

Recent biotechnology innovations have made evaluation for resistance traits and development of useful cultivars incorporating these traits cheaper and faster. Genetic marker techniques and genomic information reduce the time spent evaluating for some resistance traits. In principle, genetic engineering techniques can expedite plant breeding by enabling the insertion of genes into backgrounds that are proven to be popular without linkages to other, undesirable genes that would have been eliminated through backcrossing with conventional means. Although we often assume that the use of tools that speed evaluation and development would favor *ex post* evaluation for resistance to disease, the opposite appears to be the case. The explanation for this result is that the marginal benefit from the technological breakthrough is larger when the development process is started earlier.

FIGURE 1 **The cost advantage of *ex ante* evaluation and likelihood of disease infestation**



Implications

The agricultural environment is continuously changing, and so is the demand of plant breeders and other scientists for genetic resources. Predicting the future use of accessions stored in genebank collections is difficult. The timing of the evaluation of accessions is an important issue for genebank managers. A commonly expressed view is that all traits likely to be relevant in crop improvement should be completely evaluated *ex ante* in order to facilitate and encourage the utilization of the genebank by plant breeders. This analysis shows that for a trait that has a low probability of being needed soon, *ex ante* evaluation tends to be dominated by delayed evaluation. This finding has meaning for genebank managers who face chronic funding problems. Instead of spending scarce financial resources for the expensive evaluation of rarely used genes, it may well be more efficient to focus on other activities such as the provision of basic information and the construction of a network to enable better information flow (Frankel 1989). Technological breakthroughs that reduce the cost and speed of evaluating accessions and developing cultivars will encourage *ex ante* evaluation. The economic implications of various managerial strategies for evaluating genebank accessions will need to be revisited as the science becomes better understood.

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RESEARCH AT A GLANCE

Biotechnology and Genetic Resource Policies

What Is a Genebank Worth?

Brief 11

THE DEMAND FOR CROP GENETIC RESOURCES FROM A NATIONAL COLLECTION

Kelly Day-Rubenstein and Melinda Smale

Who uses a genebank? What kind of germplasm is requested and for what purpose? How is it in fact "used"? What problems do users identify? This case study seeks to answer these questions with data collected directly from individuals who requested samples from the U.S. National Plant Germplasm System during 1995–1999 for 10 major crops (barley, bean, cotton, maize, potato, rice, sorghum, soybean, squash, and wheat). Genebank accessions are used in many different ways, and large national genebanks receive many requests from international sources. In contrast to the perception that genebanks are rarely used, the findings reveal the sheer numbers of germplasm samples distributed by a large national genebank to many types of scientific institutions located in numerous countries around the world.

Like other national genebanks, the U.S. National Plant Germplasm System (NPGS) has a clear mandate to serve the needs of national scientists, and for the 10 crops studied, about three-quarters of the 621,238 samples shipped during the survey period were destined for requestors located in the United States. Nevertheless, of this number, 162,673 samples were sent to scientists located in 191 other countries and in 45 territories or commonwealth associations. Of these, 46 percent were destined for developing countries, 17 percent for transitional economies, and 37 percent for other, richer countries in Europe. The vast majority of all samples (77 percent) were sent to noncommercial organizations. Another 13 percent were sent to other genebanks, while only 5 percent and 6 percent were distributed to commercial companies and international agricultural-research centers, respectively.

The survey of requestors outside the United States, conducted by the International Plant Genetic Resource Institute (IPGRI), provides additional details on the kind of genetic resources demanded and their uses. Roughly half of all respondents requested improved cultivars, and an equal number requested either landraces or wild relatives—revealing a surprisingly high demand for exotic materials. On the other hand, the request for advanced materials and genetic stocks represented smaller shares. Demand for germplasm type depends on the crop, with landraces and wild relatives apparently more attractive to respondents working with potato, a crop with a very narrow genetic base. Genetic stocks with improved breeding lines were more likely to be requested by respondents working with maize, a crop with a relatively advanced level of basic research.

About 78 percent of the intended use of samples requested from the genebank was for breeding, prebreeding, and evaluation purposes to search for desired traits. Others were

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intended for basic research or for adding to collection. The major focus for trait evaluation was biotic resistance or tolerance to abiotic stress. Respondents from developing countries requested landraces and wild relatives less frequently than did those from developed and transitional economies. Perhaps they sought materials that could be more immediately brought into their breeding programs, or perhaps, for traits such as resistance or grain quality, they tend to look first among their own locally adapted landraces.

Within the brief five-year period covered by the respondents, 11 percent of germplasm samples had already been incorporated into breeding programs (Table 1). Given the long time period required to breed a new variety, it is not surprising that much of the material is still being evaluated (43 percent). Respondents considered 19 percent of samples to be useful in other ways, leaving 28 percent of received materials described as “not useful.” The long-term nature of plant breeding and agricultural research, combined with the reproducible nature of seed, implies that the utilization rates calculated over a short period of time underestimate actual use patterns in both temporal and spatial terms. That is, materials may be useful much later in a breeding cycle than when they are first received, and they may be incorporated into research multiple times by different users.

The percentages estimated from the survey data were applied to actual distribution data to estimate the utilization of germplasm samples sent to requestors outside the U.S. during the 1995–1999 period. In those years only, for 10 major crops alone, scientists in other countries have already used an estimated 17,686 samples in breeding or in other ways.

Notably, respondents located in developing countries reported a much higher share of samples—nearly 80 percent—to be useful in one way or another. They also reported a much higher rate of secondary transfers or sharing of samples with other scientists than did respondents in developed or transitional economies. A majority of these respondents also expected to increase their requests from the genebank during the next decade and were more likely to respond positively than those from either developed or transitional economies (Figure 1, next page).

In contrast to the perception that genebanks are seldom used, the data demonstrate in simple, unequivocal terms the volume of genetic resources distributed to scientists, redistributed to others, and used in various ways. Although maintaining public access to the

Table 1—Utilization of germplasm samples sent to other countries by the U.S. National Plant Germplasm System, 1995–1999

	Being used in breeding	Still being evaluated	Being used in other ways	Not used (not useful)
Estimated percentage of recipient			**(percentages)**	
Developed countries	6	41	29	25
Developing countries	18	55	8	20
Transitional countries	7	24	19	50
All recipients	***11***	***43***	***19***	***28***
Estimated number of samples			**(counts)**	
Developed countries	1,220	8,632	6,018	5,175
Developing countries	5,644	17,531	2,516	6,462
Transitional countries	733	2,473	1,984	5,168
All samples	***6,794***	***27,299***	***11,777***	***17,686***

Source: Survey conducted by International Plant Genetic Resources Institute.

Note: Number of respondents is 380. Survey estimates are applied to actual distribution data provided by the U.S. National Plant Germplasm Resources Laboratory resources housed in this large national genebank serves its national scientists, the international scientific community also benefits. Even national genebanks generate global benefits in use.

For more detailed information, see

Smale, M., and K. Day-Rubenstein. 2002. The demand for crop genetic resources: International use of the U.S. National Plant Germplasm System. *World Development* 30 (9): 1639–55.

FIGURE 1 Expectations for U.S. National Plant Germplasm System germplasm use over the next decade, by development status of country

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Biotechnology and Genetic Resource Policies

What Is a Genebank Worth?

Brief 12

THE DEMAND FOR CROP GENETIC RESOURCES FROM INTERNATIONAL COLLECTIONS

Cary Fowler, Melinda Smale, and Samy Gaiji

It is commonly known that most major agricultural crops were domesticated over a period of a thousand years in what are now termed "developing" countries of the "South." Path-breaking conservationists such as Vavilov (1926) and Harlan (1975) have documented the great genetic diversity found in these countries. There is little doubt that the flow of crop genetic resources from developing countries to Europe and North America provided much of the biological foundation for agriculture in today's developed countries (Fowler 1994).

However, comparatively less attention has been given to the patterns of more recent flows of genetic resources. It is suggested that recent flows of genetic resources are generally directed at crop improvement, where as historical transfers were often aimed at crop introduction. While acknowledging the significance of historical patterns, this study provides a snapshot of more recent flows enabled through the centers of the Consultative Group on International Agricultural Research (CGIAR). Data sources for the analysis include the International Maize and Wheat Improvement Center (CIMMYT), the System-wide Information Network for Genetic Resources (SINGER), and a set of case studies for 15 developing countries from 1972 to 1991.

The CGIAR is the largest consortium of crop-oriented research facilities in the world, concentrating on major crops of importance to world food security. The germplasm held "in trust" at the genebanks in the CGIAR remains part of the "public domain." Landraces make up a substantially larger portion of the CGIAR collections (59 percent) than they do in national (12 percent) or private (9 percent) collections (FAO 1998). Experts generally agree that for highly bred crops such as wheat and rice, much of the breadth of the gene pool is represented by samples held in genebanks (FAO 1998), with only a few pockets of diversity remaining in farmers' fields. Countries in what is known as the Vavilovian centers of origin are no longer the principal suppliers of such materials, and some areas ceased filling this role decades ago. In some sense, the genebank has become a modern-day "center of diversity."

Data from detailed case studies for 15 developing countries reveal that the number of germplasm samples received from the CGIAR collections were many times more than they contributed to the collection over the period 1972–1991. Although this is the time period in which the greatest outflow of genetic resources from developing countries took place during collection missions, the countries in these studies clearly received more of samples than they contributed (Table 1, next page). The 15 countries were net recipients of germplasm during the two decades in all crop categories except roots and tubers.

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Table 1—Flow of germplasm between less developed countries (LDCs) and CGIAR genebanks, from 1972 to 1991

Crop Category	LDCs → CGIAR genebanks	CGIAR genebanks → LDCs
	(number of samples)	
Cereals	63,479	247,386
Roots and tubers	17,726	15,470
Legumes and pulses	33,031	202,130
Vegetables	2,712	47,502
Forages	7,381	16,928
All crops	***124,329***	***529,416***

Source: Fowler, Smale, and Gaiji 2001.

Note: LDCs include Chile, Colombia, India, Indonesia, Kenya, Madagascar, Pakistan, Peru, Philippines, Rwanda, Saudi Arabia, Syria, Tanzania, Uruguay, and Zimbabwe.

Subsequent analysis of records amassed over the past 28 years of samples of key crops from six of the CGIAR centers (CIAT, CIMMYT, ICARDA, ICRISAT, ILRI, and IRRI) shows that more than 80 percent of the materials distributed by genebanks, which totaled about one million samples, went to organizations in developing countries, the vast majority being universities and national agricultural research systems (SINGER, singer.cgiar.org). Nearly three-quarters of the material that had originated from developing countries flowed back to those countries. Developing countries that requested the same material were furnished an average of four times per accession (as opposed to twice per accession for developed countries), indicating the important service of the genebanks to their national agricultural research needs.

Although germplasm transfers from genebanks at CGIAR centers are significant in terms of both volume and value to breeding programs, the transfers of breeding lines through their nurseries are much greater both numerically and, most likely, in terms of economic importance. These breeding lines help to reduce the costs of national crop improvement programs, speed up the varietal development and release, and broaden the pool of materials accessible to scientists. For the past few decades, the productivity gains stimulated by germplasm exchanges through the CGIAR have been large, although unevenly distributed across crops, regions, and time periods (Evenson and Gollin 2003).

This international exchange of germplasm has increased the likelihood of introducing new materials to the genealogies of a variety, although often the genetic contribution of any particular landrace is small. For example, of the 1,162 spring bread wheat cultivars released by developing countries from 1965 to 1997, an estimated 87 percent had at least one CIMMYT progenitor (Smale et al. 2002). Measured by either genealogical or molecular indicators, the genetic diversity of major CIMMYT progenitors has increased over the past three decades. Because national programs in developing countries cross CIMMYT lines with their own materials before releasing them, the genetic diversity of their cultivars is at least as great as that present among CIMMYT lines. Heisey, Lantican, and Dubin (1999) have estimated that for an annual investment of only $100 million to $150 million, the international wheat breeding system produces annual benefits ranging from $1.6 billion to $6 billion or more, in 1990 U.S. dollars. The size of benefits depends on how the credit for yield gains is distributed between yield gains and crop management practices and on numerous other economic and technical assumptions.

The transactions costs involved in negotiating bilateral access for all of these transfers would have been enormous, and it is suggested that a multilateral system would likely reduce transactions costs of exchanging major food crops. Minor food crops with limited exchange and less complex negotiations may be amenable to bilateral arrangements, but the lack of sizable commercial seed markets may also limit transaction of these crops. Bilateral transaction costs may be acceptable only for a very restricted number of industrial, medicinal, and ornamental crops (Visser et al. 2003). Transactions costs are only one component of a wider set of opportunity costs involved in the exchange of genetic resources, such as the benefits missed through reduced access to diverse materials in breeding and research.

The recently agreed International Treaty on Plant Genetic Resources for Food and Agriculture will help facilitate access to genebank accessions for the 35 crops (and crop complexes) and forage crops with a multilateral system. However, the treaty contains some ambiguities, and many questions still need to be resolved to achieve its objectives. First, some major crops such as soybeans and groundnuts are excluded from the list of crops that are subject to the multilateral system of transaction. There is also a lack of consensus regarding the meaning of "equitable" benefit sharing, the magnitude of benefits derived from the use of shared germplasm, and the methodology of estimating the benefits (Day-Rubenstein and Heisey 2003).

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For more detailed information see

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Biotechnology and Genetic Resource Policies

What Is a Genebank Worth?

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