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Report to the Secretary of Agriculture

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PLANT GERMPLASM

Improving Data for Management Decisions

142425

GAO United States
General Accounting Office
Washington, D.C. 20548

Program Evaluation and
Methodology Division

B-240699

October 10, 1990

The Honorable Clayton K. Yeutter
Secretary of Agriculture

Dear Secretary Yeutter:

We prepared this report (in two volumes) to examine the management of germplasm stores and the National Plant Germplasm System. In this report, we address five evaluation questions:

1. What information does the Agricultural Research Service (ARS) collect and how does it set priorities for plant germplasm management activities?

2. What are the conditions and activities that affect a crop's or a species' long-term survival?

3. How can ARS obtain the best possible data on scientists' plant germplasm use and needs?

4. How can ARS assess the effects of biotechnology application on the use of plant germplasm?

5. How can ARS obtain scientists' opinions on the relative importance of activities pertaining to the preservation and use of plant germplasm?

We found that despite the best effort of ARS, more can be done to make the information collected more complete and comparable. We developed and tested one possible new methodology for obtaining more complete and comparable information relevant to improving the management of the National Plant Germplasm System. We describe this methodology in detail in this report and stand ready to assist the Department of Agriculture in implementing this methodology or a similar one that incorporates the same basic concepts for gaining information on a wide range of crops, as we have recommended.

If you have any questions or would like additional information, please call me at (202) 275-1854. Major contributors to this report are listed in appendix VI.

Sincerely yours,

Eleanor Chelimsky
Assistant Comptroller General

Executive Summary

Purpose

Effective management of plant genetic resources (germplasm) is critical to maintaining an effective base for world agriculture and food supplies, developing and improving crops, and ensuring against widespread crop losses from disease, pests, and other environmental stresses.

The National Plant Germplasm System is a network of public and private institutions that was formed to acquire and maintain adequate supplies of germplasm to meet national needs. The Department of Agriculture's (USDA's) Agricultural Research Service (ARS) is responsible for acquiring and managing germplasm collections (primarily seeds and plants) for the system. ARS gathers information about the condition of many different crops and obtains germplasm specimens from a variety of sources to facilitate setting priorities among its germplasm management activities. With a germplasm management budget of $28 million, ARS allocates limited funds among a broad spectrum of different and competing needs.

The criticality of adequate plant genetic resources to the world food base spurred five GAO questions relating to the management of germplasm stores in general and the National Plant Germplasm System in particular: (1) What information does ARS collect and how does it set priorities for plant germplasm management activities? (2) What are the conditions and activities that affect a crop's or a species' long-term survival? (3) How can ARS obtain the best possible data on scientists' plant germplasm use and needs? (4) How can ARS assess the effects of biotechnology applications on the use of plant germplasm? (5) How can ARS obtain scientists' opinions on the relative importance of activities pertaining to the preservation and use of plant germplasm? Answers to these questions as well as a new system for obtaining information relevant to improving germplasm management form the basis for this report.

Background

Throughout history, the world's agricultural system has depended on the continued development and improvement of cultivated varieties through manipulation of genetic traits, usually by plant breeding. Breeders select and crossbreed plants with desirable traits such as taste and yield, nutritional quality, resistance to disease and pests, and environmental and climatic hardiness. The continued ability to meet world food needs and guard against crop loss depends on maintaining genetic diversity (that is, the range of traits existing within a genus or species) for plant breeding.

However, genetic diversity is continuously lost through natural selection, destruction of natural plant habitats, displacement of locally cultivated varieties by modern varieties, and overgrazing. Breeding can also eliminate genes and reduce genetic diversity.

The National Plant Germplasm System was therefore established to help maintain supplies of germplasm adequate to sustain national and world agriculture and to guard against crop vulnerability. Through this system, the United States has worked with many other countries to collect, preserve, and exchange a wide variety of germplasm. Over 2.5 million samples are held in germplasm collections throughout the world. The U.S. contribution to this worldwide effort to maintain genetic diversity is valued at $1 billion annually in increased agricultural production. In administering the system, ARS is responsible for managing a network of plant gene banks containing about 400,000 germplasm samples.

Results in Brief

GAO found that although ARS gathers much valuable information for its management decisions, the information is often incomplete and not comparable across crops. This makes it extremely difficult for ARS to set priorities and allocate funding among the various types of genetic resources and management activities. (See pages 24 - 31.)

ARS currently gathers information on plant germplasm through several means. Evaluations of crop vulnerability and recommendations provided by USDA's crop advisory committees are major sources of information. However, data derived from these committees are often inadequate, because ARS provides neither funding nor detailed procedural guidance to the crop advisory committees. (See pages 24 - 31.)

ARS supplements crop advisory committee reports with results from its research and such information as identification of germplasm collections that are endangered because of circumstances such as program cancellation or a curator's retirement or death or special studies such as one recently completed that identified the germplasm collection needs of 84 commodity crops. ARS is also considering the establishment of core collections to improve the usefulness of stored germplasm resources to plant breeders. (See pages 24 - 31.)

GAO determined that seven categories of conditions and activities affect crop species' long-term survival: the amounts and types of germplasm that are acquired by germplasm managers and other crop scientists; the locations in which plant species are endangered because of natural or societal factors; the conditions (for example, viability or accessibility) of germplasm stored in gene banks or other important collections; the amounts, types, quality, and availability of evaluation data and other information that describes germplasm held in collections; the emphases placed on plant breeding and research programs with respect to the objectives, rationale, and use of germplasm; the susceptibility and known resistance to disease, insects, pests, and other environmental stresses; and the size of the genetic base of commercial crops and the range of genetic and species diversity. (See pages 32 - 34.)

From these seven categories, GAO developed an alternative data collection instrument that allows ARS to collect uniform, comparable data on any crop, genus, or species. The instrument was then pilot-tested to determine whether different types of plant scientists who use germplasm would and could provide the necessary data. The effort proved entirely feasible; information was collected that tapped scientists' knowledge in areas including the acquisition, preservation, and description of germplasm and the effects of biotechnology applications, as well as their opinions on the relative importance of activities pertaining to germplasm management. (See pages 35 - 60.)

GAO's Approach

GAO developed a framework to guide data gathering that presents (1) the seven conditions and activities that affect crop or species long-term survival, about which information can be obtained for any specific crop, and (2) suggested analyses of the information obtained from germplasm users for use in comparing germplasm needs among crops. Building upon crop advisory committees' lists of germplasm users (for example, private and public sector breeders, researchers, and germplasm collection curators), GAO identified a judgmental sample of 71 germplasm users. (See pages 32 - 33.)

With this sample, and with the assistance of ARS officials, germplasm experts, and several crop advisory committees, GAO demonstrated the application of the framework and survey using two crop genera and one crop species. The two crop genera were *Brassica* (broccoli, cabbage, and the like) and sorghum (a grain extensively used worldwide). The crop species was *Prunus persica* (peaches). (See pages 35 - 60.)

GAO's Results

The survey demonstrated that uniform and comparable data on individual crops and their associated germplasm resources can be collected from different types of germplasm users worldwide. This suggests that with the widespread application of systematic data collection methods, ARS could more effectively assess the status of germplasm resources. For example, the data could assist ARS decisionmakers in their efforts to set priorities for germplasm acquisitions and to provide descriptions of stored germplasm that are most useful to scientists who need the resources in their crop improvement and research efforts. Priority-setting and resource allocation among crops and management activities would be facilitated by the adoption of these methods. GAO also believes that ARS could use information obtained from users of its germplasm resources to assess the effectiveness of its current Germplasm Resources Information Network. (See page 61.)

Because the survey was designed and tested to obtain data on virtually any type of plant germplasm, GAO notes that ARS could, over time, implement the method for many crops at the cost of mailing the survey and analyzing the results. Established in this manner, a data base of information describing the status of the crops could be used to help set priorities and to more effectively allocate the limited germplasm budget. (See page 61.)

Recommendation

GAO's effort has shown that it is feasible to collect data that directly target the information needs of germplasm management. Therefore, to supplement information currently obtained and to facilitate germplasm management decisions, GAO recommends that the administrator of ARS determine which crops would most benefit from the full implementation of GAO's methodology, or a similar one that incorporates the same basic concepts, and implement it for those crops.

Agency Comments

ARS commented on a draft of this report. (The letter is in appendix V.) Some concerns were raised about the difficulty of implementing the data collection method, particularly because of lack of funding and support for the effort. In response, GAO offered to share with ARS software and questionnaire design to minimize the initial implementation costs for ARS.

Beyond this, ARS commended GAO's effort to develop a methodology to aid in the assessment of priorities on a crop basis for germplasm held in the National Plant Germplasm System. ARS said that GAO's refinement of questions asked of scientists working in the field provides an excellent base from which to examine agency priorities and funding justifications.

Contents

Figures

Abbreviations

ARS	Agricultural Research Service
CRIS	Current Research Information System
DNA	Deoxyribonucleic acid
GAO	General Accounting Office
GRIN	Germplasm Resources Information Network
NAS	National Academy of Sciences
NPGS	National Plant Germplasm System
OTA	Office of Technology Assessment
PGOC	Plant Germplasm Operations Committee
RFLP	Restriction fragment length polymorphism
USDA	U.S. Department of Agriculture

Introduction

Germplasm is the material in seeds or other plant materials that controls heredity. The availability of plant germplasm and the genetic diversity it contains is essential for the continued development and improvement of crop varieties and to protect them against loss from biological and environmental stresses. For this reason, over 2.5 million accessions, or samples, of germplasm are held in collections throughout the world.[1] Plant breeders worldwide use this germplasm to develop new, superior crop varieties that can ensure a stable, plentiful supply of high-quality food, feed, and fiber. The Office of Technology Assessment (OTA) reported in 1987 that these crop genetic resources have accounted for 50 percent of agricultural productivity increases and for annual contributions of about $1 billion to U.S. agriculture.

However, the use of germplasm for crop improvement, as well as other natural and societally influenced factors, can result in the loss of genetic traits that might protect crop varieties against disease, pests, and other environmental stresses. This loss of genetic diversity (the range and variation of genes in a species or crop variety) increases the likelihood that crops will be vulnerable to ever changing stresses.

To maintain genetic diversity and ensure that supplies of germplasm are adequate to meet future crop improvement needs, the U.S. Department of Agriculture's (USDA's) Agricultural Research Service (ARS) is responsible for acquiring and preserving germplasm collections in the National Plant Germplasm System (NPGS) and for making accessible new sources of germplasm for meeting agricultural and industrial needs.

Loss of Genetic Diversity and Crop Vulnerability

Loss of genetic diversity and of plant species diminishes the amount of genetic resources that will be available to future generations for crop development and improvement. Further, lack of diversity in commercial varieties of a crop can lead to the vulnerability of the crop to widespread loss. Measures of genetic diversity are difficult to define, and uneven knowledge about the approximately 250,000 plant species of the world makes losses of diversity difficult to assess.[2] According to one estimate prepared for OTA, at least 60,000 plant species may be at risk of extinction within the next 30 to 40 years.

[1]Donald L. Plucknett et al., Gene Banks and the World's Food (Princeton, N.J.: Princeton University Press, 1987), p. 110.

[2]U.S. Congress, Office of Technology Assessment, Technologies to Maintain Biological Diversity, vol. 2, contract papers part A, papers 1-6 and 8, plant technologies, PB87-139200 (Washington, D.C.: U.S. Government Printing Office, December 1986), p. 37.

The loss of genetic diversity has occurred naturally through evolution for millions of years. Plant varieties that have been able to adapt to different environmental factors, or have been resistant to disease and pests, have survived natural selection, while others have become extinct.

Human influence on the use of land has contributed to the loss of genetic diversity through a variety of causes, including industrialization, urban expansion, deforestation, and changes in land use and agricultural practices. Most natural genetic diversity originated and still resides in developing countries such as those in Africa, Asia, and South America. Development has brought the destruction of the native habitats of plant varieties and their wild and weedy relatives, thus eliminating resources of potential value for future agriculture and research.

In an effort to preserve germplasm, some organizations and nations have established gene banks where seeds and plant material are stored. However, diversity can also be lost through inadequate germplasm storage and maintenance practices, potentially resulting in the loss of whole collections of seeds or plants. For example, gene banks are potentially vulnerable to inadequate maintenance techniques, poor management practices, natural disasters, and technical problems such as power failures or fires, any of which can decrease the viability of stored seeds or result in the destruction of unique plant material.

In breeding plant germplasm into extremely productive varieties, breeders have also reduced the genetic diversity in these varieties and have made them more uniform. This uniformity results when breeders inadvertently eliminate certain traits (such as resistance to disease and pests) that did not contribute directly to the desired characteristics (such as high yield) for which the breeders were searching.

As the use of the improved varieties has increased, they have replaced many of the local varieties—landraces—traditionally grown by farmers. These landraces typically contain greater genetic diversity than uniform varieties, because they have coexisted, and sometimes crossbred, with their wild relatives. Though some landraces have been collected and are now stored in gene banks, many of these locally cultivated resources have become extinct.

Widespread and continued use of genetically uniform crop varieties is often characterized by a narrowed genetic base of germplasm used in the breeding process. Although uniformity may lead to greater yields and make possible the sophisticated methods of mechanized sowing, fertilization, and harvest, widespread use of uniform crop varieties also increases the probability of devastating crop losses. For example, the 1970 southern corn leaf blight epidemic destroyed 15 percent of the U.S. crop—with losses of up to 50 percent in some states. Genetic diversity in varieties and hybrids can be an important source of protection against environmental stresses that are not predictable, by reducing the probability that entire crop populations will be affected by them.

Commercial crop breeders can also reduce the uniformity of improved crop varieties by incorporating traits from new sources of germplasm, including landraces and distant relatives. However, research and breeding efforts and funding are generally concentrated on today's major commodity crops such as corn, soybean, and wheat. With this commercial focus, lower-valued crops, as well as germplasm whose value has not yet been identified, tend to receive less emphasis. Because the future value of such crops and germplasm is difficult to foresee, the acquisition and preservation of germplasm that adequately represents plant genetic diversity is important.

The importance of protecting crops against vulnerability through the introduction of genetic diversity has been emphasized over the past decade. The role of germplasm preservation in affording this protection was expressed in a 1983 USDA program plan:

> "Crops become vulnerable when stresses from diseases, insects, drought, or temperature extremes exceed the crops' ranges of tolerance or resistance to such factors. The results can vary from localized yield reduction to disastrous crop failures over large areas. Protection from crop losses through control [of stresses] is far more difficult and costly than is protection through increased genetic diversity among varieties of a given crop."

Further, the report stated that developmental crop breeding ties together the work of germplasm collection, screening, and genetic analysis as scientists sort from the many objectives or traits that might be pursued those with a high probability of success.

To develop and improve successful varieties and to meet future unknown stresses, breeders need an adequate supply of germplasm with diverse genetic characteristics. Even if such germplasm is available, however, introducing traits from wild or distantly related germplasm is time-consuming and difficult. Figure 1.1, for example, shows a plant physiologist and a graduate student working at the Fresno, California,

Figure 1.1: Transplanting Seedless Grape Varieties

field location, transplanting seedless grape varieties from growth chamber containers to greenhouse soil pots as part of an effort by the genetics unit of the Horticultural Crops Research Laboratory to develop new and improved varieties for fresh and dry fruit markets.

Private sector breeders concentrate on developing products that offer the promise of good return on investment, while public sector breeders have traditionally enhanced or improved germplasm by identifying useful traits and breeding them into interim products, which private sector breeders can more readily incorporate into commercial varieties.

Difficulty of Predicting Germplasm and Crop Improvement Needs

Germplasm and crop improvement needs are difficult to predict because of ever changing environmental and human factors that demand responsive changes in crop improvement efforts. Over time, diseases and pests adapt to a crop's defenses, making it necessary for scientists to develop new crop varieties and products such as pesticides. Major climatic changes may change plant habitats, forcing agricultural modifications. Changing agricultural and land use practices modify the land's ecology, forcing scientists to develop new, cost-effective materials and methods to meet the new needs. In addition, scientists must develop higher-yielding crops to meet the projected long-term nutritional needs of a world in which the population is expected to increase substantially for the remainder of this century and beyond.

New scientific knowledge and techniques may also affect crop improvement possibilities. Advances in biotechnology (advanced techniques that use biological systems to produce products) may allow much more rapid development of crop varieties. For example, biotechnology applications may allow scientists to more readily and precisely transfer genes between plants, even distantly related varieties, than is possible with conventional plant breeding methods. Biotechnology also permits scientists to analyze specific genes and thereby "screen" or select needed germplasm more rapidly. In addition, conservation biology, a rapidly evolving discipline involving new theoretical models, research findings, and emerging management techniques, challenges traditional approaches to conservation. This change, sparked by basic research in population biology and genetics, may help scientists develop better germplasm preservation strategies, thereby facilitating decisions on germplasm storage needs.

ARS Management of Germplasm

The Agricultural Research Service is responsible for preserving and distributing plant germplasm and improving the productivity, quality, and other desired characteristics of crops. Working within an annual germplasm budget of about $28 million (fiscal year 1989 funding), ARS manages germplasm collections and repositories containing about 400,000 germplasm accessions. In managing these resources, ARS officials determine germplasm preservation needs within and among different crops and germplasm management activities, manage germplasm collections, and conduct research to evaluate and improve germplasm. Table 1.1 lists and defines ARS's germplasm management activities.

Table 1.1: ARS's Germplasm Management Activities

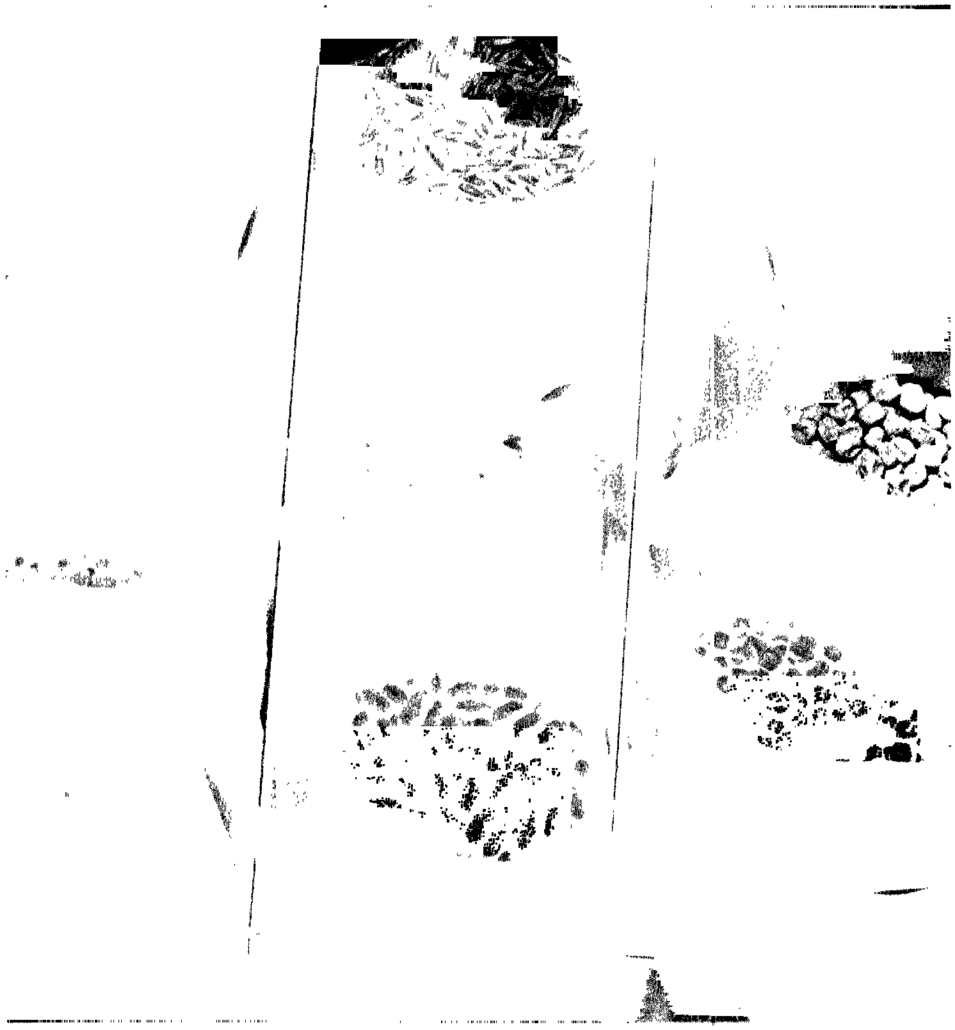
Activity	Definition
Acquisition	Collecting plant germplasm from natural habitats and from exchange with other scientists or gene banks
Preservation	Storing and maintaining plant germplasm in gene banks throughout the world to ensure that a diverse supply of germplasm is available to breeders and researchers and sufficient genetic diversity exists in gene banks to ensure the long-term survival of cultivated crop varieties
Distribution	As part of the preservation effort, providing germplasm from National Plant Germplasm System (NPGS) collections to scientists or breeders worldwide
Description (evaluation)	Identifying, evaluating, and providing accurate written descriptions of stored plant germplasm and its genetic characteristics
Enhancement (prebreeding)	Incorporating desired traits of wild germplasm into a domesticated crop variety, so that the resulting variety will be suitable for crossbreeding with commercial varieties
Breeding	Developing new crop varieties or improving existing ones (especially commercial crops) by making crosses over several generations
Biotechnology	Developing and applying advanced techniques, including molecular genetics, to identify and manipulate genes or to improve storage technologies for plant germplasm

ARS coordinates the operation of NPGS and collaborates with other agencies; national and international organizations that preserve, manage, and exchange germplasm; and a set of advisory committees. NPGS has been evolving since USDA was founded in 1862, but the first official facilities for storing germplasm were established under the Agricultural Marketing Act of 1946 (Public Law 733, 79th Congress).

Today, the system is user-oriented, having a goal of acquiring, preserving, and distributing plant germplasm. It includes ARS operational units, four regional plant introduction stations, National Potato Plant Introduction Station, eight national clonal germplasm repositories, and various other crop-specific collections, each of which contains one or more particular crop species.

Scientists at these facilities maintain, evaluate, and distribute plant germplasm and conduct various types of research. In addition, the

Figure 1.2: Seeds in Uniform Containers for a Germination Test



National Seed Storage Laboratory at Fort Collins, Colorado, stores a wide range of plant germplasm long term and conducts research on germplasm preservation techniques. See figure 1.2, for example, which shows open bags of seeds at the National Seed Storage Laboratory being prepared for planting of a germination test. When dried and sealed in preparation for storage, seed samples are placed in uniform containers of flexible packaging material made (from the inside out) of 40-pound white kraft paper, polyethylene, 0.005 foil, and polyethylene. When properly sealed, such containers are essentially moisture proof.

ARS also maintains the National Germplasm Resources Laboratory, which coordinates the acquisition and exchange of germplasm between the United States and other countries and documents and catalogs acquired germplasm for inclusion in the NPGS collections. The laboratory assigns plant introduction numbers, publishes a USDA plant inventory, and manages the Germplasm Resources Information Network (GRIN)—a centralized, computerized data base containing an inventory of NPGS accessions as well as descriptive information about them. Finally, the laboratory assists with the quarantine and distribution of plant materials obtained through exploration or exchange.

ARS coordinates its efforts with scientists from the federal, state, and private sectors of the agricultural research community. A number of agencies and groups provide funding, local facilities, seed increases (growing-out seed to replenish stocks), germplasm evaluations, and general policy and program direction. These include the Cooperative State Research Service, the Animal and Plant Health Inspection Service, the state agricultural experiment stations located at land grant colleges, and private industry. ARS also coordinates with other agriculture-related organizations such as the Soil Conservation Service, the Extension Service, the Office of International Cooperation and Development, and the State Department's Agency for International Development.

In making germplasm management decisions, ARS works with several advisory committees, which provide expertise and guidance on germplasm needs, collection gaps, adequacy of germplasm descriptions, regeneration needs, evaluation plans, and research needs. For example, 39 crop advisory committees provide expert advice to the National Program Leader for Germplasm on germplasm management priorities. Each committee represents the germplasm user community for a particular crop or group of crops. In addition, the National Plant Genetics Resources Board advises the secretary of USDA on national plant germplasm needs and policy matters related to germplasm preservation. Another advisory group, the National Plant Germplasm Committee, coordinates federal, state, and private research and services. Also, the Plant Germplasm Operations Committee, composed of the curators of the gene banks and clonal repositories, coordinates day-to-day operational activities by identifying germplasm problems and needs, implementing operational changes, and reviewing plant exploration proposals and priorities.

International organizations with which ARS coordinates its activities include the International Board for Plant Genetic Resources and the

International Agricultural Research Centers, both of which are sponsored by the Consultative Group for International Agricultural Research.[3]

The Difficulty of Decisionmaking

In carrying out its germplasm management responsibilities, ARS must make intrinsically difficult decisions about how to set priorities and allocate resources among competing projects, including its various germplasm management activities, as well as among various crops. In addition, the uniformity of information on which to base decisions can vary widely among crops. For example, one crop advisory committee may submit detailed information on crop needs and status, whereas another committee may submit very sparse or general information or none at all.

When data are missing or existing data are fragmented, decisions must be made without the data tools that are the basic requirement for decisionmaking. Concerns about insufficient information and its effect on ARS's management effectiveness have been cited for years in various studies. In our 1981 report, for example, we found that USDA

> "does not know the universe of germplasm stored in the United States, and . . . [w]ithout knowing what germplasm is available and what has been collected, meaningful planning for collection is difficult and subject to omissions."[4]

Since then, other studies have cited the need to assess the adequacy of the germplasm base for each crop or group of crops and to broaden and strengthen each base by additional exploration, evaluation, or enhancement work. The studies found that scattered distribution of material

[3]The International Board for Plant Genetic Resources is an autonomous international scientific organization established in 1974 to promote and coordinate an international network of genetic resource centers to further germplasm preservation and use. The Consultative Group for International Agricultural Research was set up in 1971 to help coordinate the efforts of public and private institutions, international and regional organizations, and representatives from developing countries to support a network of 13 international agricultural research centers.

[4]See U.S. General Accounting Office, Better Collection and Maintenance Procedures Needed to Help Protect Agriculture's Germplasm Resources, GAO/CED-82-7 (Washington, D.C.: December 4, 1981), p. 7.

among public and private institutions, inadequate knowledge about specific institutional collections and diversity, and deficiencies in descriptive information cause a lack of use of many collections and hinder decisionmaking and priority-setting.[5]

Currently, the National Academy of Sciences (NAS) is concluding a study of NPGS and crop vulnerability. According to NAS officials, their vulnerability study has been hampered by insufficient data on the number of varieties and acreage planted of a given commercial crop. In addition, they found that the crop advisory committee network does not in its present form work well because of limitations in membership and funds and the inconsistent reporting of information on which to base decisions.

Objectives, Scope, and Methodology

Because of the long-term and continuing criticisms of ARS's effectiveness in managing germplasm and assessing crop vulnerability, we sought to demonstrate ways in which ARS could gather uniform and comparable information from germplasm users on the various factors that affect vulnerability, in order to assist with germplasm management decisionmaking. Specifically, we addressed the following five evaluation questions.

1. What information does ARS collect and how does it set priorities for plant germplasm management activities?

2. What are the conditions and activities that affect a crop's or a species' long-term survival?

3. How can ARS obtain the best possible data on scientists' plant germplasm use and needs?

4. How can ARS assess the effects of biotechnology applications on the use of plant germplasm?

5. How can ARS obtain scientists' opinions on the relative importance of activities pertaining to the preservation and use of plant germplasm?

[5]U.S. Department of Agriculture, National Plant Genetic Resources Board, Plant Germplasm: Conservation and Use (Washington, D.C.: October 1984); Council for Agricultural Science and Technology, Plant Germplasm Preservation and Utilization in U.S. Agriculture, no. 106 (Ames, Iowa: November 1985); U.S. Congress, Office of Technology Assessment, Technologies to Maintain Biological Diversity, OTA-F-300 (Washington, D.C.: U.S. Government Printing Office, March 1987).

To answer these five questions, we combined an information synthesis with data from selected case studies. We conducted a literature review; interviewed ARS managers, curators, and other experts; and reviewed planning, budgetary, strategic, and other ARS documents. For our case studies, we developed a framework for analyzing available information about crops and a corresponding mail-out questionnaire.

Although ARS is responsible for acquiring, preserving, distributing, describing, and improving germplasm and crops, the scientists (public, private, and foreign) who themselves work with germplasm are the most knowledgeable about its condition and needs. Therefore, we believed it was important to obtain information directly from scientists on the factors that influence their activities, as well as their opinions on such things as the most important germplasm management activities for their crops. Accordingly, our study focuses on these users.

To answer evaluation question 1, we interviewed managers and program and research leaders and other personnel from ARS's headquarters and the director of ARS's Beltsville Agricultural Research Center, all located in Beltsville, Maryland. We also interviewed curators and research leaders at several regional plant introduction stations and clonal repositories. In addition, we analyzed documents obtained from these officials, including various reports, mission and responsibilities statements, priorities for acquisition, and project funding.

To answer question 2, we conducted a literature review and interviewed scientists within and outside ARS. In order to categorize our findings for this question, we developed a framework that identifies the conditions and activities most likely to affect the long-term survival of a crop or species as well as its associated germplasm. The various components of the framework represent the areas in which uniform and comparable information should be collected for many crops and their associated germplasm. We formed an advisory panel to assist us in developing and modifying the framework components. (See appendix I for the panel members.) Collectively, the advisory panel had expertise in plant breeding, genetics, and pathology; entomology; germplasm management and conservation; horticulture; and the use of biotechnology tools. We revised and refined the framework throughout our evaluation with the assistance of the advisory panel and other experts. (Appendix I in volume 2 presents the framework.[6])

[6]Volume 2 is entitled Plant Germplasm: A Data Collection Framework and Questionnaire, GAO/PEMD-91-5B (Washington, D.C.: October 1990).

To answer questions 3, 4, and 5, we designed a questionnaire to obtain the status of information available for the components of the framework. (Appendix II in volume 2 is our questionnaire.) Our intent was to demonstrate the feasibility of using a single survey instrument that, with minor modification, could obtain uniform and comparable information for any crop, species, or genus. We administered the questionnaire to a judgmental sample of scientists who use germplasm and analyzed selected questions to demonstrate the types and amounts of information that can be obtained, including (1) scientists' satisfaction with the quality of information and germplasm they obtain; (2) descriptions of scientists' germplasm accessions, maintenance, and use; and (3) scientists' opinions on where emphasis is needed to address genetic resource management issues.

Question 4 is answered by a set of questions that ask scientists about the effects of biotechnology on their work and on their use of germplasm.

Question 5 is also answered by a set of questions asking scientists' opinions about which specific germplasm management activities they believe should be emphasized over others. In addition, we designed a pairwise comparison question that asks scientists their opinions of the relative importance of six broad activities: acquisition, preservation (including distribution), description (including evaluation), breeding, enhancement, and biotechnology. To analyze these responses, we used a method termed the analytic hierarchy process, which quantifies sometimes small differences in opinion about the relative importance of things that are inherently difficult to measure. The process attaches weights to a set of decision criteria in a multicriteria decisionmaking situation.

We selected three crops as the focus of our effort. We presented initial crop selection criteria to our advisory panel, and with their assistance we consolidated the list into five broad categories. We used the five criteria to select three crops having characteristics typical of the wide range of crops. We chose two genera and one species: *Brassica* (broccoli, cauliflower, and the like), sorghum (a grain crop), and *Prunus persica* (peach). We originally selected the genus *Prunus* (plums, cherries, almonds, and so on), but because of the large differences among the species within this genus, we decided to focus on the peach as the species with the highest production in the United States. Table 1.2 compares our five selection criteria with the selected genera and species.

Table 1.2: Comparison of Crop Selection Criteria

Criterion	*Brassica*	*Prunus persica*	Sorghum
Number of international centers, working groups, gene banks, other informational networks, and amount of existing information	No international center; many gene banks; many global users	No international center; many gene banks	An international center; many gene banks
Type of reproductive and storage methods	Open-pollinated; seed storage; some DNA libraries	Clonally reproduced and stored; some DNA libraries	Self-pollinated; seed storage; few DNA libraries
Degree of amenability to biotechnology	Biotechnology tools are currently being applied	Few biotechnology tools are being applied	Good potential for biotechnology use, but limited applications
Degree of diversity and adaptability	Many wild relatives	Latitudinally limited but moderate degree of adaptability	Very diverse and widely adapted
Degree of contribution to society	Globally an important crop, especially cabbage and turnips	Minimal total worldwide hectares; limited number of uses	Second in the world in total hectares; many uses

To ensure that we gathered information from a wide range of plant scientists, we identified 15 categories of scientists who use germplasm (such as U.S. private sector plant breeders and foreign national public sector geneticists or biotechnologists). (Appendix II presents the 15 categories.) Then, to identify potential questionnaire respondents, we worked with the chairs of the crop advisory committees and subcommittees for the three selected crops. We began with their lists of scientists who use the crops' germplasm, and we supplemented the lists with information we developed from other sources to identify plant scientists in all 15 categories.

We judgmentally selected scientists from these lists as questionnaire respondents for our demonstration. We sent questionnaires to scientists in the United States, India, Israel, Japan, Mexico, the Netherlands, Venezuela, and Zimbabwe. This international focus provides a broader base of respondents and a more realistic perspective on international plant germplasm conditions and activities than would have been possible with domestic respondents alone.

We sent out a total of 71 questionnaires: 52 to scientists in the United States and 19 to scientists in the seven foreign countries, as shown in table 1.3. We received completed questionnaires from 85 percent of the domestic scientists and 79 percent of the scientists in other countries.

Table 1.3: Questionnaires Mailed Out and Returned

Genus or Species	Mailed U.S.	Mailed Foreign	Returned[a] U.S.	Returned[a] Foreign
Brassica	13	6	10	4
Prunus persica	12	3	12	2
Sorghum	27	10	22	9
Total	**52**	**19**	**44**	**15**

[a]Although we received 44 questionnaires from domestic scientists, we excluded 2 surveys (1 *Brassica* and 1 sorghum) from our analysis because the surveys were incomplete. For these 2 questionnaires, we were unable to follow up on all incomplete responses. We excluded 4 foreign sorghum surveys that arrived too late to incorporate into our analysis.

Because our sample was small and judgmentally selected, we cannot generalize from the results to the populations of all scientists who use germplasm from these crops. However, our data collection and analyses meet our objective—demonstrating that it is feasible to obtain uniform information needed to manage germplasm activities from a wide range of plant scientists worldwide.

We conducted our fieldwork between January 1989 and January 1990. Our work was conducted in accordance with generally accepted government auditing standards.

Chapters 2 through 6 address the individual evaluation questions. In chapter 7, we present our conclusions and recommendations, agency comments on our report, and our responses to those comments.

USDA's Data Collection and Priority-Setting for Germplasm Management

In this chapter, we address our first evaluation question: What information does ARS collect, and how does it set priorities for plant germplasm management activities? To identify ARS's information-gathering and priority-setting efforts, we interviewed ARS officials, including national program staff, an area director, curators, and research leaders. We also obtained and analyzed ARS documents on strategic planning, budgeting, and germplasm management.

To set priorities for its germplasm management activities, ARS gathers information about the condition of different crops and their related germplasm, drawing on the results of ongoing work on the germplasm program. ARS supplements its own information with that obtained from sources such as the crop advisory committees, scientists conducting work for ARS, national program staff, advisory committees, and private industry representatives.

Where ARS Gathers Information

The results of ARS's various germplasm management activities provide the agency with valuable information on the status of germplasm acquisition, preservation, description, and enhancement. ARS conducts the work needed to fulfill its germplasm management objectives through 3- to 5-year Current Research Information System (CRIS) projects. For example, research projects are under way to evaluate horticultural and vegetable germplasm for important characteristics and resistance to pests. Each approved project receives funds to accomplish its objective, and scientists report to ARS on each project's progress. Project objectives, status, completion date, and results are also contained in CRIS and are available to scientists.

To identify gaps in germplasm collections, ARS has gathered information on the type and amount of germplasm for different crops that is already contained in the NPGS inventory. A method was used to rank 84 crops by dollar value of production and to assess how equitably germplasm accessions were distributed within or among the crops. To determine whether additional exploration or exchange of germplasm is necessary, the method identified the significance of gaps found in collections.

For example, the alfalfa germplasm collection contains nearly 2,600 accessions from the primary gene pool, 200 from the secondary gene pool, and 1,600 from the tertiary gene pool.[1] Only 50 percent of the

[1] Gene pools are collections of genes in an interbreeding population. See also the glossary.

known species in the secondary gene pool are represented, while 90 percent of the known species in the tertiary gene pool are represented. Yet, germplasm from the secondary pool is more useful than that from the tertiary. That is, while species in the secondary gene pool can be crossed with a particular crop with difficulty, crosses of species in the tertiary gene pool are usually lethal. In terms of setting priorities, greater effort should be made to obtain germplasm from the secondary pool. In October 1989, ARS identified strawberries, walnuts, and wheat as the three highest germplasm acquisition priorities, based on this type of information.

ARS tries to determine the extent that U.S. or other gene banks adequately represent the germplasm potentially available for crops and, to the extent possible, whether a crop's germplasm is threatened. For example, ARS conducted a survey of U.S. public and private institutions that conduct breeding and genetics programs to identify collections that may be in danger of loss because of the discontinuation of the programs.

Ongoing preservation efforts also provide ARS with information to help set germplasm preservation priorities, including ongoing efforts to establish core collections of germplasm that would contain diversity representative of the genus or species preserved. ARS obtains information from research leaders at the plant introduction stations and clonal repositories on the status of their preservation efforts. For example, they provide information on which crops have accessions that need replenishing, whether new or additional equipment is needed to conduct preservation and maintenance activities, and whether the greenhouse or other facility space is adequate.

ARS also gathers information from its descriptions of germplasm accessions. Description efforts help discern priority needs for additional acquisitions and to better meet the needs of the germplasm user community. The gene banks and clonal repositories enter descriptive information about the germplasm accessions maintained in their inventories into the Germplasm Resources Information Network. GRIN is used to facilitate the management of NPGS germplasm and to provide readily accessible information to scientists on the location and characteristics of germplasm contained in the collections. ARS's plant exploration office uses information from GRIN to identify gaps in NPGS germplasm collections.

The Plant Germplasm Operations Committee (PGOC) provides information on such topics as site regeneration plans, germination testing, ARS acquisition policy, and findings from subcommittees, such as one studying the need for plant exploration trips to obtain new samples of germplasm. This subcommittee coordinates the day-to-day operational activities, reviews and prioritizes plant exploration proposals submitted by scientists, and conducts other activities relating to the operation of the plant introduction stations and clonal repositories. The PGOC recommends acceptable plant exploration proposals to the Germplasm Matrix Team.[2] The latter ultimately decides which proposals to fund.

ARS also gathers information from the results of its research projects designed to enhance existing germplasm collections and to develop improved breeding material. The funding provided to projects for enhancing germplasm is based on information received from ARS's Germplasm Matrix Team and from crop advisory committees. For example, ARS currently funds a project to genetically enhance cotton germplasm for resistance to insects. From this project, ARS made available to plant breeders eight new cotton germplasm lines that are tolerant to tobacco budworm. As a result of the success of this enhancement project, it could be given priority for continued funding over other, less productive enhancement activities.

Advice From Outside Sources

ARS obtains technical advice from sources outside the agency to carry out its responsibilities. ARS is responsible for the operation of facilities supporting NPGS, and with assistance from advisory and technical committees and other groups and individuals, ARS identifies needs and sets priorities among germplasm management activities and crops. ARS obtains general information from groups such as the National Plant Germplasm Committee, and the National Plant Genetic Resources Board, while specific information on crops is obtained from the crop advisory committees. As of January 1990, 39 crop advisory committees represent the germplasm user community, serve their crop commodity groups, and provide expert advice to ARS and others on technical matters relating to plant germplasm collection, preservation, enhancement, and effective use.

The crop advisory committees provide reports to ARS on the status of their particular crops. According to an ARS official, the committees' recommendations are considered in establishing germplasm management

[2]The Germplasm Matrix Team is chaired by the program leader for plant germplasm. The team makes specific recommendations to the service relative to funding explorations, quarantine problems and procedures, special funding needs, and policy and operational procedures.

priorities by crop. For example, the crop advisory committee for walnuts (*Juglans*) recommended that priority be given to acquisition because, in its opinion, the current U.S. and world collections of *Juglans regia* (the English or Persian walnut of commercial importance) are inadequate. The report identified acquisition as a priority to minimize vulnerability of the species, to provide genetic variation for selection and breeding, and to provide basic scientific information about this crop species. The advisory committee for the sweet potato (*Ipomoea batatas*), in contrast, recommended that priority be given to the description and evaluation of its crop's germplasm through biological and molecular techniques to characterize accessions. The report also noted that the characterization of the clones in the collection with regard to the reaction of stored roots to storage rot disease also needed immediate attention.

Although ARS relies on the crop advisory committee reports in setting priorities, the program leader for germplasm said that the reliance is situation-dependent and that he would probably rely on the committees more for evaluation than for enhancement. The information the committees submit is inconsistent and often incomplete. For example, although all committees are asked to submit reports addressing the status of their crops, of the 39 advisory committees, 7 had not submitted a report as of November 1989, despite the fact that all the committees had been operating for more than a year.

Further, although ARS provided general guidelines outlining the duties and responsibilities of the committees, the committees gather information in different ways and report it in varying degrees of completeness and specificity and in different formats. For example, the committees are asked to consider the need for fundamental and applied studies and to make suggestions on promising research approaches and enhancement opportunities. While the Leafy Vegetables Crop Advisory Committee report did not even address this topic, the Barley Crop Advisory Committee reported in some detail that ongoing barley research on morphological, biochemical, and DNA-based markers indicates that saturation of the barley genome with genetic markers is possible in the near future.

ARS officials believe they cannot dictate committee work and requirements because the committees are voluntary organizations. According to an ARS official, some committees are constrained by factors such as lack of administrative support, the chairs' limited time available for committee activities, inconsistent membership and attendance, misunderstanding of the committee mission, infrequent or short meetings, and lack of remuneration for committee work or travel. For example, the membership of a committee may not be representative of all the various crop disciplines (for example, plant pathology, entomology, breeding, genetics, or taxonomy) or of the federal, state, and private sectors in which the crop is grown. They often do not meet at set times but, rather, meet during other crop society meetings. Whereas the citrus committee meets twice a year for 1 to 1-1/2 days, for example, the leafy vegetables committee meets once a year for 2 hours.

For two of the three crops we reviewed (*Prunus persica* and sorghum), the applicable crop advisory committees have obtained and presented information and priorities in reports to ARS. (As of January 1990, the committee for the third crop, *Brassica*, had not submitted its report to ARS.) According to the chairman of the Sorghum Crop Advisory Committee, he wrote the committee's report after obtaining comments from other committee members. Public and private sector sorghum germplasm users provided information through informal interactions. The sorghum report submitted to ARS recommended that priority be given to sorghum acquisition and preservation. For example, it recommended that priority be given to establishing a quarantined field introduction site, assembling unique germplasm from individual collections, and making descriptive information available to all scientists.

Although the *Prunus* Crop Advisory Committee also made recommendations, it did not address specific priorities among the four management activities. It did, however, cite several areas that need attention, including eliminating obstacles to the introduction of plant material into the United States, identifying gaps in the U.S. germplasm collections, and acquiring wild germplasm before it is lost from native forests being destroyed in Europe, China, and elsewhere in Asia.

The crop advisory committees also provide ARS with evaluation descriptors for the traits they believe are the most important for their crops. Once the committees develop and provide these descriptor lists, ARS can decide whether to begin funding CRIS projects to carry out the evaluations. For example, ARS is evaluating various small fruit germplasm for drought resistance and has identified traits that may contribute to better fruit "skin" appearance. Once such traits have been identified and described, ARS could identify additional germplasm acquisition needs or determine that more description work was needed.

ARS and researchers elsewhere have conducted surveys to gather information from scientists using or managing germplasm. Though these surveys had narrow focuses, useful information has been obtained from them. For example, ARS mailed questionnaires to about 200 plant breeders in the United States to identify germplasm collections in danger of being lost as a result of the retirement of the scientist responsible for the collection.

Outside ARS, researchers at Cambridge University conducted a survey of 279 European (and 10 U.S.) plant breeders and gene bank curators for two crops: barley and *Allium* (onions).[3] The aim of this survey was to obtain additional information on the use and availability of material in germplasm collections in relation to specific breeding objectives and to relate needs to the availability of data on samples. The survey concluded that the evolution of breeding information needs cannot be predicted. The survey also found that to increase the use of germplasm from collections, emphasis should first be placed on satisfying the most simple and basic needs of breeders. While these and similar efforts demonstrate that germplasm users can provide information useful for managing genetic resources, the survey questions were focused on a few crops and questions within only one area of germplasm management.

How ARS Sets Priorities

Agricultural Research Service officials determine germplasm priorities on the basis of the information obtained from their own activities, the activities of scientists conducting work for ARS, the crop advisory committees, other advisory committees, and private industry contacts. ARS officials judgmentally determine the relative priority of activities within acquisition, preservation, description, and enhancement and make funding decisions accordingly. Once potential priorities are developed, the Germplasm Matrix Team recommends activities to fund, or refund, through CRIS projects.

According to an ARS official, they try to fund at least the most important need of each crop advisory committee. However, they cannot fund all the activities that the advisory committees recommend. They must make difficult decisions about which activities to fund for the different crops. It is here that the need for uniform information from a generalizable

[3]John P. Peeters and Nick W. Galwey, "Germplasm Collections and Breeding Needs in Europe," Economic Botany, 42:4 (1988), 503-21.

sample of respondents becomes most clear. ARS currently bases its priorities on an uncertain sample and on noncomparable, inconsistent inputs across its various sources. This complicates resource allocation.

Further, since ARS does not gather comparable data across crops, decisions may be affected less by the data than by the judgments of those who provide input to ARS. ARS needs to solicit uniform data from a large or representative number of scientists, curators, and breeders worldwide who work with a particular crop and use germplasm collections.

As already noted, ARS determines its priorities from the opinions of a core group of scientists, germplasm curators, and breeders inside and outside the agency's purview. Other factors influencing those priorities are budgetary constraints and economic or political pressures.

According to the ARS national program leader for germplasm, ARS's budgeting process related to CRIS projects is inflexible and thus constrains priority-setting. ARS officials stated that most CRIS projects are rewritten to update project information and are then refunded. In fact, ARS officials were unable to identify a germplasm CRIS project that was terminated within the last year (that is, a project not rewritten and refunded) or a project scheduled for termination in the near future. However, the national program leader for germplasm was able to identify one CRIS project in the plant breeding category that was terminated, with the funding transferred to a project in the germplasm category. Both projects were related to research in St. Croix, one of the Virgin Islands.

The ongoing nature of the CRIS projects limits ARS's flexibility to shift funds to other crops or germplasm management activities. The official noted above also stated, for example, that some aspects of the Russian wheat aphid (*Diuraphis noxia*) problem could have been addressed sooner than it was if ARS's headquarters had discretionary funds for emergencies. The Russian wheat aphid has done more than $200 million in damage since it infested U.S. wheat fields in 1986. While biological control of the aphid through natural enemies may take 5 years to be effective, breeding resistant strains of wheat will probably take even longer.[4]

Other difficulties facing ARS in setting effective program priorities, according to agency officials, are economic and political pressures. For

[4]Billy Goodman, "From Russia With Love," Discover, May 1990, pp. 63-65.

example, major high-value commodity crops tend to receive higher priority for funding breeding and research projects to preserve and use the germplasm that supports those crops. Although it is appropriate for ARS to address concerns about high-value crops, we believe it must also ensure that crops of lesser value whose future importance has not been determined are adequately preserved and evaluated.

According to ARS officials, lobbyists and politicians also pressure ARS to maintain funding levels for projects related to certain commodities (for example, corn, tobacco, and wheat) even when the approved projects have been completed. Many politicians, according to ARS officials, strongly resist efforts to shift funding from their congressional districts to others—and therefore from one commodity to another.

With more uniform and comparable information about existing genetic resources, and the risk of loss of genetic diversity, ARS would be better able to document and defend its decisions to allocate funding to the activities or crops it determines are priorities and to terminate some CRIS projects and fend off political pressures. Better data collection and documentation would assist ARS in setting priorities and support allocation of resources to crops with the greatest needs.

A Framework to Guide Data Collection

This chapter addresses our second evaluation question: What are the conditions and activities that affect a crop's or a species' long-term survival? As discussed in the previous chapters, there exists a need for uniform and comparable data on which to base decisions about germplasm management priorities. In order to design a survey instrument that would obtain such information, we first developed a framework to provide criteria for the data collection. The framework components are the conditions and activities that affect the survival of crops and germplasm, a sound basis for setting priorities among the many types of genetic resources and management tasks. We developed the framework through a synthesis of information obtained from about 50 sources, listed in the bibliography in volume 2.

The literature describing the various aspects of the conservation and use of plant genetic resources clearly shows that the complex interaction of conditions and activities occurring worldwide affects the amount and quality of genetic resources available now and in the future for crop development and improvement.

The literature generally describes crop vulnerability in terms of potential widespread crop losses from a narrow genetic base and uniform varieties. Further, the ability to widen a crop's base or to develop new varieties to replace crops susceptible to stresses is dependent on the availability of appropriate and diverse germplasm, its ability to be used by plant breeders, and the level of research and breeding emphasis given to a crop. The amount, availability, and condition of the stored germplasm, in turn, depend on the knowledge of sites where important germplasm is endangered and the quality of ex situ germplasm acquisition and preservation and in situ conservation efforts that preserve native habitats.[1]

We included in our framework information not only on survival of crops but also on the survival of the genetic resources supporting agricultural production. We sought the advice of plant scientists, including members of an expert advisory panel, to develop the framework into 31 conditions and activities that can affect a crop's or a species' long-term survival. These framework components are grouped under the seven major categories shown here and in appendix I in volume 2.

[1] Ex situ preservation pertains to the study or maintenance of collections of plants or animals away from the place where they naturally occur. In situ pertains to organisms within their native environment.

- Amounts and types of germplasm that are acquired by germplasm managers and other crop scientists.
- Locations in which plant species are endangered by natural or societal factors.
- Condition (for example, viability or accessibility) of germplasm stored in gene banks or other important collections.
- Amount, type, and availability of evaluation data and other information that describes germplasm held in collections.
- Emphases on plant breeding and research programs with respect to objectives, rationale, and use of germplasm.
- Susceptibility and known resistance to disease, insects, pests, and other environmental stresses.
- The size of the genetic base of commercial crops and the range of genetic and species diversity.

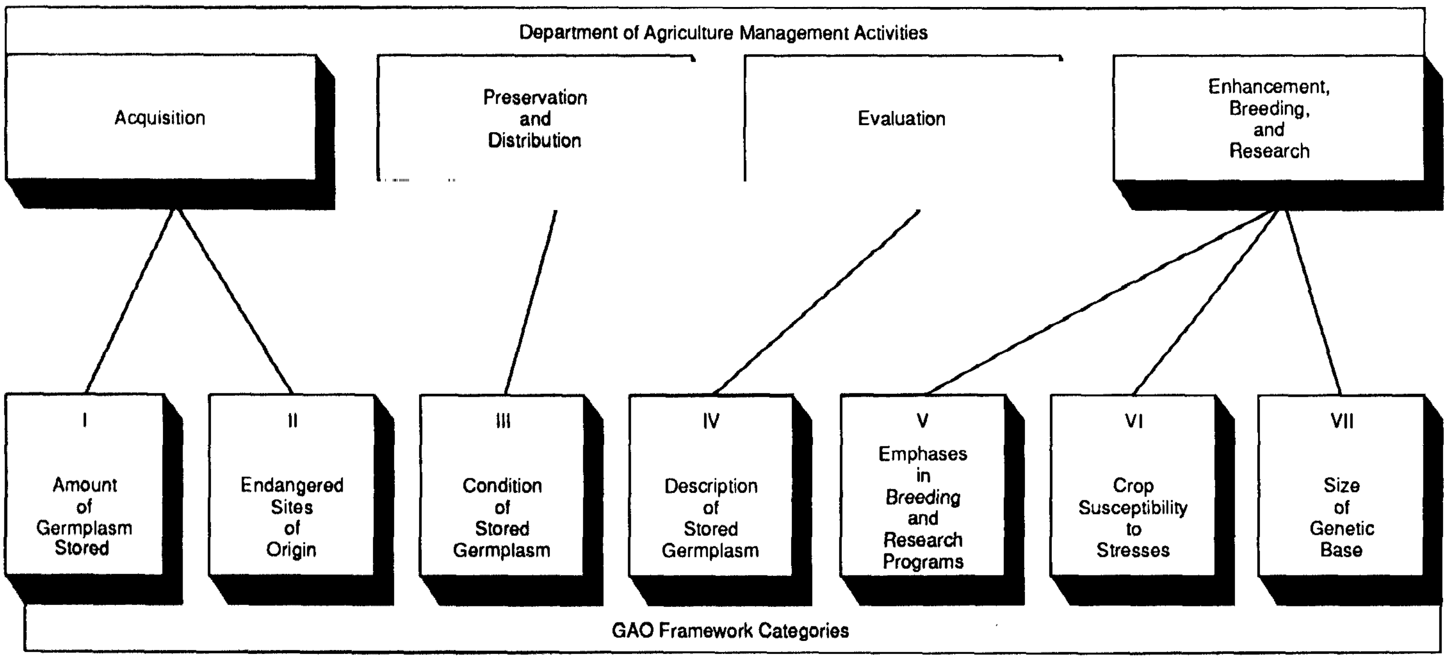
The complete framework organizes the 31 components within these categories and includes under each component suggested analyses of data to be obtained through survey responses.

Not surprisingly, the conditions and activities represented by these categories are associated with activities that ARS performs in carrying out its germplasm management responsibilities, as shown in figure 3.1 on the next page.

If natural and societal conditions for individual crops and germplasm are viewed as indicators of the risk of loss of genetic resources, then management activities under ARS's control can be viewed as potentially affecting or compensating for the conditions that exist for a crop at a particular time. That is, ARS needs to maintain sufficient amounts of germplasm by acquiring new and endangered germplasm but also needs to improve the condition of existing collections and evaluate and otherwise describe germplasm to increase its usefulness to plant breeders. Although such needs—arising from existing conditions or from past or current activities—may vary relative to one another, we believe it is clear that ARS needs to sustain a minimum level of effort in each area of germplasm management to maintain the diversity of the stored resources and to ensure that levels of stored germplasm are adequate for future needs.

Decisions to support varying levels of effort among activities, and among the many types of genetic resources maintained, require many trade-offs. Our framework provides a way to organize data to analyze

Figure 3.1: USDA's Germplasm Management Activities Related to GAO's Framework



the availability and reliability of information among crops as input for these decisions. Data describing the framework components for a crop can indicate trends in germplasm acquisition, preservation, and use and can identify gaps in information or types of information that are difficult or impossible to obtain. Collecting and analyzing such information is important to ARS in assessing the vulnerability of a particular crop, especially in comparing the potential risk of vulnerability among and between crops. In addition, the framework components contain items that the crop advisory committees are asked to include in their vulnerability reports. Data collection based on the framework components could supplement this information uniformly across crops.

Feasibility of Obtaining Uniform Data About Scientists' Germplasm Use and Needs

During our examination of the data ARS now collects and how it collects them, we discovered that the information being obtained on the status of the various crops and their associated genetic resources is inadequate for setting germplasm management priorities. To answer our third, fourth, and fifth evaluation questions—How can ARS obtain the best possible data on scientists' plant germplasm use and needs? How can ARS assess the effects of biotechnology applications on the use of plant germplasm? How can ARS obtain scientists' opinions on the relative importance of activities pertaining to preservation and use of plant germplasm?—we used our framework to do two things. First, we developed a survey instrument capable of collecting the needed data from users of the germplasm. Second, by applying the instrument to a judgmental sample of scientists involved in germplasm work, we determined whether germplasm scientists could and would provide the types of information ARS needs.

Collecting and Analyzing Uniform Data

By applying our survey instrument and framework, we gathered information on acquisition, preservation, description, enhancement, breeding, and research (including biotechnology) activities from a judgmental sample of 15 different types of scientists who work with the three selected crops (see appendix II). Following are just some examples of questionnaire responses and analyses within the germplasm activities of acquisition, preservation, description, and breeding and research for *Brassica*, sorghum, and *Prunus persica*.

Acquisition

Our first two sets of examples demonstrate information on the acquisition needs of scientists working with the three selected crops. (See volume 2, appendix I, category I, Amount of Stored Germplasm.) Survey respondents identified the locations (such as countries, states, or provinces) from which they or others had collected germplasm through plant exploration trips in the past 3 years; the locations from which they or others plan to collect germplasm in the next 3 years; and the locations from which they believe germplasm should be collected (whether by them or someone else). Table 4.1 shows respondents' past and planned acquisition destinations and the world locations from which they believe germplasm should be collected.

Table 4.1: Locations of Completed, Planned, and Recommended Acquisition Locations

Genus or species	Visited	To which trips are planned	In which acquisition is recommended
Brassica			Africa (e.g., east and north regions, Ethiopia)
	Asia (India, Turkey, U.S.S.R.)	Asia (Bhutan, East India, Nepal)	Asia (e.g., Afghanistan, Bangladesh, China, India, Iran, Japan, Korea, Middle East, Pakistan, Taiwan, Turkey)
	Europe (Holland, Portugal, Sweden)		Europe (e.g., Coast of England, Crete, Greece, Greek and Turkish isles, Italy, Mediterranean area, Portugal, Spain)
	North America (Canada; United States: Montana, New York, Washington)	North America (United States: Montana)	North and Central America
Prunus persica	Africa (Morocco)		
	Asia (China, Japan, Pakistan, Taiwan, Thailand)	Asia (U.S.S.R.)	Asia (Bhutan, Burma, China—Qinghai, Sichuan, and Yunnan—India, Iran, Japan, Nepal, Pakistan, Syria, Tibet, Turkey, U.S.S.R.)
	Europe (France, Italy)	Europe (France)	Europe (e.g., eastern Europe, Italy, Spain)
	North and Central America (Mexico; United States: California, Georgia, Texas, Washington)	North America (e.g., United States: North Carolina	North and Central America (United States, Mexico)
	Oceania (New Zealand)	Oceania (New Zealand)	
	South America (Brazil, Venezuela)	South America (Argentina)	South America
Sorghum	Africa (e.g., Botswana, Burkina Faso, Cameroon, Egypt, Ethiopia, Kenya, Lesotho, Mali, Morocco, Niger, Nigeria, Somalia, South Africa, Sudan, Swaziland, Tanzania, West Africa, Zambia, Zimbabwe)	Africa (e.g., Chad, Ivory Coast, Kenya, Mauritania, Mali, Niger, Sudan, Tanzania, Uganda, West Africa)	Africa (e.g., African Highlands, Botswana, Burkina Faso, Ethiopia, Kenya, Mali, Mozambique, Niger, Nigeria, Senegal, Sudan, Tanzania, Uganda, West Africa, Zaire, Zambia)
	Asia (Northeastern China, China, India, Yemen Arab Republic)	Asia (People's Democratic Republic of Yemen)	Asia (e.g., Burma, China, Far East Highlands, India, Iran, Iraq, Middle East, Northern Syria, Pakistan, Philippines, Saudi Arabia, U.S.S.R.)
	Australia		Australia
	Central America (Guatemala, Honduras)	Central America (Honduras)	Central America (El Salvador, Guatemala, Honduras)
	South America (e.g., Argentina, Brazil)		South America (Venezuela)

The table thus allows the development of information in several areas, among them the knowledge of gaps in current acquisitions. These data are given in the columns showing recommended acquisition locations in which collection has not yet been accomplished or is planned—for example, sorghum acquisition in Mozambique, Senegal, and Zaire.

The respondents also indicated the sources of funding for their planned plant exploration trips. For example, of the four *Prunus persica* respondents who plan to acquire germplasm through their own trips or through trips by people they know, one reported he would receive funds from private industry to finance four different plant exploration trips. Another reported that he would receive funding for two trips from ARS exploration grants, and another reported that he would receive funding for six trips from a university. The fourth respondent had not yet obtained funding for an exploration trip.

Finally, the domestic respondents reported the importance of various factors influencing their decisions to collect germplasm. For example, the factor most influencing *Brassica* and sorghum respondents' decisions was commercial interest in the crop. The *Prunus persica* respondents' decisions whether to acquire particular genetic resources were most influenced by U.S. regulations, practices, or changes in the policy that inhibit the importation of genetic resources, while insufficient diversity stored in collections worldwide was the least influencing factor.

Taken as a whole, information such as that presented for the three questions above could supplement ARS's existing acquisition plan information, as discussed earlier, with more uniform acquisition data from scientists working with many different crops. ARS would, for instance, have more complete information on scientists' completed and planned acquisition trips and on locations from which germplasm still needs to be collected. ARS could then better assess what germplasm it needs to collect and coordinate its own trip destinations with those of other individuals or organizations to avoid duplicative efforts whenever possible and to optimize its use of its own funds for acquisition.

A second set of examples deals with knowledge of scientists' own germplasm accessions. Table 4.2 shows 32 respondents reporting that they probably possessed unique germplasm in their collections that they believed would be useful to ARS. This is important because with this information, ARS could identify germplasm it might obtain from the scientists rather than through more-expensive exploration trips. Without this information, ARS might fail to fill gaps in a collection, thereby limiting the usefulness of the collection to breeders and researchers.

Table 4.2: Respondents With Unique Accessions and Whose Accessions Were Offered and Accepted by ARS in the Last 5 Years

Genus or species	Have unique accessions	Offered accessions	Had accessions accepted
Brassica	7	1	0
Prunus persica	9	0	0
Sorghum	16	4	4
Total	**32**	**5**	**4**

ARS is currently gathering some information on existing collections from selected organizations (for example, land grant colleges and companies with breeding programs) within the National Plant Germplasm System. Through a survey of these organizations, ARS is attempting to identify unique germplasm accessions that may be endangered (for example, those that may be discarded upon discontinuance of the breeding or research program for which they were used).

By applying our questionnaire to a large number of scientists using germplasm, ARS could supplement or replace current efforts to obtain information on unique accessions. For example, it could gather accession data from a much wider range of germplasm users—from private, public, other domestic, and foreign companies and individuals—and could identify those who have unique accessions that may be valuable additions to NPGS collections. Once it identifies such accessions, ARS can decide whether to acquire the germplasm and add it to an existing collection.

Besides the types of information in the previous examples, opinions could be obtained about the number of species in each gene pool of genetic resources. For example, questions 30 and 31 on the survey can provide data on respondents' degree of satisfaction with the quality of information they have obtained from various sources about the amount of germplasm (1) existing in nature, (2) existing in gene banks, and (3) declining for different types. Question 32 can provide information on scientists' opinions on the quality of the sources of information and can identify the types of germplasm scientists know the most about. With uniform data on these subjects, ARS could better identify gaps in information about existing genetic resources. In addition, ARS could better assess the information sources with which respondents have been most satisfied and, hence, the best sources of information. Such data would then assist ARS in setting priorities for developing or distributing information about the amounts of different types of germplasm existing in nature or in gene banks.

ARS could also obtain uniform information about the existing diversity represented in gene banks. For example, question 35 on the survey can provide scientists' estimates of the percentage of the total existing diversity for their crops that is represented in gene banks, for the six different types of germplasm. With this information, ARS could better assess the consistency of existing information and the need to collect different types of germplasm.

Preservation

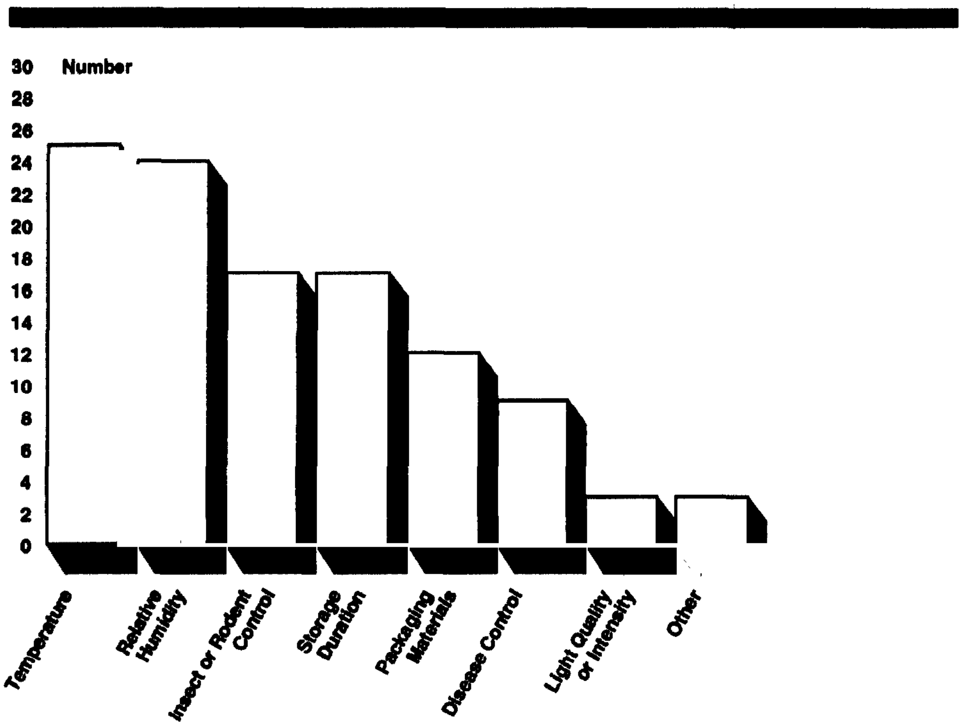
Our next two examples address the preservation activities of scientists working with the three crops. (See volume 2, appendix I, category III, Condition of Stored Germplasm.) The first example deals with the (1) composition of germplasm collections, (2) types of preservation conditions that scientists regulate, and (3) maintenance activities that scientists typically perform.

The respondents reported the various forms of germplasm (such as seed or clonal materials) stored in their collections. For example, the 25 sorghum respondents who maintained germplasm collections stored virtually 100 percent of their collections as seed; the 11 *Brassica* respondents stored 91.3 percent as seed, 7.7 percent as clones, and less than 1 percent as in vitro cultures; the 11 *Prunus persica* respondents stored about 1 percent as seed, 89 percent as clones, 9.5 percent as in vitro culture, 1.4 percent as pollen, and less than 1 percent as DNA.

Respondents also provided information on the preservation conditions they typically control. Among these are temperature, humidity, disease and pest control, packaging materials, and storage duration. Figure 4.1, for example, shows the types of preservation conditions that the 25 sorghum respondents usually regulate.

Respondents also engage in various maintenance activities. Among these are germinating seed prior to placing it in storage, testing germplasm for viruses, and growing out seed to replenish collections. Figure 4.2 shows the maintenance activities that the 19 sorghum respondents usually perform to preserve the germplasm in their collections.

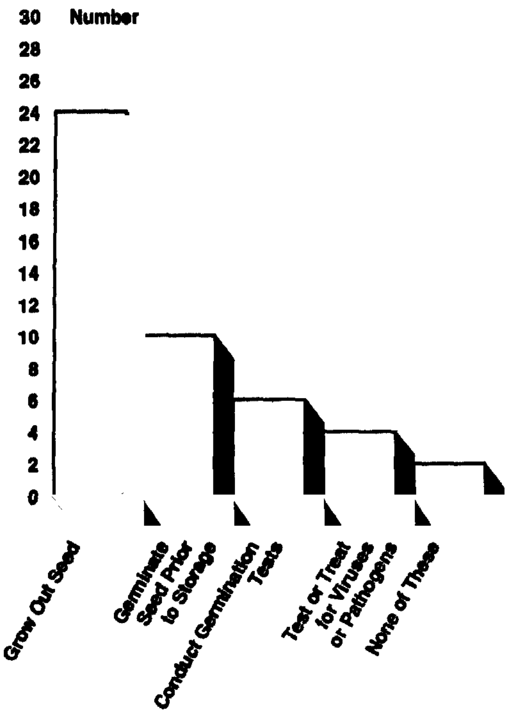
Figure 4.1: Preservation Conditions Regulated or Recorded by Sorghum Respondents



Data on the preservation status of individual scientists' collections could supplement ARS's knowledge about the general condition of germplasm held by breeders and other plant scientists for various crops. ARS officials could compare differences in the preservation and maintenance procedures and thereby gain indications of the overall viability of collections. Information about the conditions of individual collections could also help ARS officials assess whether they would want to obtain germplasm from these individual collections.

Our second preservation example deals with the preservation standards that scientists use. For example, 7 of 11 *Brassica* respondents reported that they usually conducted one or more maintenance activities (for example, germinating seed prior to placing it in storage or growing out seed to replenish collections) on the germplasm in their collections. Of these 7 respondents, 5 applied personal standards, 2 applied institution or industry standards, and 1 applied International Board for Plant Genetic Resources standards as well. None of the respondents reported using standards established by the National Seed Storage Laboratory.

Figure 4.2: Maintenance Activities Performed by Sorghum Respondents

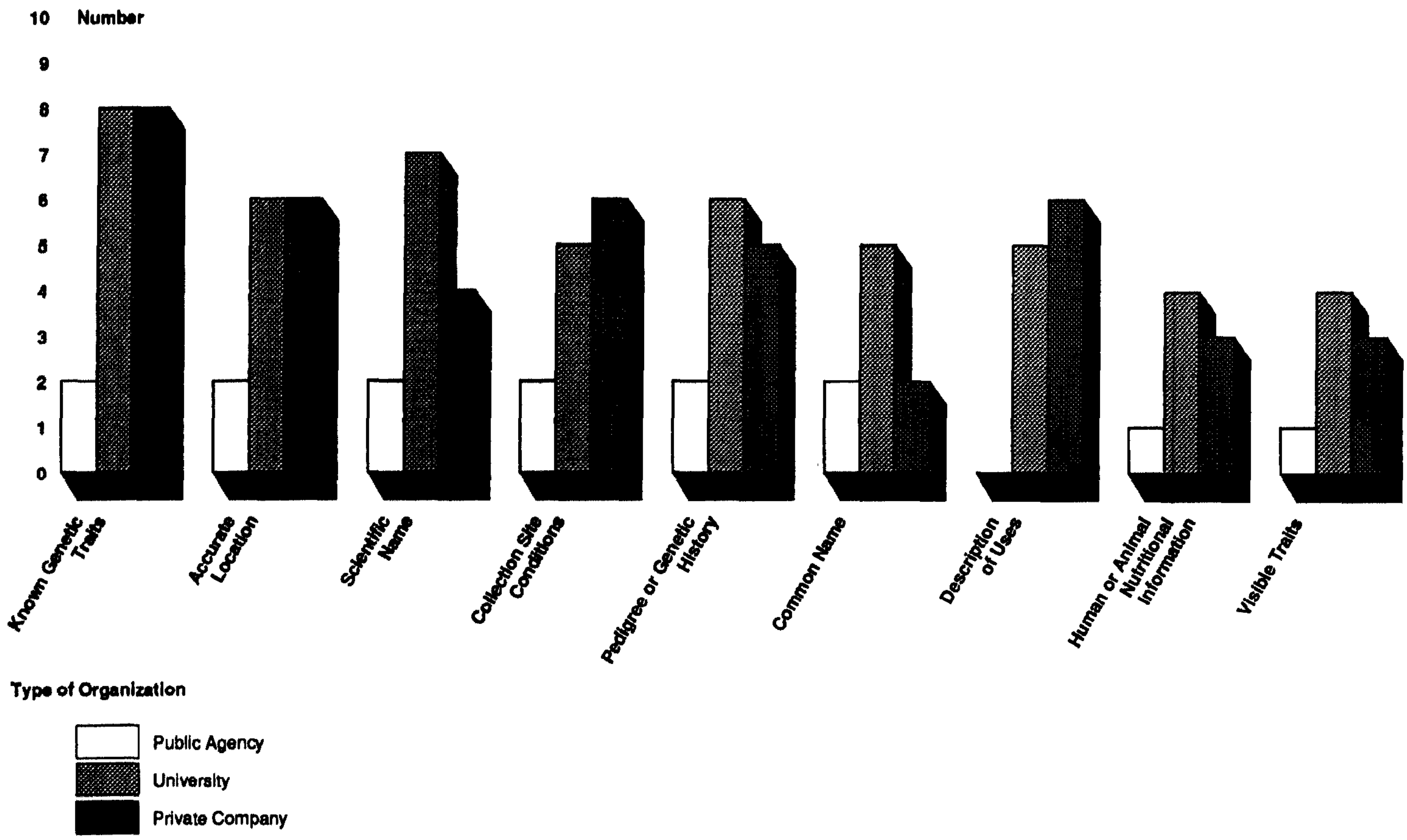


Knowledge of the extent to which preservation standards are applied to germplasm collections, depending on length of time stored and which standards are most used, could help ARS assess both the likely condition of useful germplasm held in the collections and the need for the dissemination of information about the importance of adequate germplasm preservation.

Description

Our next two examples address the description needs of scientists working with the three selected crops. With regard to different types of descriptive information about germplasm accessions, the survey respondents reported the importance and accessibility of various types of descriptive information to their work. (See volume 2, appendix I, category IV, Status of Description of Stored Germplasm.) Figure 4.3 illustrates the importance of some of these types of information. For example, known genetic traits and scientific name were important to more of our sorghum respondents working at universities, and common name was important to fewer scientists at private companies compared to other types of descriptive information.

Figure 4.3: Descriptive Information of Great or Very Great Importance to Sorghum Respondents



Note: A total of two scientists from public agencies and nine scientists each from universities and private companies responded to this question. All were from U.S. organizations.

Respondents also provided information about the accessibility of these types of information. Overall, 24 of 25 sorghum respondents, for example, said that information about known genetic traits (resistance to disease or environmental stresses; mineral tolerance; yield and adaptation) was of great or very great importance to their work. However, 9 of these respondents also said such information was hard or impossible to obtain. ARS could use such information to assess priorities for evaluating or otherwise describing accessions in order to respond to the needs of germplasm users.

In addition, ARS could identify crops for which scientists do not request germplasm from NPGS collections because of past difficulties in obtaining reliable information. For example, one *Brassica* scientist who has reportedly found the collections to be unreliably catalogued and lacking in descriptive information has avoided using them. Instead, the scientist tries to obtain germplasm from private companies and scientists who work with *Brassica*. Thus, ARS could use the survey data to assess the effectiveness of GRIN.

In our second example, scientists reported the types of descriptive information (in addition to those shown in figure 4.3) that, if available, would assist their work. For instance, of the five *Prunus persica* respondents who answered this question, one said that information about the adaptability of cultivars to various geographic locations would be useful if it were available. Another reported that information about the best conditions for long-term storage, as well as bloom and fruiting information, would be useful, and another reported that information about forming fertile hybrids between *Prunus persica* and other species would be of assistance. Two *Prunus persica* respondents stated that more information about known genetic traits and about diversity levels would be helpful.

These and other types of descriptive information provided by periodically implementing a broad survey could supplement ARS's knowledge about the information that is most important to scientists' work. It could also help ARS identify the types of information that are lacking or difficult to obtain for different crops. Such knowledge could then help ARS set evaluation priorities within and among different crops, as well as help discern the need to improve the accessibility of certain types of information to scientists.

Breeding and Research

Our next three examples address the breeding (including enhancement) and research needs of scientists working with the three selected crops. The first example deals with breeding and research objectives the scientists have most emphasized during the last 3 years or expect to emphasize during the next 3 years. (See volume 2, appendix I, component V.) Table 4.3, for example, shows six breeding and research objectives that are among the top four objectives for at least one of the three selected crops. The objective ranked first by the majority of the 13 *Brassica* and the 13 *Prunus persica* respondents was enhancing traits for commercial use. For most of the 26 sorghum respondents, the most important objective was increasing crop yields.

Table 4.3: Respondents' Top Four Breeding and Research Objectives[a]

Objective	*Brassica*	*Prunus persica*	Sorghum
Enhancing traits for commercial use	1st	1st	2nd
Increasing crop yields			1st
Identifying traits for greater adaptation to environmental stresses		2nd	3rd
Improving genetic manipulation (biotechnology) techniques for breeding and research	2nd	4th	
Enhancing traits to facilitate the production of crops (e.g., pesticide tolerance)	3rd		4th
Identifying traits for resistance to known pathogens, pests, and so on that have not yet been found in genetic resources for this genus	4th	3rd	

[a]During the last 3 and next 3 years.

By gathering uniform information about the types of breeding and research objectives scientists are emphasizing or expect to emphasize in the future, ARS could supplement its knowledge of the breeding and research areas that are already being addressed by different respondent groups, such as public versus private sector breeders. Such information could help ARS identify areas in which emphasis is lacking or assess its need to conduct different types of enhancement, breeding, and research work for different crops.

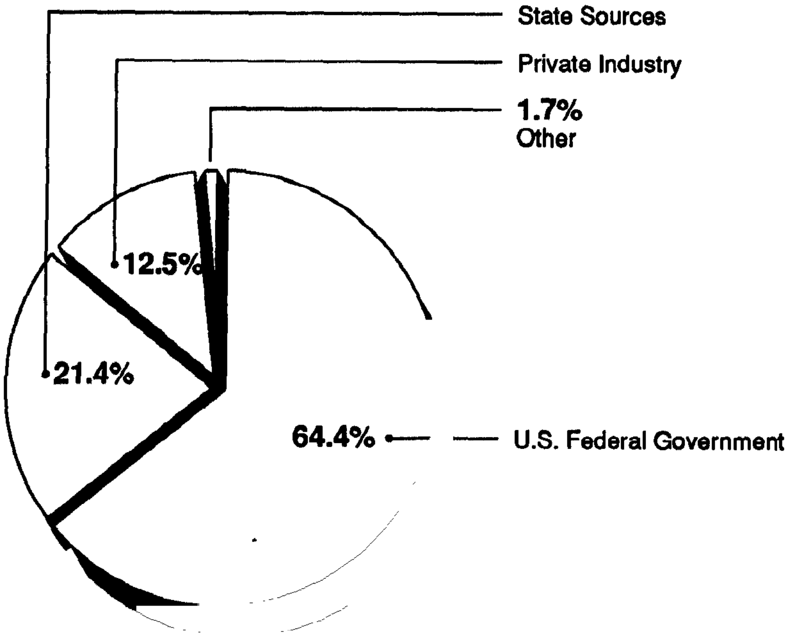
In our second example, the respondents estimated the level of breeding and research effort associated with their crops as measured by (1) the estimated total level of breeding and research funding in the last 3 years, (2) the estimated number of full-time-equivalent scientists, and (3) the sources of breeding and research funding. For example, table 4.4 illustrates that information can be obtained to measure levels of staff and funding effort invested in breeding and research programs for the various crops.

Table 4.4: Full-Time-Equivalent Staff and Funding Levels for Breeding and Research

Genus or species	Number of respondents	Staff: Total	Staff: Average	Funding: Total	Funding: Average
Brassica	12	59	4.9	$8,833,000	$149,712
Prunus persica	12	41	3.4	1,508,000	36,780
Sorghum	25	251	10.0	12,463,000	49,653

In addition, the respondents reported the sources from which they received most of their funding. Figure 4.4, for example, shows that almost two thirds of the funding for breeding and research for the 12 *Prunus persica* respondents was from the U.S. federal government.

Figure 4.4: Percentage of Funding Received From Various Sources by *Prunus persica* Respondents



The amount and sources of funding and full-time-equivalent scientists could help ARS identify gaps (or over-investment) in effort among crops, thus helping to more appropriately target limited funds to areas needing attention. Using this information, ARS should be better able to set priorities in a manner that responds to scientists' needs for crop improvement and research.

Table 4.5: Resistance Traits for Which Respondents Are Searching and Traits That Need Greater Emphasis

Genus or species	Currently being searched for	Needing greater emphasis
Brassica	*Alternaria,* aphids, Blackleg, Club root, Diamondback moth, Downy mildew, early maturity, frost tolerance, *Fusarium oxysporum*, heat tolerance, insects, *Leptosphaeria, Mycosphaerella*, saline and alkaline soil, *Sclerotinia*, Thrips, white rust and mold, *Xanthomonas campestris* (black rot)	*Alternaria*, Bacterial soft,[a] Blackleg, disease (any), Downy mildew, fungal and foliage diseases,[a] hypersensitivity,[a] insects and pests, *Mycosphaerella Sclerotinia*, stress tolerance, *Xanthomonas*
Prunus persica	Bacterial leaf spot, brown rot, calcareous soil, cankers, cold resistance, Collar rot, Crown gall, cytospora cancer, early and late maturity, late bloom-freeze avoidance, leaf curl, Nematodes, oriental fruit moth, peach dwarf, peach scab, peach tree borers, *Prunus* ring spot, slow softening, tomato ring spot, *Valsa* cancer, winter hardiness	Bacterial leaf spot, brown rot, cold hardiness, drought,[a] fungus, insects and pests, Nematodes, peach scab, *Phytophthora*,[a] scale,[a] viruses, winter injury
Sorghum	Acid soil, aluminum and manganese toxicity, Anthracnose, aphids, Banded leaf blight, Banks spider mite, chinch bug, Downy mildew, drought or moisture, Greenbug, head or grain molds and smut, heat tolerance, herbicides, host-pathogen interaction, isozymes, leaf diseases, Long smut, mineral stress, mites, mosaic virus, salt tolerance, seedling diseases, Sheath blight, Shootfly, sorghum midge, Stem borer, *Striga*, sugarcane mosaic virus, tropical adaptation, viruses, weathering	Acid soil; aphids; biotic stress;[a] chinch bugs; cold tolerance;[a] Downy mildew; drought and moisture; Dwarf maize mosaic; heat, nutrients, and water; insects; Ergot;[a] grain mold; Greenbug; Headbug;[a] Long smut; mites; Shootfly; sorghum midge; small seed malady;[a] stalk rot;[a] viruses; water logging[a]

[a]Respondents are not currently searching for this trait but believe it warrants greater emphasis.

Our third example deals with (1) the resistance traits for which scientists are searching, (2) traits they believe should receive greater research emphasis, and (3) whether they believe the descriptors listed by major organizations include traits that are of high priority. For example, table 4.5 shows the specific resistance traits for which respondents working with the selected crops are currently searching, as well as the traits that they believe need greater emphasis as research priorities.

The survey respondents for the selected crops also reported the extent to which they believed descriptors listed by major organizations include those that should be research priorities. For example, all 5 of the *Brassica* scientists, 16 of the 21 sorghum scientists, and 9 of the 11 *Prunus persica* scientists who responded to the question believed that the resistance descriptors recommended by major advisory organizations include the traits that should be research priorities.[1]

This information can clearly identify the extent to which important traits are receiving little or no research emphasis. In addition, the information could help ARS officials or major advisory organizations compare the resistance descriptors they recommend with those that scientists working with the germplasm believe are most important. Such information would help identify resistance traits for which more emphasis is needed and thereby help set priorities and allocate resources.

Summary

Surveying a sample of germplasm users for three very different crops, we have demonstrated that it is feasible to collect uniform, comparable information on germplasm acquisition, preservation, description, breeding, enhancement, and research from a wide variety of scientists who work with germplasm. This method, implemented periodically, would allow ARS to compare germplasm users' needs and opinions, as well as to identify trends in the use of germplasm and information gaps among the various crops. Such information, currently lacking, is critical to ARS officials' function of setting priorities across germplasm management activities within and across crops.

[1]Respondents answered in the moderate to very-great-extent categories.

Determining the Effects of Biotechnology on Germplasm Use

The term biotechnology includes many ideas and advanced methods, derived from molecular and cell biology, that use biological systems to produce products. Germplasm and, in particular, the adequate conservation of genes are the essential resource for applying biotechnology techniques to plants. Evaluation question 4—How can ARS assess the effects of biotechnology applications on the use of plant germplasm?—is important because the use of these advanced techniques is changing the way germplasm is preserved and used and may ultimately affect genetic or species diversity. Biotechnology use is included in the research and breeding emphasis category of our framework. (See volume 2, appendix I, component V.I.)

Potential Effects of Biotechnology

Many complex issues of worldwide economic importance have been linked to the eventual effects of biotechnology applications in plant breeding and research. Some of these issues are related to concerns regarding the possible reduction of diversity and negative effects on world agricultural production and trade. Other issues are related to the promise of increased crop production and the potential for great advances in the preservation and use of germplasm resources.

Experts have expressed concern that emphasis on using biotechnology applications for plant breeding and research may influence the types and amounts of genetic resources used and, thus, preserved. They are concerned, as well, that emphasis and funding may be shifted away from traditional plant breeding methods and toward biotechnology development or improvement of particular crops that have become lucrative because of the products of biotechnology.

Finally, concern exists over the ultimate effect that the use of biotechnology will have on genetic or species diversity. Genetic uniformity could actually increase if a limited number of engineered genes of major commercial interest were selected and bred into the commercial varieties of a large number of crops. Uniformity could also result from emphasis in financing biotechnology work on producing hybrid seeds of major crops or uniform clonal populations. However, while biotechnology applications do not create genetic diversity, they can create diversity by rearranging and transferring existing genes across natural breeding barriers, creating new combinations not possible with traditional methods.

The widespread use of biotechnology also has implications for political aspects of germplasm management, such as the policy of free exchange.

The possibility of patenting plant parts and even individual characteristics or gene sequences made possible by biotechnology is controversial, and the outcome is still unknown. If the patenting of this genetic material becomes commonplace, private companies may be unwilling to share their valuable genetic material with public sector breeders, and the public sector may be fearful that its unreleased material, if shared, may become private property through patents.

Despite these concerns, significant improvements in germplasm preservation and in crop improvement are anticipated with the widespread implementation of biotechnology techniques. For example, preservation using cell or tissue culture, or even gene libraries, may ultimately make genes easier to retrieve and manipulate than is possible with traditional seed storage facilities and clonal repositories. This is especially important for crop species that do not produce seed, such as yams, coffee, potatoes, or bananas, or species for which seed storage at low temperatures is difficult or impossible. Tissue culture also makes possible the virus-free storage of germplasm, as well as techniques used to induce mutations in seed, thereby effecting useful changes in crop plants.

The costly and difficult task of evaluating germplasm accessions to identify the genetic traits they contain would be greatly speeded by the widespread use of various techniques. Several techniques allow the rapid screening of a container of cultured cells containing about the same diversity as would be present in 1,000 acres of whole plants. Among these techniques are using restriction fragment length polymorphisms (which are DNA fragments that can be used as markers to map the position of genes on chromosomes), analyzing nucleic acids, and using electrophoresis of isozymes and other proteins.

The use of many biotechnology techniques is dependent on adequate evaluations of germplasm accessions. Powerful biotechnology techniques, such as protoplast fusion and DNA or gene synthesis and gene transfer, offer the promise of cloning and inserting selected genes into plants without conventional parental crosses—that is, moving individual genes between plants and potentially across species and genus barriers. To effectively transfer genes, however, scientists need detailed mapping of chromosomes for each crop and its wild relatives, to identify the location of genes for important traits. The task of mapping chromosomes is enormous, as each plant contains between 1 million and 10 million genes. Yet without more thorough evaluation of germplasm accessions, scientists may not know where to find the sought-after traits in gene bank collections. However, even if advanced techniques could be used now to evaluate collections, according to the International Board for Plant Genetic Resources, at least a decade and $120 million would be required to evaluate the world's germplasm for major food crops.

Use of these and other advanced techniques may increase the demand for wild and weedy germplasm, because the techniques facilitate widecrossing (that is, crossing distantly related and unrelated species). Biotechnology may eventually speed the screening and transfer of traits, shortening the 10- to 14-year period traditionally needed to move important genes into crop plants. However, new varieties must still be field tested, a process that accounts for about 40 to 50 percent of the time needed to develop a new variety. Traditional breeding techniques and knowledge are still needed to incorporate these biotechnology products successfully into commercial crops.

How Knowledge of Biotechnology Use Can Assist Germplasm Managers

Germplasm management decisions related to such activities as preservation, description, enhancement, breeding, and research should include some knowledge of trends in the application of biotechnology for individual crops, species, or genera, including differences in breeding or research emphasis and in the use of germplasm among crops. Therefore, our framework components and questionnaire include information on the extent to which plant scientists are using biotechnology techniques and their opinions on how, if at all, this use is influencing their breeding and research emphases, or the amount and types of germplasm they use.

The following section presents examples of questionnaire responses obtained for the three selected crops. The data illustrate how information might be obtained to compare these factors among crops or types of genetic resources, so as to evaluate trends that may have significant implications for germplasm management resource decisions.

Extent of Use of Biotechnology Techniques

Our framework describes analyses of questionnaire responses related to the use of biotechnology techniques. (See volume 2, appendix I, component V.I.) For the three selected crops combined, 23 of the 50 scientists said that improving biotechnology techniques is a research objective of theirs to at least a moderate extent when compared with other objectives. In addition, 21 of the 23, plus 9 additional respondents, said that biotechnology improvement will be a research objective in the next 3 years.

We asked all the scientists surveyed if they use any advanced, or biotechnology, techniques in their breeding or research programs. Of the 53 scientists who responded, 39 said they use the techniques to at least some extent. For *Brassica*, 10 respondents (76.9 percent) used biotechnology techniques; for *Prunus persica*, 12 respondents (85.7 percent) used them; and for sorghum, 17 respondents (65.4 percent) used them.

We also asked about the use of seven specific biotechnology techniques. Table 5.1 shows that of the seven techniques, cell tissue culture, widecrosses, and gene mapping were used to the greatest extent by these respondents. (The respondents answered in the some to very-great-extent categories.)

Table 5.1: Respondents Using Biotechnology Techniques[a]

Technique	*Brassica*	*Prunus persica*	Sorghum	Total
Cell tissue culture	8	6	11	**25**
Widecrosses	7	9	8	**24**
Gene mapping (through RFLP or molecular markers)	6	7	7	**20**
Site-directed mutagenesis	3	2	4	**9**
Methods to achieve DNA gene transfer	5	2	3	**10**
Protoplast fusion	5	0	2	**7**
Chemical synthesis of nucleic acids or genes	2	1	0	**3**

[a]Total respondents were 10 *Brassica*, 12 *Prunus persica*, and 16 sorghum.

The responses we obtained could, given a larger sample, indicate important differences among crops with respect to the use of various biotechnology techniques, as well as overall trends in the use of the techniques in crop breeding and research. Information of this type from a sizable number of scientists could help ARS identify common techniques or emerging biotechnology areas.

Changes in Program Emphasis From Biotechnology

The scientists also responded about the extent to which the use of biotechnology techniques has changed their research or breeding emphases and the extent to which they believe the use will change their future emphases. Table 5.2 indicates trends in changing emphasis from the use of four of the techniques and indicates that the respondents generally expected more change in the future. For example, the table shows that while 5 of the 16 sorghum respondents reported that their emphasis has changed from the use of gene mapping, 11 expected such a change in the future.

Table 5.2: Respondents Reporting Changes in Emphasis From the Use of Biotechnology Techniques

Breeding and research technique	Emphasis has changed	Emphasis is expected to change
Brassica		
Cell or tissue culture	5	6
Widecrosses	3	4
Gene mapping	5	7
Methods to achieve gene transfer	0	7
Prunus persica		
Cell or tissue culture	3	4
Widecrosses	3	7
Gene mapping	4	6
Methods to achieve gene transfer	2	8
Sorghum		
Cell or tissue culture	4	5
Widecrosses	2	4
Gene mapping	5	11
Methods to achieve gene transfer	3	6

Again, with an adequate sample, it is possible that differences could be noted among crops in biotechnology's effect on breeding or research emphases. ARS could use such information, over time, along with responses about current and future program objectives, to evaluate trends in these areas.

Change in Germplasm Use From Biotechnology

Finally, the scientists responded about the extent to which they expected biotechnology techniques to change their use of germplasm. Table 5.3 presents, for the four most used techniques, the numbers of responses in the moderate to very-great-extent categories. As shown for the three crops, respondents said that their use of germplasm has changed because of the four techniques, but fewer respondents said that change occurred because of cell or tissue culture.

Table 5.3: Respondents Whose Use of Germplasm Has Changed Because of Biotechnology Techniques[a]

Technique	*Brassica*	*Prunus persica*	Sorghum
Cell or tissue culture	2	2	3
Widecrosses	4	4	8
Gene mapping	4	7	8
Methods to achieve gene transfer	3	4	6

[a]Total responses were 8 *Brassica*, 11-12 *Prunus persica*, and 14-15 sorghum.

ARS currently uses biotechnology techniques for germplasm preservation and is identifying techniques for future use. As well, ARS decisions on which genetic resources to acquire and evaluate could potentially affect the use of biotechnology techniques by breeders and researchers who use the techniques to evaluate germplasm and those who want to use germplasm that has already been evaluated in their biotechnology-related work. Biotechnology relies heavily on gene bank curators' knowledge of what germplasm is available, its characteristics and problems, where collections are held, and how to gain access. Indeed, a mission of ARS's National Germplasm Resources Laboratory is to provide accurate data to scientists who use the germplasm accessions.

Information on trends in the use of the techniques combined with other information gathered by the survey could assist with difficult decisions to invest evaluation funds among the many types of germplasm. Through question 79, ARS could determine differences among crops in the amounts of germplasm from the three gene pools that plant scientists are using in their work. This information, along with information on, for example, breeding and research objectives or specific traits needing research emphasis, could facilitate decisions about which types of germplasm accessions are most important to users and should thus be given higher priority for receiving available evaluation funds.

In addition, scientists' opinions on the importance of emphasizing biotechnology applications versus other germplasm activities for individual crops could assist ARS in setting priorities among crops. This will be discussed in chapter 6.

Opinions About the Relative Importance of Germplasm Preservation and Use

As described in the framework we developed in chapter 3, the preservation and use of germplasm involves the broad activities of acquisition, preservation (including distribution), description (including evaluation), enhancement, breeding, and research (including the implementation of biotechnology). In this chapter, we address our fifth evaluation question: How can ARS obtain scientists' opinions on the relative importance of activities pertaining to the preservation and use of plant germplasm? Answering this question is complex and involves combining responses from five questions on our survey for the three crops—questions 28, 48, 53, 76, and 80.

Opinions About the Importance of Germplasm Activities

Based on six activities that we believe compete for funding—acquisition, preservation, description, enhancement, breeding, and biotechnology—we identified 15 pairwise combinations of the activities (the total number of unique combinations) and asked the scientists to indicate their opinion of the relative importance of emphasizing each activity compared to the five other activities for the overall improvement of genetic resource management for one crop.

To analyze the data from the 15 comparisons, we used the pairwise comparison methodology termed the analytic hierarchy process.[1] The process was developed to deal with unstructured decision problems, particularly ones involving socioeconomic and political issues with qualitative and intangible factors. It allows for taking diverse judgments from people whether singly, working in a group, or by questionnaire. The objective of this approach is to use weights or priorities to assign relative importance to a set of activities in a decisionmaking situation. The process has been used for priority-setting, resource allocation, and other decisionmaking activities in a variety of different settings.

The result of the pairwise analysis yields weights or ratios assigned to the activities (the sum of the weights is equal to 1) that can be used to support decisionmaking. We asked respondents to consider a goal for each crop, which we stated as "the overall improvement of preservation and use of the crop's genetic resources." The weights assigned to the activities represented the relative importance respondents gave to each activity in reaching this goal. However, our question used a scale of importance that is more condensed than the nine-point scale suggested

[1]The underlying algorithms for solving the analytic hierarchy process procedure are presented in Thomas L. Saaty and Luis G. Vargas, The Logic of Priorities: Applications in Business, Energy, Health and Transportation (Boston: Kluwer-Nijhoff, 1982).

by the analytic hierarchy process literature. Question 80 in our questionnaire contains an expanded scale of the type suggested.

Table 6.1 illustrates the results of the pairwise comparison analysis for the three crops; it ranks the germplasm activities by the order of relative importance for domestic and foreign respondents and provides the weight of the differences in importance between each activity. These results show that the opinions of the scientists working with each of the three selected crops differed with respect to the relative importance of the six germplasm management activities. For the domestic and foreign responses combined, the sample data indicate, for example, that scientists working with *Prunus persica* believed that acquisition should receive 5.2 percent more of the total emphasis than should breeding (0.245 − 0.193). In other cases—for example, for *Prunus persica*—the difference between breeding (0.193) and preservation (0.192) is very small. However, according to an expert in analytic hierarchy process applications, these differences would probably be greater with the implementation of the expanded scale discussed above.

Table 6.1: Relative Importance of the Major Germplasm Management Activities for Domestic and Foreign Respondents[a]

Genus or species	Activity	Weight
Brassica	Preservation	0.218
	Acquisition	0.200
	Description	0.181
	Breeding	0.161
	Enhancement	0.137
	Biotechnology	0.103
Prunus persica	Acquisition	0.245
	Breeding	0.193
	Preservation	0.192
	Biotechnology	0.126
	Enhancement	0.123
	Description	0.121
Sorghum	Breeding	0.214
	Acquisition	0.199
	Preservation	0.194
	Enhancement	0.159
	Description	0.120
	Biotechnology	0.113

[a]Total respondents were 13 *Brassica*, 13 *Prunus persica*, and 26 sorghum.

By obtaining this type of information, ARS could compare what the scientists believe is the most important activity for their crops to the actual level of effort and resources allocated by ARS to these crops. For example, if scientists who use or manage a crop's germplasm identify acquisition activities as the most important for their crop, ARS could review its allocations of funds to this activity, examine the accomplishments, and determine whether additional funding is needed. In order to demonstrate how the analysis of scientists' opinions can be stratified to show differences in opinion among respondent groups, we present an analysis of domestic and foreign respondents in appendix III.

While the ranking and rating of the importance of the major germplasm activities is important and useful to decisionmakers, additional information is needed to identify the specific lower-level activities within the major activities that scientists believe should be emphasized. For example, while the *Prunus persica* scientists we surveyed reported that acquisition is the most important germplasm activity, ARS also needs to know which specific acquisition activities are most important. For this reason, our survey also obtained scientists' opinions about which specific germplasm activities should be emphasized within the areas of germplasm management. The following section provides the method used to obtain and analyze this lower-level information and how it was combined with the pairwise analysis results.

Opinions About Activities Within Germplasm Management

Our survey included four questions that asked respondents' opinions about the relative importance of specific activities within the six categories analyzed using the analytic hierarchy process. Opinions about activities within acquisition, preservation, and description were obtained through three corresponding questions, and opinions about germplasm enhancement, crop improvement, and the use of biotechnology were obtained through a fourth question. To obtain this level of detail, the survey asked scientists for their opinions on the extent to which specific activities should be emphasized to facilitate the overall management of their crop's germplasm.

Results from the initial pairwise analysis and this more-specific information go hand-in-hand. That is, they provide additional specific information that could assist ARS in allocating resources. For example, table 6.2 identifies the number of respondents who believed that the acquisition activities listed should be emphasized to a great or very great extent. For purposes of our demonstration, table 6.2 provides the results from our survey broken out by domestic and foreign respondents.

Table 6.2: Domestic and Foreign Respondents Identifying Acquisition Activities That Should Be Emphasized to a Great or Very Great Extent

	Brassica[a]		*Prunus persica*[b]		Sorghum[c]	
Acquisition activity	**Domestic**	**Foreign**	**Domestic**	**Foreign**	**Domestic**	**Foreign**
Acquiring endangered genetic resources whether or not their potential is known	7	2	8	0	17	5
Acquiring genetic resources that are considered to be potentially useful in breeding	7	3	9	2	21	5
Acquiring plant genetic resources of unknown potential whether or not they are endangered	5	2	3	1	14	0
Improving quarantine procedures and regulations to facilitate acquisition	2	1	10	1	14	2
Eliminating political barriers that hinder collection	5	2	9	1	16	4
Developing arrangements for minimizing patent restrictions in consideration of access to genetic resources	6	0	3	0	11	2
Improving techniques for collecting and recording accessions	5	1	2	0	11	2

[a]For 9 domestic and 4 foreign respondents.

[b]For 12 domestic and 2 foreign respondents.

[c]For 21 domestic and 5 foreign respondents.

The pairwise comparison analysis in table 6.1 shows that scientists working with *Prunus persica* believed that acquisition is the most important germplasm activity. Upon review of table 6.2, it appears that within acquisition, most of the responding domestic scientists (10 of 12) working with *Prunus persica* believed that improvements to quarantine procedures and regulations need to be emphasized. Both of the foreign *Prunus persica* respondents (2 of 2) believed that acquiring genetic resources useful in breeding is an activity that needs greater emphasis. ARS, upon examining this information, could seek to identify exactly what quarantine regulations need to be improved.

Table 6.3 provides scientists' opinions on the specific preservation activities they believed should be emphasized to facilitate the overall management for their crops, based on the small judgmental sample of scientists for the three crops. The data in table 6.3 identify the number of scientists (domestic and foreign) who believed that preservation activities should be emphasized to a great or very great extent.

Table 6.3: Respondents Identifying Preservation Activities That Should Be Emphasized[a]

Preservation activity	*Brassica*	*Prunus persica*	Sorghum
Developing new preservation techniques (e.g., tissue culture, cryopreservation)	3	9	6
Increasing the size or improving the quality of existing storage facilities or clonal repositories	4	9	15
Improving grow-out conditions or strategies	7	1	12
Detecting and treating diseases and insects in storage	5	6	6
Testing for and treating viruses (e.g., in clonal collections)	3	10	4
Developing core collections	5	5	11
Improving access to collections	7	3	16

[a]Total respondents, domestic and foreign, were 12 *Brassica*, 14 *Prunus persica*, and 25 sorghum.

The results from the pairwise comparison analysis in table 6.1 indicate that preservation is the most important germplasm activity to the responding scientists who use or manage *Brassica* germplasm. Table 6.3 shows that most (7 of 12) of our scientists working with *Brassica* believed improving grow-out conditions and strategies and improving their access to *Brassica* germplasm collections are the most important activities within preservation. These results reinforce anecdotal information derived from other sources. Interestingly, an NPGS official stated at an April 1989 meeting that the *Brassica* collection was in "bad shape" and that it will take NPGS about 10 years to improve it enough to be able to readily distribute germplasm. ARS could use such information to determine whether there is a problem with scientists' access to such collections.

Table 6.4 provides scientists' opinions on which specific description activities they believed should be emphasized to a great or very great extent to facilitate the overall management of their crop.

Table 6.4: Respondents Identifying Description Activities That Should Be Emphasized[a]

Description activity	*Brassica*	*Prunus persica*	Sorghum
Evaluating accessions for individual traits	8	10	20
Mapping genes in stored accessions	5	2	5
Eliminating unnecessary duplicate accessions	5	6	7
Maintaining and updating a centralized data base for users	9	7	19
Providing descriptive information, including background, taxonomy, and pedigree data	10	9	21

[a]Total respondents, domestic and foreign, were 12 *Brassica*, 14 *Prunus persica*, and 25 sorghum.

For the three crops, the pairwise comparison analysis results in table 6.1 indicate that description ranks highest (third) for *Brassica* among the three crops, based on scientists' opinions. Table 6.4 shows that most (10 of 12) scientists who work with *Brassica* germplasm believed providing descriptive (background, taxonomy, and pedigree) information on *Brassica* germplasm is the most important activity within description activities. ARS could use this information to examine its efforts and funding allocations in this area among its germplasm holdings.

Table 6.5 provides scientists' opinions on which specific crop improvement and research activities they believed should be emphasized to a great or very great extent to facilitate the overall management of their crop. For purposes of this analysis, this category includes the activities of enhancement and biotechnology development.

Table 6.5: Respondents Identifying Crop Improvement and Research Activities That Should Be Emphasized[a]

Crop improvement or research activity	*Brassica*	*Prunus persica*	Sorghum
Identifying and mapping genes	7	6	7
Developing resistance to stresses (e.g., environmental, diseases, insects, pesticides)	11	11	25
Identifying traits or improving commercial qualities	7	10	22
Improving or developing molecular genetics or other related advanced techniques	4	5	7
Transferring characteristics from nonadapted genetic resources to adapted types (prebreeding, genetic enhancement)	6	7	17
Developing new users for undomesticated genetic resources	4	1	6

[a]Total respondents, domestic and foreign, were 13 *Brassica*, 14 *Prunus persica*, and 26 sorghum.

As indicated earlier, table 6.5 contains specific enhancement, breeding, and research activities. As a result, the pairwise comparison analysis results for enhancement and breeding were added together (from table 6.1) to determine their combined importance, based on scientists' opinions for the three crops. The combined total for the two activities are sorghum (0.373), *Prunus persica* (0.316), and *Brassica* (0.298), sorghum having the greatest combined weight. As table 6.5 illustrates, almost all the scientists working with sorghum (25 of 26) believed that developing resistance to stresses should be emphasized more than the other enhancement or breeding activities. ARS could compare its sorghum enhancement and breeding efforts to scientists' opinions on the activities they believe should be emphasized most.

Our data collection and analyses discussed in this chapter illustrate that our method can be used to examine the opinions of plant scientists as to the relative importance of emphasizing germplasm management activities. As with most of our survey results discussed in chapters 4 and 5, these opinion questions are intended to be used in comparing results among various crops. The opinions of the scientists can supplement ARS information and support decisions on how to allocate resources among the crops and the activities.

Conclusions and Recommendation, Agency Comments, and Our Response

ARS would be better able to set germplasm management priorities and allocate resources if it developed more-uniform and comparable information about the status of different crops. We have demonstrated one possible approach for data collection, using a framework of conditions and activities that affect crop and germplasm vulnerability and showing that a survey instrument can be used to obtain information from plant scientists worldwide. We refined the methodology for gathering the survey information from our experience with the demonstration. To assist ARS in implementing the data collection method, appendix IV provides additional detail on our implementation.

The method could assist ARS with various decisionmaking tasks, and the resulting information could be used to form a data base, eventually encompassing a wide variety of crops and germplasm. We believe that once a number of crops have been surveyed, the data base for a given crop can be updated periodically by resurveying germplasm users to assess changes in the crop's status or in scientists' perceptions. A survey might reoccur every 5 years, for example.

More specifically, survey information could facilitate decisionmaking tasks such as identifying gaps in knowledge about germplasm, determining future needs or trends in the use of resources, assessing risk, and setting priorities for management activities among crop types. The cost of implementation would depend on the number of crops surveyed annually and the size of the samples. Since the survey has been pilot-tested successfully and a framework for analysis is available to ARS, costs would primarily stem from mailing, telephone follow-up, if necessary, and computer programming time and interpretation of the results. Moreover, the data collected could supplement or replace some of the individual data-gathering efforts of ARS personnel or crop advisory committees. In fact, the crop advisory committee chairman for *Brassica* intends to use our survey instrument in the near future as a foundation for developing the *Brassica* crop advisory committee report.

Recommendation to the Secretary of Agriculture

We recommend that the administrator of the Agricultural Research Service determine which crops would most benefit from the full implementation of our methodology, or a similar one that incorporates the same basic concepts, and implement it for those crops (perhaps four or five related crops in the first year). Although the costs associated with the survey implementation will probably compete for germplasm program funds, we believe that the methodology can supplement or replace current data collection efforts. Therefore, the survey costs will be at least partially offset by the valuable information obtained and the resulting effect on decisionmaking.

Agency Comments and Our Response

The Agricultural Research Service commented on a draft of this report. (See appendix V.) In the comments, ARS commended us for our effort in developing a methodology to aid in the assessment of priorities on a crop basis for genetic resources held in NPGS. Further, ARS agreed that the refinement of questions asked of scientists working in the field provides an excellent base from which to examine ARS priorities as well as to judge the recommendations and justifications for funding coming from crop advisory committees and other groups and organizations.

Included in its comments were concerns ARS expressed related to implementation of the data collection method. It said that we were correct in stating that funding to implement the survey method would compete with germplasm program funds but that the payback resulting from the effort may not be as great as suggested in the report. Further, the task of surveying and resurveying crops might result in lost research time on the part of scientists implementing the survey.

We have offered ARS the software program we created for tabulating response frequencies for the current version of the questionnaire, as well as the questionnaire itself on a computer disk. We have also offered a training package to ARS on the use of our questionnaire design program. We believe that these materials will substantially reduce the initial cost of implementation. However, as stated in the report, in order to proceed with phased implementation of the method for many crops, ongoing funding will be required for questionnaire modification and mailing, computer programming and data entry, and interpretation of results. We continue to believe that investment in this uniform data collection method will result in information that is much improved over what is now obtained by ARS data collection efforts and those of the crop advisory committees.

ARS also said that it would not want to supplant scientists' research with conclusions drawn from the survey and expressed concern that some of the survey data may be difficult to acquire.

We had several conversations with ARS officials after we received the agency's comments. During these discussions, in which we clarified a number of points, most of the concerns were mitigated as the officials recognized that we always intended for the survey results to be just one input into their decision process. We anticipate that crop advisory committees and NPGS managers will interpret survey results and combine them with their own expertise and research results to reach conclusions. As we explained to ARS officials, we believe that they should exercise judgment and flexibility in phasing implementation, modifying survey questions, and deciding which analyses to apply for a given crop.

Subsequent discussions with ARS officials and a GAO presentation of the method at a meeting of crop advisory committee chairs clarified some misunderstandings by ARS and greatly increased their support for implementing our method. Following the presentation, many of these individuals expressed interest in implementing the method for their crops, beginning with the *Brassica* Crop Advisory Committee in October. As a result, ARS now intends to work with interested curators of NPGS collections to determine the feasibility and need to implement the survey for individual crops. To the extent limited funds allow, ARS plans to implement the method with selected crops in order to further assess the value of the survey for establishing priorities for other species. We are very pleased that ARS has recognized the value in the method we designed, and we hope the agency will pursue options for supporting a phased implementation.

In addition to commenting on the implementation of the method, ARS pointed out that data from private industry sales and seed demand are highly proprietary for most commodities and may not be available for making adequate judgments. The questionnaire is designed to identify instances in which scientists do not want to provide proprietary information about their breeding and research objectives. However, some private sector scientists we surveyed did provide information on questions where "proprietary information" was presented as an option. We believe that implementation of the method across crops will provide more data than are currently available and will also show for which crops such information is most difficult to obtain.

ARS also commented that the survey does not consider issues on ownership and availability of plant genetic resources as is currently being debated in the Food and Agriculture Organization. This comment apparently stems from concern that scientists in some countries may be reluctant to respond to the survey while the debate about ownership of genetic resources is going on and that some countries may be unwilling to provide germplasm to the United States.

We are aware of this international debate, but we did not include an evaluation of its effect on NPGS collections in the scope of our effort. However, it is also true that we were able to collect data from seven foreign countries, as the report clearly demonstrates. We believe that part of ARS officials' judgment in implementing the survey would involve determining any countries for which the survey is currently inappropriate for political reasons. Further, we believe that many hindrances, such as political issues of this nature, can present specific data collection problems at certain points in time. However, such hindrances do not change the fundamental need to obtain the best information possible on which to base decisions about germplasm management.

Members and Expertise of GAO's Advisory Panel

Member	Area of expertise
Dr. Nicholas Frey Des Moines, Iowa	Biotechnology
Dr. George Kennedy Raleigh, North Carolina	Entomology and plant pathology
Dr. T. B. Kinney Jr. York, South Carolina	Germplasm management (previous administrator of the Agricultural Research Service)
Dr. Bill Lacy Lexington, Kentucky	Germplasm use related to social, political, and ethical issues
Dr. Calvin Qualset Davis, California	Germplasm conservation
Dr. Norman Weeden Geneva, New York	Biotechnology techniques—use of isozymes and restriction fragment length polymorphisms
Dr. Paul Williams Madison, Wisconsin	Horticulture and genetics

Fifteen Types of Scientists Who Use Germplasm

U.S. Public Sector	1. Plant breeder 2. Geneticist or biotechnologist (basic research) 3. Genetics resource manager (curator)
U.S. Private Sector	4. Plant breeder 5. Geneticist or biotechnologist 6. Genetics resource manager
Foreign Public Sector	7. Plant breeder 8. Geneticist or biotechnologist 9. Genetics resource manager
Foreign Private Sector	10. Plant breeder 11. Geneticist or biotechnologist
International Public Sector	12. Plant breeder 13. Geneticist or biotechnologist 14. Genetics resource manager
Other	15. New crop and new product development (any germplasm user, either public or private sector)

Relative Importance of Major Germplasm Activities for Three Crops

Genus or species	Activity	Factor
Domestic respondents		
Brassica[a]	Preservation	0.236
	Acquisition	0.224
	Description	0.174
	Enhancement	0.133
	Breeding	0.132
	Biotechnology	0.101
Prunus persica[b]	Acquisition	0.246
	Preservation	0.201
	Breeding	0.170
	Enhancement	0.134
	Description	0.131
	Biotechnology	0.119
Sorghum[c]	Breeding	0.222
	Acquisition	0.192
	Preservation	0.185
	Enhancement	0.171
	Description	0.117
	Biotechnology	0.113
Foreign respondents		
Brassica[d]	Breeding	0.248
	Description	0.180
	Preservation	0.168
	Acquisition	0.159
	Enhancement	0.134
	Biotechnology	0.111
Prunus persica[e]	Breeding	0.330
	Acquisition	0.238
	Biotechnology	0.149
	Preservation	0.129
	Enhancement	0.080
	Description	0.074

(continued)

Genus or species	Activity	Factor
Sorghum[f]	Acquisition	0.215
	Preservation	0.210
	Breeding	0.189
	Description	0.142
	Enhancement	0.131
	Biotechnology	0.113

[a]For 9 *Brassica* respondents.

[b]For 11 *Prunus persica* respondents.

[c]For 21 sorghum respondents.

[d]For 4 *Brassica* respondents.

[e]For 2 *Prunus persica* respondents.

[f]For 5 sorghum respondents.

Implementation of GAO's Methodology

We surveyed a judgmental sample of 71 plant scientists working with one of the three crops *Brassica*, *Prunus persica*, and sorghum. To ensure a wide range of contacts, we selected scientists from 15 different categories. In chapter 1, we presented a detailed explanation of the rationale for the selected sample, crops, and methodology. Successful implementation of the survey involves three important activities: (1) identifying a wide range of scientists who work with the crops of interest, (2) obtaining survey responses from domestic and foreign scientists who use germplasm resources associated with the crops, and (3) analyzing the survey results. From our experience in implementing the survey, we identified improvements in and refined the survey instrument for future implementation.

To develop our respondent lists, we first worked with the chairs of the crop advisory committees or subcommittees for the three crops. From them, we obtained lists of scientists who use or manage germplasm. We also asked the chairs to supplement the lists to ensure that scientists from the 15 categories were represented. The three committees had already generated lists of scientists working with their crops, but they varied in degree of completeness. For example, the chair of the *Brassica* Crop Advisory Committee provided lists believed to be relatively complete, with the names and addresses of about 1,500 *Brassica* germplasm users and managers. The subcommittee chair for *Prunus persica*, however, identified 330 users. While the subcommittee had not attempted to identify all scientists working with *Prunus persica*, the chair had a list of breeders and other peach genetic resource users and was able to provide additional names from various sources.

We used two different methods to develop even more complete lists. We searched ARS's Current Research Information System and an agricultural data base by crop, and we identified additional scientists working with the crops' germplasm.[1] Another method we used to identify germplasm users was similar to a "snowball" sample method. We used this method because, in working with the *Prunus persica* subcommittee chair, we were not able to identify many germplasm users who were foreign scientists. We added a question to the *Prunus persica* questionnaire that asked whether the scientist could identify the name and address of up to three other scientists working in the same area. Twelve of the 14 *Prunus persica* scientists who responded provided the requested information.

[1] We searched the National Agricultural Library's Agricola data base. It covers agricultural subjects, including botany, entomology, hydroponics, soils, and more. This data base contains over 2.5 million records.

As a result, we identified 22 scientists who were not on our original list. We believe ARS could use these methods, as necessary, to identify scientists working with a crop's germplasm.

In addition, we asked the respondents which plant genera they had worked with in the past 5 years. Table IV.1 lists the additional genera we identified. These data could be used over time to identify scientists working with particular crops and to revise respondent lists for future implementation of the survey.

Table IV.1: Other Genera Our Respondents Work With

Germplasm	Genus
Brassica	*Arabidopsis*
	Avena
	Capsicum
	Cichorium
	Citrullus
	Citrus
	Cucumis
	Cucurbita
	Daucus
	Eruca
	Fagopyrum
	Glycine
	Gossypium
	Helianthus
	Hordeum
	Impatiens
	Linum
	Lycopersicon
	Medicago
	Phaseolus
	Pinus
	Raphanus
	Secale
	Sinapsis
	Triticum
	Zea

(continued)

Germplasm	Genus
Prunus persica	*Actinidia*
	Avena
	Brassica
	Capsicum
	Carya
	Citrus
	Cucurbita
	Ficus
	Fragaria
	Glycine
	Gossypium
	Hordeum
	Juglans
	Lactuca
	Lycopersicon
	Malus
	Olea
	Phaseolus
	Pistacia
	Pisum
	Prunus
	Pyrus
	Rubus
	Secale
	Sorghum
	Triticum
	Vaccinium
	Vitis
	X Triticosecale
	Zea

(continued)

Germplasm	Genus
Sorghum	*Aegilops*
	Arachis
	Avena
	Cajanus
	Cicer
	Echinochloa
	Eleusine
	Eragrostis
	Gossypium
	Helianthus
	Hordeum
	Medicago
	Oryza
	Panicum
	Paspalum
	Pennisetum
	Setaria
	Triticum
	Zea

Once we demonstrated that we could identify scientists working with the three crops' germplasm, we mailed questionnaires to a judgmental sample of scientists within the United States and in seven foreign countries. We sent the questionnaires to foreign scientists to demonstrate that information on germplasm could be obtained from geographically dispersed scientists and for scientists in the 15 categories. We mailed 19 questionnaires to scientists in foreign countries, and we received almost 80 percent of them. Although mailing questionnaires to scientists in the United States does not present a problem, mailing them to scientists in foreign countries with return postage prepaid does present a logistical challenge.

To mail the foreign questionnaires, we used U.S. embassies as intermediaries. That is, we sent questionnaire packages to officials at the U.S. Department of State in Washington, D.C., and they sent them by diplomatic pouch to the U.S. embassies in the seven countries we selected. The administrative officer at each foreign embassy mailed the packages to the individual scientists. Each questionnaire had attached to it two international reply coupons, which enabled the scientists to buy postage to mail the questionnaires back to the embassy in their country. The embassies then sent the questionnaires (by pouch) back to the Department of State in Washington, D.C. According to a Department of State official, they handled the questionnaires as a service to GAO and would do the same for other federal agencies, as long as the number going to a particular country was not too great. We demonstrated that germplasm information could be obtained from the foreign community, and we believe that ARS could use the same method to mail questionnaires to foreign scientists. Providing return postage is optional, but doing so may have improved our response rate.

After the initial questionnaire mailing, we sent reminders (letters to domestic scientists and mailgrams to foreign scientists) to those who had not returned the questionnaire. Scientists who returned questionnaires with incomplete, unclear, or conflicting information were contacted by telephone to obtain more data or clarification. To facilitate our contacting the scientists, the questionnaire asked for a telephone number and the best day and time to contact them. Virtually every respondent provided this information. Through our follow-up efforts, we increased our response rate and improved the quality of the information from the questionnaire. We believe that ARS could implement the same or similar method of follow-up.

Our framework shows how combinations of responses can provide useful information for decisionmaking. (See chapters 4, 5, and 6 for examples of analyses applied to the questionnaire data.) Although the framework does not present all the possible combinations and uses of this information, it does provide examples of specific types of information that can be developed from the survey. The framework also suggests statistics and other information that should be obtained in addition to the survey data for specialized analyses.

The frequency of responses to all the questions except one were tabulated by using the Statistical Analysis System program. We will make the program we used available to ARS. We used a separate software package to analyze the pairwise comparison of various germplasm activities. The software we used to implement the analytic hierarchy process (discussed in chapter 6) can be purchased from the vendor for about $500.

We modified portions of the questionnaire at the completion of the demonstration, based on comments received from scientists and the perceived difficulty scientists had with some questions. We believe the refined questionnaire, if implemented, will receive an even higher response rate than our original one. In implementing the questionnaire, ARS could further modify sections or questions on it to respond to crop-specific interests or changing conditions.

We used an in-house program to develop the survey instrument, facilitate questionnaire development, and reduce printing costs. Using this program, we would provide technical assistance to ARS in preparing a revised questionnaire if requested.

Comments From the Department of Agriculture

DEPARTMENT OF AGRICULTURE
OFFICE OF THE SECRETARY
WASHINGTON, D.C. 20250

AUG 6 1990

Ms. Eleanor Chelimsky
Assistant Comptroller General
Program Evaluation and
Methodology Division, GAO
441 G Street, NW.
Washington, D.C. 20548

Dear Ms. Chelimsky:

Thank you for the opportunity to review the General Accounting Office Draft (GAO) Report PEMD-90-23, "PLANT GERMPLASM: Improving Data for Management Decisions." The Office of Agricultural Biotechnology and the Cooperative State Research Service did not have any comments. I am forwarding the enclosed response prepared by the Agricultural Research Service.

I concur with its conclusions that the cost of the survey will be greater than GAO indicated, that some of the suggestions made in the draft report will be difficult to carry out, and that other factors must be considered by the agency before implementing the survey methodology and conclusions.

Sincerely,

Charles E. Hess

CHARLES E. HESS
Assistant Secretary for
Science and Education

Enclosure

ARS Response to GAO Draft Report on "PLANT GERMPLASM: Improving Data for Management Decisions" and Recommendation to the Secretary of Agriculture

The Agricultural Research Service commends the effort of GAO to develop methodology to aid in the assessment of priorities on a crop basis for genetic resources held in the U.S. National Plant Germplasm System (NPGS). The refinement of questions asked of the scientists working in the field provides an excellent base from which to examine Agency priorities, as well as to judge the recommendations and justifications for funding coming from Crop Advisory Committees, the Joint Council on Food and Agricultural Sciences, National Agricultural Research and Extension Users Advisory Board, the National Plant Genetic Resources Board, the National Plant Germplasm Committee, various trade-related groups, and other advisory bodies.

GAO is correct in stating that funding to complete the survey will compete with germplasm program funds. We do not feel confident that the payback will be as great as suggested in the report. In the first place, there are 40 Crop Advisory Committees for crops and groups of crops making the task endless in terms of number of surveys and the suggested re-survey interval of 5 years. The GAO dedicated a team to conduct the survey, but ARS will have to create a survey detail team of a scientist and support staff to concentrate on the survey for a specific crop. The real cost is the loss of research time by that scientist.

Some of the suggestions will be difficult to implement or the data difficult to acquire. In addition, some judgment will have to be made on the cost in time and effort to acquire it. Data from private industry sales and seed demand are highly proprietary for most commodities and may not be available for making adequate judgment. The Economic Research Service has access to other agency varietal/acreage figures but, like ARS, does not have staff available to do surveys without financial assistance. Also, the detail for descriptors and information to be maintained in the GRIN database has a Utopian ring to it and such completeness and extensiveness is rarely achievable. In the real world, the most important data are those associated with a new pest or disease for which no one has done an evaluation because it didn't exist before. Lastly, the survey is somewhat insensitive to the issue on ownership and availability of plant genetic resources that is currently being debated in the FAO. Hopefully, that issue will be calmed with time and efforts by all nations to be more attentive to supporting plant conservation activities.

ARS has a number of concerns about the use of the survey and its objectives. Reallocation of program funds or redirection of specialized scientists is not a casual or simple event. ARS is the USDA's in-house research arm and takes the lead in the management of the NPGS. ARS has properly conserved plant genetic resources and has conducted its research program on plant germplasm within available funds. The Agency prides itself on its scientific expertise to solve problems and manage research, and it desires to provide a stable environment for its career scientists. ARS is not funded to provide service support to the entire plant community for whatever type of evaluation or enhancement effort that some group believes is desirable. Thus, it is essential that the surveys represent responses from a broad-based group rather than just the scientists associated with a particular crop species. In that sense, the Agency reserves the right to determine what germplasm management activities it can afford to fund. In this regard, some apparently logical survey recommendations may not receive support from the Agency because of competing priorities.

Major Contributors to This Report

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Glossary

Accession	An individual sample of seeds or plant material entered into a germplasm collection.
Acquisition	The collection of plant germplasm from natural habitats as well as through exchange with other scientists or gene banks.
Asexual	Any mode of reproduction not involving fertilization, conjugation, or genetic recombination. Progeny have the same genotype as the parent.
Biotechnology	Ideas or advanced techniques derived from molecular and cell biology that use biological systems to produce products.
Breeding	Developing new crop varieties or improving existing varieties (especially commercial crops) by making crosses over multiple generations.
Centers of Diversity	The regions where most of the major crop species were originally domesticated and developed. These regions may coincide with centers of origin.
Centers of Origin	The locations where a species originally evolved.
Characterization	The screening of germplasm accessions to determine traits that distinguish the accessions genetically, such as agronomic, morphological, physiological, or biochemical traits.
Chromosome	A gene-containing structure in the nucleus of a cell.
Clonal Germplasm	The genetic material of an organism that is multiplied by asexual means such that all progeny are genetically identical. In plants, it is commonly achieved through the use of cuttings or in vitro culture.
Cultivar	See Variety.

Cutting	A plant piece (stem, leaf, or root) removed from a parent plant that is capable of developing into a new plant.
Electrophoresis	The application of an electric field to a mixture of charged particles in a solution for the purpose of separating, for example, a mixture of proteins as they migrate through a porous supporting medium of filter paper, cellulose acetate, or gel.
Enhancement	Incorporating desired traits of wild germplasm into a domesticated crop variety, so that the resulting variety will be suitable for cross-breeding with commercial varieties. Also known as prebreeding.
Evaluation	Examining germplasm accessions for traits of agronomic interest such as yield, stress tolerance, disease resistance, or quality factors.
Ex Situ	Pertaining to the study or maintenance of collections of organisms away from the place where they naturally occur.
Gene	A chemical unit of hereditary information that can be passed from one generation to another.
Gene Pool	The collection of genes in an interbreeding population. The total available gene pool of a crop consists of the (1) primary gene pool, or all cultivated and wild or weedy races of a crop that can be easily crossed with each other; (2) secondary gene pool, or biological species that can be crossed with the crop but only with great difficulty; and (3) tertiary gene pool, or species in which crosses with the crop are possible only with advanced techniques, usually resulting in lethal crosses.
Genetic Diversity	The variety of genes within a particular species, variety, or breed.
Genetic Vulnerability	The extent to which a crop or species is at risk of loss to disease, pests, or environmental stresses.

Genome	The complete genetic makeup of an organism.
Genus	(Plural: genera.) A category of biological classification ranking between the family and the species and consisting structurally of phylogenetically related species or an isolated species exhibiting unusual differentiation.
Germplasm	An imprecise term generally used to refer to the genetic information of an organism or group of organisms—for example, the material in seeds or other plant materials that controls heredity.
Grow Out	The process of growing a plant for the purpose of producing fresh, viable seed to evaluate its varietal characteristics (sometimes called "growing out" or "regeneration").
Hybrid	An offspring of a cross between two genetically unlike organisms.
In Situ	The maintenance or study of an organism within its native environment.
In Vitro	The growing of cells, tissues, or organs in glass or plastic vessels under sterile conditions in an artificially prepared medium.
Isozymes	The protein product of an individual gene and one of a group of such products with differing chemical structures but similar enzymatic function.
Landrace	A primitive or antique variety usually associated with traditional agriculture. Often highly adapted to local conditions.
Morphology	A branch of biology that deals with the form and structure of organisms.

Nucleic Acid
Any of various complex organic acids (such as DNA) found especially in cell nuclei.

Passport Data
Information regarding a germplasm accession that can include general morphology, the environment of its origin, soil conditions, and uses.

Pathogen
A specific causative agent of disease.

Phenotype
The observable appearance of an organism as determined by environmental and genetic influences.

Phylogenetic
Of or relating to the evolution of a race or genetically related group of organisms (as species, family, or order) as distinguished from the development of the individual organism.

Preservation
Storing and maintaining plant genetic resources in gene banks to ensure that (1) a diverse supply of germplasm is available to breeders and researchers and (2) sufficient genetic diversity exists in the gene banks to ensure the long-term survival of cultivated crop varieties.

Progeny
Offspring of organisms.

Protoplast Fusion
The fusing, or combining, of two or more cell protoplasts after stripping away the cell walls. The process is used to produce hybrids between species that cannot be bred conventionally.

Restriction Fragment Length Polymorphism
Abbreviated RFLP, genetic traits that represent great genetic variation at the nucleotide sequence level but not necessarily detectable at the phenotypic level. RFLP is used to generate gene maps.

Species
A classification ranking immediately below genus and including closely related, morphologically similar individuals that actually or potentially interbreed.

Taxonomy
The science of naming, describing, and classifying organisms.

Tissue Culture
A technique in which portions of an organism are grown in an artificial culture medium in an organized (such as plantlets) or unorganized (such as a callus) state. See also In Vitro.

Variety
An international term denoting certain cultivated plants that are clearly distinguishable from others by one or more characteristics and that when reproduced retain their distinguishing characteristics. In the United States, "variety" is considered to be synonymous with "cultivar" (derived from "cultivated variety").

Widecrossing
Breeding crops with other species such as wild relatives in order to obtain desirable traits.

Wild Relative
Plant species that are taxonomically related to crop species and serve as potential sources of genes in the breeding of new varieties of those crops.

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