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GERMPLASM RESOURCES OF PLANTS: THEIR PRESERVATION AND USE

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Germplasm resources of a particular crop species may be divided into three groups. The first group consists of all individuals within a genus or broader cluster within which sexual compatability exists, including wild or weedy representatives. The second group is a subset of the first and includes all individuals in the working collections of the breeders. Plant breeding operations are largely limited to this group. The third group is even more restricted and includes the improved cultivars in commercial use and their potential replacements. An effective system of germplasm management must provide for gene flow from group one to groups two and three. Each group offers its own unique challenges: identification, maintenance, and evaluation. It is this genetic diversity, in its entirety, which is basic to all plant breeding improvements.

This report presents a brief resume of the US and international effort devoted to germplasm collection and preservation, the current status of this effort, some of the problems requiring further attention, and, finally, some of the benefits that have been derived from use of exotic germplasm.

Early History

In the hunting and gathering period of man's development a large number of plant species were used for food on either a regular or occasional basis. As man progressed toward a more stable agriculture many of these species decreased in relative importance. Various listings of the currently most

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important food crops have been published. The rank order may differ but all listings include rice, wheat, maize, sorghum, potatoes, and the edible legumes. These crops differ from one another in their place of presumed origin and initial area of adaptation. Their current distribution is the result of man's activity, some of it in the remote past.

If the United States were dependent on native plants for food, our diet would consist mainly of fruits (strawberries, blueberries, cranberries), nuts, and sunflowers supplemented by a large number of other species used occasionally for food. This limited array of food plants was importantly augmented by the corn-bean-squash complex which had been introduced into the United States before the advent of the white man.

The introduction and adoption of new plant materials is seldom a simple process. Wild or cultivated species near their center of origin consist of many genotypes. Variation may exist for all traits that make the plant attractive for man's use. Included in the variability is the degree of adaptation to differing ecological conditions. Thus when transferred to a new environment some introductions may survive and others may fail completely. Further selection (natural and artificial) among the survivors may isolate variants still better suited to the new environment. As long as man continued to cultivate these primitives or "land race" types, the natural variability was available for selection to better meet any specific set of environmental conditions. However, as agriculture progressed and as species spread from their centers of origin, genetic diversity was progressively reduced. New or secondary centers of diversity became established. In either case, reduction in variability was accelerated as preferred types became more widely grown. The decrease in variability has been greatly hastened in recent years by the development and widespread adoption of uniform varieties.

For at least a century there has been concern about the reduction in genetic variability of crop species and an interest in collecting and preserving germplasm. In the last few years, however, efforts to collect, maintain, and evaluate these resources have accelerated, and sizable collections exist for all major crop species.

Plant introduction and evaluation was an important component of agriculture long before there was any governmental or international involvement in the process. The early settlers in North America brought seeds of cereals, pulses, garden vegetables, and herbs. Understandably much of this material was poorly adapted and only through repeated trial and error were types identified that could be grown with some degree of success.

The pressure for an adequate food supply conditioned a continuing interest in new introductions. Each new group of immigrants brought additional seed, and trading captains also brought seed along with their other wares.

3

The first attempt at a more systematic introduction and evaluation system in the New World was inaugurated at the Ashley River Colony in South Carolina in 1669 (13). Efforts were concentrated on introduction of cotton, sugarcane, indigo, and other species from the Barbados and food crops such as beans, peas, and yams. Except for rice, which was introduced before 1700, few of these introductions were sufficiently productive to be adopted by the settlers. Still later, in 1733, an experimental garden was established at Savannah, Georgia, by the trustees of the Colony. The first emphasis was on plants collected in the West Indies and Central America. Cuttings of grapes and trees were distributed. This experimental garden was discontinued in the late 1740s.

Many influential people contributed to improvements in plants and to agricultural practices during these early years. Agricultural societies were formed and new findings were disseminated and gradually adopted.

Plant Introduction Activities in the United States

In view of the dependence upon introduced food plants it is somewhat surprising that 200 years were to elapse between the first settlements and the organization of a government-sponsored system of plant introduction. Beginning in 1819, American consuls were encouraged to collect and transmit plant materials that might be useful in the United States. In 1836 this policy was broadened, and responsibility for introduction of new plant materials was assigned to the US Patent Commissioner. This arrangement persisted until 1862 when the US Department of Agriculture was established. Under this organization a Commissioner of Agriculture was appointed with the responsibility to collect, test, propagate, and distribute potentially valuable plant materials. A section for seed and plant introduction was established in 1898. This specialized responsibility has persisted with several changes in name but only minor changes in responsibilities and system of operation.

Plant collection through direct field exploration has been conducted by the US Department of Agriculture during most of this century (6). Field explorers usually have been interested in specific crop groups, and the collections have been evaluated largely by an Agency within the USDA responsible for the crop or groups of crops involved. Before the establishment of the regional centers, plantings were made at appropriate sites and only the material that offered some immediate usefulness was saved; a system had not yet been established to preserve a representative array of new material as insurance against future needs.

The Research and Marketing Act of 1946 provided, among other things, for a "new crops" program. The objective was to provide "research to encourage the discovery, introduction and breeding of new and useful agri-

4

cultural crops, plants and animals, both foreign and native, particularly for those crops and plants which may be adapted to utilization in chemical and manufacturing industries." Under this Act four regional plant introduction stations were established at Ames, Iowa in 1947; Geneva, New York in 1948; Experiment, Georgia in 1949, and Pullman, Washington in 1952 (1). Each of these stations involves a cooperative effort between the states of the region and USDA and each has specific crop responsibilities. In 1958 the National Seed Storage Facility was established at Fort Collins, Colorado, and began to receive and store seeds. This National Facility assumed responsibility for long-term seed storage while the regional centers were concerned with the preservation and evaluation of working collections. In the period from 1946 through 1971 the USDA sponsored some 65 plant exploration expeditions. These have covered a wide array of plant species including oil seeds, forages, vegetable crops, potatoes, sorghum, beans, peas, citrus, as well as drug and medicinal plants.

Genetic Vulnerability

The corn leaf blight epidemic of 1970 brought increased attention to the problem of genetic diversity and genetic vulnerability. A special study group was appointed by the Agricultural Board of the National Research Council–National Academy of Sciences (NRC-NAS) to examine the blight epidemic. The committee decided to broaden their charge and examine the adequacy of the germplasm base at the farmer's level for several of our major crops and to explore the various phenomena of epidemics, i.e. the interaction of weather, pathogens, and hosts over time, and to assess some of the economic implications. The final report (5) gives some detail on the narrow germplasm base supporting the commercial production of several of our most important crops.

The NRC-NAS report stimulated interest in the genetic vulnerability problem, and the Agricultural Research Policy and Advisory Committee (ARPAC) of the USDA and National Association of the State Universities and Land Grant Institutions appointed an ad hoc subcommittee to recommend policies and actions to minimize the problem of genetic vulnerability as it affects our major crops. The report of this subcommittee (7), in addition to the NRC-NAS report (5), greatly stimulated interest in the broad problem of germplasm resources. Subsequently the National Plant Germplasm System within the US Department of Agriculture was reorganized and greatly strengthened (1). A National Plant Germplasm Committee was established to provide scientific advice for and coordinate the activities of the National Seed Storage Facility and the Regional Plant Introductions Stations. In addition, the ARPAC report recommended establishment of a National Plant Germplasm Resources Board. In 1976 this influential board was charged by Secretary of Agriculture Earl Butz to (*a*) inform themselves

of domestic and international activities to minimize genetic vulnerability of crops, (*b*) formulate recommended actions and policies on collection, maintenance, and utilization of genetic resources, (*c*) recommend actions to coordinate the plant genetic resource plans of several domestic and international organizations, (*d*) recommend policies to strengthen plant quarantine and pest monitoring activities, and (*e*) advise on new and innovative approaches to plant improvement. By congressional requirement, appointments to all US Government Advisory Boards are limited to two-year terms. Thus in 1978 an exhaustive review was made of the function, usefulness and membership of the many boards then reporting to the Secretary of Agriculture. The role assigned to the National Plant Genetics Resources Board was judged to be significant and the board was reestablished in 1978 by Secretary Bob Bergland with its original membership. The first formal report of the National Plant Genetics Resource Board was made to the Secretary in January 1979. This report has since been published (8).

In the past 60 years many other countries have built germplasm collections to serve their own agricultural needs or to further special research interests. The most extensive collecting activity was performed by the USSR under the direction and supervision of N. I. Vavilov. The period of most active collection was from 1916 to 1931. Vavilov's studies of these collections provided much of our knowledge of species diversity and led to the original formulation of the concepts of centers of origin and centers of diversity (18).

Extensive additional collections were made later for several crop species, e.g. rice in southeast Asia by the International Rice Research Institute, maize in Meso and South America under the auspices of the Rockefeller Foundation and the US National Research Council, sorghum and millets in Asia and Africa through the cooperative efforts of the Rockefeller Foundation and the Indian government supported, in part, with US Public Law 480 funds.

Genetic variation in native populations of wild or weedy species and landrace varieties is governed by many factors including spacial isolation, population size, and genetic mechanisms that restrict gene flow in the population. Detailed information on population dynamics would facilitate more effective planning for sampling such populations but such information is usually lacking. In the course of collecting, however, it has become apparent that genetic diversity in many species of plants has been greatly diminished by pressure on the land in the countries of origin to produce food for a rapidly expanding human population. Thus if a significant portion of the remaining diversity is to be salvaged, an immediate and extensive international effort will be required.

Close cooperation between the Food and Agricultural Organization (FAO) of the United Nations and the International Biological Program

6

(IBP) provided much of the impetus for an expanded international effort. In 1967 a technical conference was held in which the methodologies of plant exploration and genetic conservation were examined and goals and strategies developed. A summary of genetic resources was published in 1973 (9, 10). The necessity for germplasm collection and preservation was also emphasized at the United Nations Conference on the Human Environment held at Stockholm in 1972. These and other activities developed a broader public awareness of the problem.

IBPGR Activities

The Consultative Group on International Agricultural Research (CGIAR) established the International Board of Plant Genetic Resources (IBPGR) in November 1973. The basic function of IBPGR as defined by the Consultative Group is "to promote an international network of genetic resource activities to further the collection, conservation, documentation, evaluation and utilization of plant germplasm and thereby contribute to raising the standard of living and welfare of people throughout the world."

Collection activities of the past have often been in response to a particular need rather than an attempt to assemble an adequate and representative sample of the diversity available within a given species or group of species. With the establishment of IBPGR, several new activities and policies have been initiated. Among these was the establishment of a worldwide network of institutions, organizations, and programs concerned with all aspects of germplasm resources. Where necessary, new institutions or centers have been established and close cooperative ties fostered among the new and the previously existing centers. As an aid to furthering this cooperative effort, internationally staffed advisory committees of experts have been appointed for each of the major crops or group of crops. They have been asked to evaluate the adequacy and current status of existing collections and to identify areas or regions where additional collection activity is necessary to achieve adequate representation. Where collection activities have been mounted, the effort, where possible, has been cooperative, with the collected material being shared among replicate storage centers.

IBPGR, with the help and advice of FAO and other agencies, has established priorities for collection activities based on an assessment of the existing collections, the rapidity of genetic erosion within a region, the financial resources available, and other pertinent factors. Details of these activities are presented in the annual reports (2–4).

Technical meetings on crop genetic resources have been sponsored and special training schools developed for potential plant explorers or collectors. Guidance and financial support for the development of computerized information storage and retrieval systems suited to the needs of the several genetic stock centers and to all users of genetic resources have also been

provided. IBPGR has contributed immeasurably to the modernization and integration of all aspects of germplasm collection, preservation, and use.

Since 1976 IBPGR has sponsored plant collection activities in over 20 countries or areas. The crops of interest have included all of the major cereals, the pulses, grasses, forage legumes, groundnuts, vegetables, potatoes, cassava, and sweet potatoes. The IBPGR-sponsored collections were specifically designed to salvage materials in areas where genetic erosion was proceeding most rapidly. The centers currently involved in the international network concerned with collection, conservation, and documentation are illustrated in Figure 1 (4). Center locations and responsibilities for a few of the crop species are described in Table 1.

In cooperation with FAO, IBPGR is preparing a compilation of stocks of various species currently held in storage at research or governmental centers throughout the world. Copies of certain listings have been supplied to me in advance of a more general distribution. These listings are too extensive for detailed presentation here. A consolidation has been attempted in Table 2 which provides some indication of the numbers of items and the countries in which they are stored.

Figure 1 Location of National Agencies and International Centers cooperating with IBPGR in 1977–1978 in various aspects of germplasm collection, conservation, and documentation (from IBPGR annual report for 1977).

Table 1 A partial listing of national and international centers responsible for germplasm collections of crop plants[a]

Crop	Genus and species	Location
Rice	*Oryza sativa indica*	IRRI Los Banos, Philippines
	O. sativa javanica	IRRI Los Banos, Philippines
	O. sativa japonica	National Institute of Agricultural Science, Japan
	Mediterranean forms, temperate and intermediate from USA	National Seed Storage Laboratory, Fort Collins.
	Wild species	IRRI, Los Banos, Philippines
	African forms	IITA, Nigeria
Wheat	Culivated species	N. T. Vavilov Institute of Plant Industry (VIR) USSR, CNR Germplasm Laboratory, NSSL, Bari, Italy, Fort Collins (Each institute's collection duplicated at one of the others.)
	Wild species of *Triticum* and *Aegilops*	Plant Germplasm Institute, University of Kyoto, Japan (Duplicated in one of the above institutes.)
Maize	New World material	NSSL, Fort Collins
	Asiatic material	NIAS, Japan
	European material	VIR, USSR and another center to be designated
Sorghum	Cultivated and wild	NSSL, Fort Collins
Millets	Cultivated and wild	
	Pennisitum spp.	NSSL, Fort Collins Canadian Gene Bank, Ottawa
	Eleusine	ICRASAT, Hyderabad, India
	Panicum miliaceum	ICRASAT, Hyderabad, India
	Setaria italica	ICRASAT, Hyderabad, India
	Minor Indian millets	Indian Council for Agriculture Research New Delhi, India
	Eragrostis spp	Plant Genetics Resource Center, Addis Ababa, Ethiopia
Legumes	New World	
Phaseolus	All species, but special emphasis on *P. vulgaris*, *P. coccineus*, *P. lunatus*, and *P. acutifolius*	CIAT, Cali, Colombia
Pigeon pea	*Cajanus cajan*	ICRASAT, Hyderabad, India
Groundnut	*Arachis hypogaea*	ICRASAT, Hyderabad, India
Chickpea	*Cicer arietinum*	ICRASAT, Hyderabad, India
Cowpea	*Vigna sinensis*	IITA, Ibadan, Nigeria
Vegetables	Southeast Asian species	Institute of Plant Breeding, Los Banos, Philippines

[a] Taken in part from 1977 annual report of the International Board of Plant Genetics Resources (3).

9

In some countries several research centers were listed as maintaining germplasm collections. In Table 2 only the total for the largest collection within a country is listed. To the extent that the individual collections within a country are independent, the choice of the largest number would represent an underestimate of the total diversity present. This simplification is probably a lesser source of error than the unknown duplications among country collections. The magnitude of this source of error can be reduced only after an adequate information retrieval system becomes fully operative. Even if there were no reservation regarding the numbers listed in Table 2 their accuracy would be short-lived due to new additions to the collections.

In spite of the limitations of the original tabulation and of the condensation presented, the data serve to emphasize two important points. First, the total numbers of collections are quite large. Second, the working collections of each species are widely distributed throughout the regions of their economic importance. Certainly the value of these germplasm resources will increase as they become more adequately described, evaluated, and cataloged.

Collections

The extent to which the naturally occurring diversity in a species should be preserved is controversial. There is no consensus as to what constitutes an adequate collection. Reitz & Craddock (15) define an adequate collection as one that meets the needs placed upon it. However, "needs" will vary over time so this represents a conceptual rather than an operational definition. It is clear that all naturally occurring variation cannot be preserved. The objective then becomes one of maximizing allelic rather than genotypic diversity. The problem is further complicated by lack of a way to detect specific alleles of potential value.

Field collections normally are made without prior knowledge of the specific genetic parameters of importance. Judgments must be made on the basis of phenotypic diversity, which is not always an adequate guide as to latent variability or variability requiring different environmental conditions for expression. Under such circumstances, numbers (scale) of collections provides the only safeguard that potentially desirable but unrecognized alleles will be included in the collectors' samples.

The distribution of desirable alleles is difficult to predict. In some cases, alleles that condition resistance to some disease may occur in reasonable frequency, e.g. (virus disease of potato or barley yellow dwarf mosaic virus in barley) in a given region possibly as a result of natural selection. In other cases the presence of resistance alleles appears to be unrelated to the presence of the pest; resistance to the Hessian fly has been found in some wheat accessions in Portugal though the pest is unknown in that area.

10

Table 2 Number of samples held in national collections of seven crop species[a]

Country[b]	*Triticum aestivum*	*Oryza sativa*	*Zea mays*	*Sorghum bicolor*	*Glycine max*	*Phaseolus vulgaris*	*Vigna sinensia*
Argentina	1,300	3,200	3,600	2,700			
Australia	10,000	200	1,500	1,000	400	300	
Belgium						450	
Brazil	250	1,000	1,800	110	650	500	
Bulgaria	7,000	390	2,800	700	800	3,000	
Canada	2,000		200		600	2,000	
Ceylon		500					
Chile						700	
China	400	2,500	200	300			
Costa Rica						3,000	
Czechoslovakia	3,000		1,400	100			
Ecuador			500				
Ethiopia	500			2,000			
France	3,000	100	1,000	250		200	
Germany	1,200						
Ghana		400	150	160			100
Greece	2,000	200	800			150	
Guatemala	3,000	400					
Guyana		20,000					
Hungary	4,800	290	820	270	650	450	
India	5,000	5,000	5,000	9,000	1,000		3,000
Iran	10,000						
Israel	2,500		2,300	100			
Italy	500						
Japan	250	4,000	1,700		1,900	600	
Kenya	700			9,000			
Laos		600					
Mexico			12,000			500	
Madagascar			400	300			
Malawi			200				
Mali		200					
Mexico			12,000			500	
Nepal		200					
Netherlands	700					250	
New Zealand	3,000		100				
Nigeria		740					
Pakistan	5,000		5,000	5,000	110		110
Peru	3,000	500	1,500				
Philippines	400	11,900	2,000	4,000			400
Poland	1,800						
Portugal	400						
Rumania	15,000		2,500				
Senegal		200		500			
Spain			1,000				
Sudan		320		800			
Surinam		70	250				
Sweden	1,200						
Switzerland	2,500						
Tanzania		160					100
Thailand		1,200	1,000	1,500			

Table 2 *(Continued)*

Country[b]	*Triticum aestivum*	*Oryza sativa*	*Zea mays*	*Sorghum bicolor*	*Glycine max*	*Phaseolus vulgaris*	*Vigna sinensia*
Uganda						3,500	250
United Kingdom	2,600					300	
Upper Volta		500					
USA	21,000	16,340	5,000	7,200	3,000	2,500	1,600
USSR	21,100						
Venezuela				2,100			
Yugoslavia	1,000		1,000				

[a] The data from which this information was developed were supplied by Dr. N. M. Anishetty, Genetic Resources Officer, IBPGR.

[b] Only those countries have been listed in which collections for at least one of the seven species total 100 or more. Additional countries would be involved had further species been included.

Collections may be made in several ways. The extreme situations may be represented by (*a*) collections to sample the range of observed variation or (*b*) collections of specific phenotypes, e.g. resistance to a particular disease. Under *a* the collector will be aware of possible differences in phenotypic arrays under differing habitats as an aid in maximizing the total diversity collected. Obviously this potentially valuable information is lost if the bulk of the materials collected has their origin in village markets.

System *b* represents a special case. Normally it would be feasible only after detailed studies of existing collections had identified particular areas as likely sites for the trait of interest, e.g. resistance to barley yellow dwarf mosaic in Ethiopia. Even in this case, seed would be collected from mature plants with only limited knowledge of their disease reaction.

After an operational decision has been made regarding the numbers of individuals to be collected in a given ecological area, two alternatives are available. The identity of each sample may be retained by assignment of individual collection numbers, or all samples from a given site may be combined to form a bulk sample. The arguments for maintaining individual identity possibly have greater pertinence with the largely self-pollinating species than with the commonly cross-fertilizing types. In either reproductive type, however, the numbers involved are the overriding consideration.

Marshall & Brown (14) have calculated that a random sample of 50–100 individual plants is adequate to provide a 95% probability of obtaining at least one copy of an allele that occurs with a frequency greater than 0.05. Alleles occurring at lesser frequencies will likely not be represented in the collected material or if collection will be subject to high rates of loss during subsequent maintenance increases.

The maintenance of individual identity simplifies subsequent description and evaluation. If a desired allele occurs in homozygous form in an entry, its subsequent maintenance poses no problem. However, if the allele of

12

interest occurs as a heterozygote subsequent maintenance depends either upon identification of the desired type or propagation in numbers adequat for its retention.

Maintenance

Since seeds do not retain their viability indefinitely, seed collections must be regenerated periodically. Increases also are necessary in order to fill requests for seed. The important objective during maintenance is to ensure minimum genetic drift, i.e. to maintain as nearly as practicable the gene frequency of the original collection. Rapid shifts in gene frequency can occur with small populations or when certain genotypes within a collection differ in relative productivity or viability.

If one knew the genetic history of a related group of collections, i.e., whether they represent a group of individual collections or a bulk collection, and the frequency of a specific allele of interest it would be possible to calculate a sample size necessary to maintain the desired allele at some selected level of probability. In most cases, however, both of these elements (breeding history and allelic frequency) are unknown and therefore rough approximations must suffice. If a bulk collection were drawn from a population at equilibrium and an allele of interest occurs with a frequency of 0.05, then the figure 50–100 cited earlier from Marshall & Brown (14) would be an approximation.

This figure may be too low, however, unless precautions are taken to minimize sampling bias and differences in productivity among the collections. The simulation study reported by Hammond & Gardner (11) suggests that, without special precautions, effective sample size may easily be reduced by as much as one third by drawing seed at random from a bulk sample.

The possibility of differential viability has been largely ignored and may not be of general importance. Weiss & Wentz (19) demonstrated that the luteus genotype (a chlorophyll-deficient seedling type) lost viability rather rapidly upon storage. Until the recent development of isozyme techniques, methods were not available for a ready evaluation of this problem. If adequate study shows that differential viability is important, then the present practice of deferring renewal until there has been substantial reduction in viability may require revision.

One can infer from the general lack of definitive answers that problems relating to germplasm renewal merit a greater research effort than they have received to date.

Handling Germplasm Resources

Documentation, evaluation, and information retrieval are necessary components of an efficient system for preservation of germplasm resources. These

13

three distinct operations serve separate needs but are so closely associated in practice that each plays a role in decision making relative to the other two. Limitations in any one of these three components will drastically reduce the usefulness of any sizable collection.

DOCUMENTATION Genetic resource centers are called upon to serve the interests of several different disciplines. Dissimilarity among these interests must be accommodated through the information available on each sample in the collection.

On collections made at earlier dates, little information is available other than the assigned accessions number, species, and site of collection. Until recently no effective machinery was in place to record additional information as it became available.

A system of documentation serves several functions; it is an aid to inventory management, it facilitates exchanges among centers, and it provides a repository for diverse types of information. It is a necessary adjunct to any system of management for germplasm resources. It provides a necessary repository for various types of pertinent data.

Uniformity of data handling is necessary to facilitate information retrieval. The differing types of information have been given the general designation, *descriptors* (12). Where possible, the appropriate descriptors have been chosen by a panel of experts for each of the crop species. In addition to the historical categories of accession number, country of origin, and other data provided by the collector, the descriptors fall into several general categories, including appropriate morphological, genetic, and biochemical attributes. Reaction to pests and environmental hazards will also be of great importance. Much of this information will be collected sequentially; therefore, a system of great capacity and flexibility is required.

Data must be presented in a uniform manner to ensure compatability of inputs among centers; for example, if in scalar form, data must agree as to the number of classes recognized and whether class 1 is to be best or poorest. The number of descriptors must also remain open-ended to provide the flexibility to accommodate data on new traits such as ratings on some new or previously unimportant disease.

EVALUATION The first concern involving germplasm resources has been collection—the assemblage of types before they disappear. As indicated earlier in this chapter, considerable progress has been made. Adequate collections, however, have only limited usefulness until they have been described and adequately evaluated.

A detailed description of the physical characteristics of an accession or group of accessions serves a necessary purpose but will often fail to reveal the most useful characteristics, e.g. resistance to some disease or insect pest,

14

reaction to various stresses, or the potential for some special nutritional or industrial use. Such information must come mainly from planned studies conducted by a specialist rather than as chance observations during seed multiplication.

In the collections held at the National Seed Storage Facility at Fort Collins, descriptive and evaluative data are extremely uneven. For some items the accession number and source is the only information available. For others extensive data are available. In the screening of the cereals, the primary objective has been to find resistance to some particular pest. When one or more source of resistance have been identified, further screening has often been deferred until a new problem required a new search effort.

In only a few instances has comprehensive screening been attempted. The oat and barley collections have been screened for reactions to barley yellow dwarf virus and for various other diseases. Large segments of the wheat collection have been screened for a number of important diseases. Unfortunately, much of the information that was accumulated during the screening process has not been fed back into the system to become a part of the permanent record.

The desirability of screening is illustrated by the accession P.I. 178383. It was collected in Turkey and has no outstanding physical characteristics, but upon testing was found to carry resistance to several races of stripe rust, common bunt, and dwarf bunt and tolerance to flag smut and snow mold. This strain has become a valuable addition to breeders' working collections.

Information on collections held in US repositories varies widely. For some collections only source and taxonomic information is available. For others a substantial amount of information has been assembled. Potatoes and maize provide a useful contrast.

The center for the tuber-bearing solanums is headquartered at Sturgeon Bay with associated research at Madison, Wisconsin. Collections are maintained as seed and tubers; seed are used for long-term storage and to minimize quarantine problems in international exchange. Additions to the collection, representing at least 92 solanum species, are initially screened for reaction to several viruses and insect pests as well as fungal and bacterial diseases. When resistance to pests or other desirable traits is found, the species can be retained in a stable condition through asexual propagation. Because of the simplicity of identification and propagation of desirable traits, exotic material is used extensively in current breeding programs both here and abroad. Of the 135 potato varieties released since 1932, 131 have involved some exotic germplasm. This fact indicates the adequacy of the evaluation system and the usefulness of exotic material in breeding operations.

In contrast to potatoes, information on the much larger maize collection is largely limited to place of collection, varietal or racial designation, and

15

a few readily observable traits such as maturity, height, and cob and grain color. No serious attempt has been made to evaluate this material for either disease or insect resistance.

In the cross-pollinating species an accession may be both highly heterogeneous and heterozygous. It is possible that direct evaluation of any trait depends upon gene frequency among loci conditioning the trait. If gene frequency is low, some type of controlled pollination may be required to reveal recessive traits. In some species this control may be accomplished through self-fertilization. Where self-pollination is impractical because of self-sterility or other genetic mechanisms, the production of half-sib families may be the only feasible alternative. Consequently, costs are greater and efficiency is lowered. The problems inherent in characterizing cross-pollinating species account for their limited evaluations.

In maize, sources of simply inherited resistance have been found to several diseases including those induced by *Helminthosporium turcicum, H. maydis, Puccinia sorghi,* and *P. polysora.* Resistance to other diseases (stalk rots and ear rots) and to insect pests appears generally to be polygenic. In several cases resistance has been found within adapted materials, lessening the pressure for a systematic evaluation of exotic types.

Regardless of the type of reproduction, a basic requirement for any systematic evaluation program is the availability of a simple and reliable assay technique. Such techniques are available for several of the major diseases. Adequate techniques for evaluating differences in resistance to insect pests are somewhat less common because of problems in achieving controlled density of infestation. Marked progress has been made in recent years in mass rearing techniques for several species, thus permitting adequate and repeatable levels of infestation. Techniques for evaluating differences in response to stress (heat, drought, cold, etc) are even more difficult and time consuming because responses are often influenced or conditioned by the stage of plant development.

The great majority of evaluations accomplished thus far has been through the cooperative efforts of pathologists, entomologists, and breeders. This pattern will likely continue as information accumulated as a by-product of seed renewal will not adequately serve today's needs. Any systematic evaluation requires not only trained manpower but also adequate facilities, both laboratory and field. We can expect that genetic material identified and isolated by such groups will flow rapidly into plant breeding programs and ultimately improve world agriculture. Without such systematic evaluation programs production hazards will remain unnecessarily high.

Information Retrieval

With the large numbers of accessions available at any genetic resource center and the much greater total internationally, the recovery of any

16

desired segment of information in a readily usable form must be based on a computer-assisted retrieval system: In its simplest form such a system has two distinct components: appropriate computer hard- and software with the necessary capacity and flexibility for the task and an appropriate set of descriptors amenable to computer storage and retrieval.

No standard computer equipment or program has been adopted at all genetic research centers, and several different systems are in operation worldwide. Uniformity among centers is not required as long as the system in use at a given center is known to other centers. Within the United States a system designated Taxonomic Information Retrieval (TAXIR) is being used for several crops. The system was developed at the Taximetric's Laboratory at the University of Colorado at Boulder (12, 16). For TAXIR to become an effective system several requirements must be met. These include agreement on appropriate descriptors on a crop by crop basis, the assembling of existing information on collections and the transfer of this information to cards or tape, recording of new descriptor information as it becomes available, and any modification of the system necessary to achieve maximum efficiency. These and other related functions are being coordinated by the Germplasm Resources Information Project (GRIP).

Value of Introductions

The potential value of exotic germplasm to US and to world agriculture is difficult to assess. The role of introduced species has changed drastically over time. Initially the whole of U.S. agricultural development could be attributed to introductions, for the cultivation of native species comprises only a small fraction of our total productivity. One need only cite the introduction of Turkey winter wheat, soybeans, and alfalfa to emphasize the profound impact of introductions on our current agricultural system. However, the likelihood of introducing a new species that can play an important role in our system becomes increasingly remote. Suggestions that such possibilities exist tend to overlook the long period of development and evaluation required to make a new crop competitive. Sporadic attempts have been made to introduce and develop new crops for special uses. The results have not been impressive. Opportunities may exist, but the long-term financial and manpower commitments required usually have been inadequate to the task.

Following the introduction of new crop species into the United States, drastic changes in genetic characteristics were subsequently effected through a combination of natural selection and plant breeding. The net effect has been to isolate types better suited to our environmental conditions and farming systems. As a result of these changes, commercial varieties represent only a small fraction of the total genetic diversity. At any given

17

time varieties in widespread use tend to have reasonable levels of resistance to major pests of the area. They may be highly susceptible, however, to new physiologic races of a pathogen or biotypes of insect or to newly introduced species. Parasites and predators also have the potential for genetic modification, and new variants are continually being produced. Some of these new forms may have the capacity to induce serious loss. When this happens new control measures must be sought. If available, host resistance often if not always is the preferred control. Germplasm resources appear to be increasingly important sources of resistance genes, and they certainly will be of greater value as collections are more adequately characterized.

Selected listing of a few of the many traits obtained from existing collections and used to solve or alleviate production problems provides some insight into the importance of maintaining an adequate germplasm collection. As might be expected, collections have been of more value in crops of relatively recent introduction (e.g. wheat, potatoes, alfalfa) than others with a much longer period of adaptation and thus an increased likelihood of greater local genetic diversity (e.g. maize).

The genetic diversity within US maize collections has been enough to obtain some degree of resistance to our more important disease and insect pests. In spite of this diversity within adapted material, introductions have been useful in providing new or additional sources of resistance to *Puccinia sorghi, P. polysora, Helminthosporium turcicum,* and *H. maydis.* Several tropical races offer promise of resistance to fall army worm, the corn earworm, and certain stalk borers. In addition they have provided the source of the C type of cytoplasmic male sterility.

Wheat was introduced in the early Colonial period. The hard red winter wheats are largely of Crimean origin, the soft red wheats from the Mediterranean, and the white wheats from Australia, Mexico, and Spain. This basic diversity has been greatly augmented by more recent introductions. Areas from which important sources of resistance to certain disease and insect pests have been obtained are listed below:

Leaf rust	China, Balkans, Russia, Brazil, Argentina
Stem rust	Russia, Canada, Kenya, Australia, Brazil, Egypt
Stripe rust	Turkey, Europe, Latin America
Bunt	Russia, Turkey, Australia
Hessian fly	Uruguay, Greece, Portugal
Cereal Leaf Beetle	Russia, China

Much of the current breeding work with alfalfa makes use of germplasm pools. Varieties having greater resistance to several diseases and insect pests including bacterial wilt, fusarium wilt, leaf spot, phytophthora root rot,

nematodes, potato leaf hopper, and pea and spotted alfalfa aphids have resulted. Resistance to one or more of these pests has come from introductions from the following countries: Afghanistan, India, Arabia, France, India, Iran, Israel, Spain, Sweden, Turkey, USSR, and Yugoslavia.

In the potato, collections from Argentina have contributed resistance to the A, X, and leaf roll viruses, verticillum wilt, nematodes, and leaf hoppers. Genes for resistance to the A, Y, and leaf roll viruses, late blight, bacterial wilt, the peach and potato aphids, and leaf hoppers came from the collections made in Mexico.

The contribution of exotic germplasm to US agriculture could be detailed for additional members of our important crop plants. It is clear that investment in the preservation of germplasm resources has already paid a substantial dividend and should become even more valuable as the collected materials become more adequately characterized.

Summary

The intentional transfer of germplasm resources dates back to the beginnings of civilization. Intensive efforts to collect and preserve the genetic variability of our important crop species, however, is a fairly recent development. Large numbers of collections of many species are now held in international centers distributed around the world. Additional collections are being made in areas where genetic erosion is progressing most rapidly. Work is progressing on description and evaluation of existing collections. The value of the collections will increase in direct proportion to the adequacy of the descriptive information available. Computer-based systems are being developed to permit rapid retrieval of information on any collection. Exotic germplasm has played an important role in our agricultural development —a role that will be of increasing importance as the evaluation of collections becomes more adequate.

19

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10