Our Vanishing Genetic Resources

Modern varieties replace ancient populations that have provided genetic variability for plant breeding programs.

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All of the major food and fiber crops of the world are of ancient origin. The main sources of human nutrition today are contributed by such plants as wheat, rice, corn, sorghum, barley, potatoes, cassava, taro, yams, sweet potatoes, and grain legumes such as beans, soybeans, peanuts, peas, chickpeas, and so on. All of these plants were domesticated by Stone Age men some thousands of years ago and had become staples of the agricultural peoples of the world long before recorded history. We are not able to trace with certainty the genetic pathways that led to domestication, but we do know that these crops evolved for a long time under the guidance of man living in a subsistence agricultural economy. In the process of evolution, the domesticated forms often became strikingly different from their wild progenitors and generated enormous reserves of genetic variability.

Darwin opened his book *On the Origin of Species* with a discussion of variability of plants and animals under domestication. Genetic variability is the raw stuff of evolution, and he was struck by the range of morphological variation found in domesticated forms in contrast to their wild relatives. We are all familiar with the enormous differences among such breeds of dogs as Pekingese, dachschund, beagle, bulldog, Afghan, and Great Dane and how far removed they are in appearance from either wolves or any other wild species that could have been progenitor to domestic dogs. Similar ranges of diversity are seen in chickens, pigeons, cats, cattle, horses, and so on. Domestic plants exhibit the same phenomenon, especially among species that have been cultivated for a very long time and that have wide distributions. Genetic diversity is essential for evolution in nature and is, obviously, equally necessary for improvement by plant breeding.

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Crop evolution through the millennia was shaped by complex interactions involving natural and artificial selection pressures and the alternate isolation of stocks followed by migrations and seed exchanges that brought the stocks into new environments and that permitted new hybridizations and recombinations of characteristics. Subsistence farmers of what we often call "primitive" agricultural societies have an intimate knowledge of their crops and a keen eye for variation. Artificial selection is often very intense, for the only forms to survive are those that man chooses to plant. The end products that emerged in primitive agricultural systems were variable, integrated, adapted populations called land races.

While land race populations are variable, diversity is far from random. They consist of mixtures of genotypes or genetic lines all of which are reasonably well adapted to the region in which they evolved but which differ in detail as to specific adaptations to particular conditions within the environment. They differ in reaction to diseases and pests, some lines being resistant or tolerant to certain races of pathogens and some to other races. This is a fairly effective defense against serious epiphytotics. Some components of the population are susceptible to prevalent pathogenic races, but not all, and no particular race of pathogen is likely to build up to epiphytotic proportions because there are always resistant plants in the population. Land races tend to be rather low yielding but dependable. They are adapted to the rather crude land preparation, seeding, weeding, and harvesting procedures of traditional agriculture. They are also adapted to low soil fertility; they are not very demanding, partly because they do not produce very much.

Land races have a certain genetic integrity. They are recognizable morphologically; farmers have names for them and different land races are understood to differ in adaptation to soil type, time of seeding, date of maturity, height, nutritive value, use, and other properties. Most important, they are genetically diverse. Such balanced populations—variable, in equilibrium with both environment and pathogens, and genetically dynamic—are our heritage from past generations of cultivators. They are the result of millennia of natural and artificial selections and are the basic resources upon which future plant breeding must depend.

In addition to variable land race populations, traditional agriculture generated enormous diversity in identifiable geographic regions called "centers of diversity" or "gene centers." Such centers are (or were) found on every continent, except Australia where the native people did not cultivate plants. Wherever they are located they are always characterized by (i) very ancient agriculture, (ii) great ecological diversity (usually mountainous regions), and (iii) great human diversity in the sense of numerous culturally distinct tribes with complex interacting histories. Centers of diversity were first recognized and described by the great Russian agronomist and geneticist N. I. Vavilov in the 1920's and 1930's (*1*).

H. V. Harlan and M. L. Martini, concerned with genetic resources of barley, put it this way as early as 1936 (*2*):

> In the great laboratory of Asia, Europe, and Africa, unguided barley breeding has been going on for thousands of years. Types without number have arisen over an enormous area. The better ones have survived. Many of the surviving types are old. Spikes from Egyptian ruins can often be matched with ones still growing in the basins along the Nile. The Egypt of the Pyramids, however, is probably recent in the history of barley. In the hinterlands of Asia there were probably barley fields when man was young. The progenies of these fields with all their surviving varia-

tions constitute the world's priceless reservoir of germ plasm. It has waited through long centuries. Unfortunately, from the breeder's standpoint, it is now being imperiled. When new barleys replace those grown by the farmers of Ethiopia or Tibet, the world will have lost something irreplaceable.

That is the way it was before World War II. Genetic erosion was already well advanced in much of Europe, the United States, Canada, Japan, Australia, and New Zealand, where active plant breeding programs had been under way for some decades. But, the ancient reservoirs of germ plasm were still there in the more remote parts of the world and seemed to most people as inexhaustible as oil in Arabia. We could afford to squander our genetic resources because we never had much of our own, and we could always send collectors to such places as Turkey, Afghanistan, Ethiopia, India, Southeast Asia, China, Mexico, Colombia, and Peru and assemble all the diversity we could use. No one paid much attention to the prophetic warning of Harlan and Martini.

International Programs for Genetic Resource Conservation

After World War II, the picture began to change. Modern plant-breeding programs were established in many of the developing nations and often right in the midst of genetically rich centers of diversity. Some of the programs were successful, and new, uniform, high-yielding, modern varieties began to replace the old land races that had evolved over the millennia. The speed with which enormous crop diversity can be essentially wiped out is astonishing, and the slowness with which people have reacted to salvage of threatened genetic resources is dismaying (*3*).

Cries of alarm began to be sounded on the international scene about 15 years ago. A short chronology of events and actions associated with the Food and Agriculture Organization (FAO) of the United Nations is presented below.

1961. FAO convened a technical meeting on plant exploration and introduction. Among the recommendations was one to the effect that a panel of experts be appointed "to assist and advise the Director of the Plant Production and Protection Division in this field."

1962. A proposal for a Crop Research and Introduction Centre, Izmir (Turkey), was submitted to the United Nations Special Fund.

1963. The twelfth session of the FAO conference also recommended the establishment of a Panel of Experts on Plant Exploration and Introduction to advise FAO on these matters.

1964. The Crop Research and Introduction Centre, Izmir, became operative with U.N. Special Fund support. The Centre has collected, stored, and distributed germ plasm and now, under support of the Swedish government, is serving as a regional center for the Near East.

1965. The panel of experts was appointed.

1967. FAO and the International Biological Program (IBP) jointly sponsored a Technical Conference on Exploration, Utilization and Conservation of Plant Genetic Resources (*4*).

1968. A Crop Ecology and Genetic Resources Unit was established in the Plant Production and Protection Division, FAO.

1971. The Consultative Group on International Agricultural Research (CGIAR) was established under joint sponsorship of the World Bank, FAO, and U.N. Development Program (UNDP). Members include governments, private foundations, and regional development banks, and money is generated to support international agricultural research programs and institutes.

1971. A Technical Advisory Committee (TAC) was established to assist the CGIAR.

1972. Under joint sponsorship of TAC, FAO, and CGIAR a meeting was convened at Beltsville, Maryland, and a plan for a global network of Genetic Resources Centers was drawn up. Recommendations for location and funding were made and suggestions for international organization and coordination submitted to CGIAR through TAC.

1972. The U.N. Stockholm Conference on the Human Environment called for action on genetic resource conservation.

1973. A second FAO/IBP technical conference was convened in Rome (*5*).

1973. The CGIAR established a subcommittee on genetic resources.

1973. The International Board for Plant Genetic Resources (IBPGR) was established with a secretariat in FAO and financial resources provided by CGIAR, as recommended at the Beltsville meeting.

1974. Portions of the global strategy devised at Beltsville began to be funded through bilateral agreements with donor governments; for example, Sweden agreed to support the Izmir Centre for a time, and the Federal Republic of Germany agreed to support genetic resources centers in Ethiopia and Costa Rica. Other similar agreements have been or are being arranged.

Within the FAO structure, rather parallel developments took place with respect to forest genetic resources. Reports of technical conferences and meetings of the panel of experts, *Plant Introduction Newletter*, and *Forest Genetic Resources Information* are published by FAO.

It must be admitted that for all the organizational developments, and despite repeated and urgent pleas by the panel of experts, remarkably little collecting has been done to date. The Izmir Centre has been plagued with political, financial, administrative, and personnel problems from the start. It has managed to assemble a modest collection of some 10,000 accessions, and the long-term storage facilities now installed are excellent. The conception of the Izmir Centre is sound, and it is to be hoped that it will eventually perform the function for which it was established. FAO has conducted a few collecting expeditions and has given support to more, but the urgency of the situation demands much more vigorous action than has been generated so far.

The next few years, however, should show an increase in plant exploration. Funds should be available from the consultative group to support adequate exploration programs. For some regions it will probably be too late to salvage much.

It must also be admitted that much less would have been achieved without the dogged and determined insistence of Sir Otto Frankel of Australia (*4*). Through the years he has refused to abandon hope that serious action could, one day, be launched through an international cooperative program, and he has shaped most of the events described above.

Meanwhile, the international institutes, supported largely by CGIAR, have fared somewhat better. They each deal with one or a few crops and have usually understood that a part of the mission was to assemble and preserve germ plasm of the crops being developed. The world maize collection, for example, traces back to early international agricultural research sponsored by the Rockefeller Foundation in Mexico, Colombia, and elsewhere. A rather systematic effort was made to collect the races of maize, country by country, throughout Latin America. A major portion of the collection is maintained by the Centro Internacional de Mejoramento de Maíz y Trigo (CIMMYT) in Mexico, the Andean collection by the Instituto Colombiano Agrapucuerio (ICA) in Colombia, and the eastern South American collection is maintained at Piracicaba, Brazil. The maize collection appears to be in reasonably good shape, although some additional exploration is desirable.

The world rice collection has been growing rapidly in recent years through activities of the International Rice Research Institute (IRRI) in the Philippines. It is certainly not complete, but it is far better than it was 3 to 4 years ago. The Centro Internacional de Agricultura Tropical (CIAT) in Colombia is assembling cassava and beans. The International Institute of Tropical Agriculture (IITA) in Nigeria has been collecting cowpeas, pigeon peas, yams and other tropical tuber crops, and tropical vegetable species. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India, has assumed responsibility for world collections of sorghum, millets, chickpeas, and pigeon peas. The Centro Internacional de Papas (CIP) in Peru is starting to assemble potatoes for breeding work. All of these institutes are located in the tropics and should be able to maintain and rejuvenate collections of these crops much more efficiently than can be done in temperate countries.

National Programs: United States

The agriculture of the United States is an imported agriculture. Even crops domesticated by the American Indians —such as corn, potatoes, peanuts, cotton, tomatoes, and so on—originated in Latin America outside of the United States, and were introduced, some by Indians and some by Europeans. Because of our dependence on exotic germ plasm, the national government has sponsored collections and introductions from the beginning. As early as 1819, the Secretary of the Treasury issued a circular requesting Americans serving as consuls to send useful plant materials back to the United States. Formal plant exploration was conducted by the Office of the Patent Commissioner before 1862, when the U.S. Department of Agriculture (USDA) was created. In 1898 a Section of Seed and Plant Introduction was established in the USDA; and ever since, through various name changes and reorganizations, some unit within the department has been charged with responsibility for germ plasm assembly and maintenance (*6*).

A considerable impetus was given the plant introduction program by the Research and Marketing Act of 1946. Regional Plant Introduction Stations were established in the four administrative regions of the country. An Inter-Regional Potato Project was established in 1949 with a special station at Sturgeon Bay, Wisconsin, where exotic potato germ plasm could be grown and evaluated. A National Seed Storage Laboratory was built in Fort Collins, Colorado, and began operation in 1958. The primary objective of the laboratory is long-term seed storage, although research on the physiology of germination, dormancy, and longevity of seeds is also conducted.

Nearly 400,000 accessions have been introduced since 1898, but there has been substantial attrition over the years. The importance of maintenance was not at first generally realized, and much material was lost for one reason or another. Nevertheless, the present holdings of the USDA are very considerable and extremely important. The small grains (wheat, barley, oats, and rye) collection, for example, consists of more than 60,000 items, many of which could not possibly be replaced because they have disappeared from their original homelands. Substantial "world collections" of the major crops and many of the minor ones are being maintained at the Regional Plant Introduction Stations or through cooperative arrangements with other state and federal stations.

It would be nice to think that all the genetic diversity we will ever need is safely stored away in gene banks for future use. Unfortunately this is hardly the case. Some of our collections are large even when the numerous duplicates are accounted for, but none is really complete, and sources of diversity are drying up all over the world. We are particularly deficient in the wild and weedy relatives of our more important crops, and some geographic regions have been very poorly sampled. While the USDA has sponsored plant introduction work from the beginning, it has never been able to obtain enough support to systematically sample the world's germ plasm. The National Seed Storage Laboratory has received stepchild treatment with no increase in the operating budget for more than 15 years after establishment.

The southern corn leaf blight epidemic in 1970 aroused some activity in the area of crop vulnerability. A survey was commissioned by the National Academy of Sciences, resulting in a report on genetic vulnerability (*7*). It was found, not surprisingly, that not only corn but also every major crop we grow has a very narrow genetic base. The entire soybean industry, for example, traces back to six introductions from the same part of China. The leaf blight epidemic of 1970 came about because most of the hybrids produced had a common cytoplasm which conferred susceptibility to a particular race of the pathogen. We are just as vulnerable in sorghum where a cytoplasmic sterile system is used to produce hybrids. A crop-by-crop analysis reveals an extremely risky dependence on narrow genetic bases.

More than this, the number of crops we grow has been declining steadily. More and more people are being fed on fewer and fewer crops and these are becoming increasingly uniform, genetically.

After a series of meetings in Washington, an ad hoc committee drew up recommendations and presented them to the Agricultural Research Policy Advisory Committee (ARPAC) of the Agricultural Research Service. Among the recommendations was the establishment of a Genetic Resources Board at the national level which would, among other things, devise a national plan and program for systematic assembly, maintenance, evaluation, and utilization of plant genetic resources. It is to be hoped that a more systematic, coordinated, and effective program of genetic resource management can be generated for the country and that adequate financial support can be found. Approval for the board was obtained in January 1975.

National Programs: Other Countries

The U.S.S.R. probably has holdings of about the same magnitude as ours. No doubt, there is a good deal of duplication, yet they have arrays of collections that we do not have and we have materials they do not have. It would undoubtedly be of great mutual benefit if we could exchange collections and hold a complete set of duplicates in two different parts of the world. It would be a disaster if something should happen to either collection. Duplicate storage would be much safer.

National collections can be vulnerable. There is a heroic tale about the seige of Leningrad during World War II. People were dying of cold and starvation, reduced to eating rats, cats, dogs, dried glue from furniture joints and wall paper, or anything else that might prolong life. All this time, truckloads of edible seeds were in storage at the All-Union Institute of Plant Industry. The seeds were too precious to be sacrificed even at the cost of human life, and the collections survived for future use. We may pray that such a threat will never occur again, but prayer may not be adequate to save priceless genetic resources.

The Vavilovian emphasis on plant genetic resources persisted despite the long twilight of genetics under the political influence of T. D. Lysenko and Vavilov's tragic death as a result (*8*). The institute, which he directed for 20 years (1920–1940), was renamed the N. I. Vavilov All-Union Institute of Plant Industry (VIR) in 1968, just in time for the 75th anniversary of the organization in 1969 (*9*).

There may be some question as to how well the original collections of the Vavilovian era have been maintained with respect to genetic authenticity, but there is no doubt that Soviet scientists are more collection minded than plant scientists elsewhere. Genetic resource management has been emphasized since 1920 and has become an integral part of the national agricultural development program. No doubt there are genes in Soviet collections that no longer exist anywhere else.

The Japanese, under the stimulus of H. Kihara, have also had strong genetic conservation programs, especially with certain crops. Expeditions have been sent to several centers of diversity over the decades and a national seed storage facility has been established at Hiratsuka. The University of Kyoto and the National Institute of Genetics, Misima, have been especially active, although others have also participated.

Genetic resources centers with cold storage for long-term conservation have been established in a number of other countries. Some of the major ones include Brisbane, Australia; Prague, Czechoslovakia; Copenhagen, Denmark; Gatersleben, German Democratic Republic; Braunschweig-Volkenröde, German Federal Republic; New Delhi, India; Bari, Italy; Wageningen, Netherlands; and Warsaw, Poland. Others are being constructed or present facilities are being upgraded. Substantial holdings are being maintained in the United Kingdom, France, Sweden, Canada, and elsewhere. The necessity for genetic conservation is gradually being accepted throughout the world, but the urgency of salvage collection operations has yet to be generally appreciated.

A recent visit by a Plant Studies Delegation to the People's Republic of China revealed a somewhat ambiguous situation. The following observations may be pertinent. (i) China is, indeed, very rich in genetic diversity for many crops; (ii) Chinese scientists are not collection minded, and little effort is being made to conserve land races as they are replaced by modern varieties; (iii) the trend, at the moment, is to produce many species and varieties of fruits and vegetables, which tends to maintain diversity; and (iv) there is a strong emphasis on local self-sufficiency with respect to seed production at both the people's commune and production brigade levels which may tend to maintain variability at the national level. Overall, the picture is discouraging with respect to major crops. Two rice collections are being maintained, one for *japonica* and one for *indica* rices, but the ancient kaoliangs are disappearing from the Chinese sorghum belt, and the traditional millets are hanging on primarily in marginal dryland zones.

Altogether, a good deal has been done to collect genetic resources, and tentative, if unsystematic, steps have been taken to conserve much of it on a long-term basis. In view of the obvious limitations of our collections and in face of the current genetic "wipe out" of centers of diversity, it may be too little and too late. We continue to act as though we could always replenish our supplies of genetic diversity. Such is not the case. The time is approaching, and may not be far off, when essentially all the genetic resources of our major crops will be found either in the crops being grown in the field or in our gene banks. This will be a risky state of affairs and will demand a great deal more time and effort on genetic resource management than we have ever devoted to it in the past.

References and Notes

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