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Genetic Conservation : Microbes to Man

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A wider perspective on conservation of genetic resources is provided. The importance of nitrogen fixing organisms, legume-rhizobium germplasm collection and utilisation is stressed. The history and developments in the field of collection, conservation and utilisation of genetic resources are highlighted for the crop plants. Both in situ *and* ex situ *measures are highlighted for conservation of germplasm. The recent use of molecular techniques is stressed. Looking ahead, it is advocated that there is a need for a global germplasm ethics, guidelines for which can be developed by UNESCO with the help of IUCN and other appropriate international conservation organisations.*

The enormous variability occurring in nature has always fascinated botanists. Though attempts were made to collect and conserve useful economic plants in botanical gardens and national parks, it was, however, only after the rediscovery in 1900s of the laws of inheritance propounded by Gregor Mendel in 1865 that planned and intensive research on the effective utilisation of genetic diversity in plants and animals began. We owe it to Vavilov for showing the importance of genetic diversity in crop improvement. Vavilov's great contribution was not only that he demonstrated the value of genetic diversity in breeding research but that he also developed a systematic plan of action for collecting genetic material from the primary centres of origin of crop plants. He explained the relationships between genetic diversity and centres of origin of crop plants. Addressing the 6th International Congress of Genetics held at Ithaca, USA in 1932, Vavilov pointed out that "the growing needs of civilised man and the development of industry make the introduction of new plants necessary. The vast resources of wild species, especially in the tropics, have been practically untouched by investigation."

Even as Vavilov was explaining the importance of plant exploration and conservation, concern was expressed by several geneticists over the loss of primitive cultivars due to the process of modernisation of agriculture. It was pointed out that without coordinated efforts around the world, valuable genes could be lost through neglect. In recent decades, the need for a clear national policy on genetic stocks and genetic diversity has been stressed at numerous

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symposia on genetic conservation. Further, tissue culture and genetic engineering techniques have opened up possibilities for the transfer of genes across sexual barriers. This possibility has enhanced the value of wild relatives of crop plants. Interest in genetic conservation has, therefore, enormously grown in recent years. Here, I would like to briefly refer to a few key issues in genetic conservation ranging from microbes to man. I shall confine myself to problems of particular interest in the field of crop improvement. In my Presidential Address at the XV International Congress of Genetics, I had dealt with the current status of our efforts in the conservation of biological diversity in considerable detail (Swaminathan, 1983). I shall hence deal with a few of the recent developments here.

NITROGEN FIXING ORGANISMS

There is a growing interest in the conservation and utilisation of biological nitrogen fixing organisms. The reason for this interest is the rapid increase in the energy needed to produce a ton of grain using essentially mineral fertilizer produced from fossil fuel based feedstocks.

At the International Rice Research Institute (IRRI), an extensive programme of research on *Azolla*, bluegreen algae and green manure crops is in progress. Recently, it has become possible to produce hybrids among *Azolla* species. The conservation of *Azolla* species, many of which have distinct characteristics, has become important. The IRRI collection now consists of 359 accessions from different parts of the world (Table 1).

TABLE 1. AZOLLA COLLECTION AT *IRRI*

Species	Number of collections	Origin
A. pinnata var. *imbricata*	117	Australia, Bangladesh, China, India, Indonesia, Japan, Malaysia, Nigeria, Pakistan, Philippines, Sri Lanka, Thailand, Taiwan, USA, Vietnam
A. filiculoides	81	Brazil, China, Colombia, Germany, Japan, Peru, Philippines, UK, USA
A. mexicana	5	USA, Guyana
A. caroliniana	44	Brazil, China, Philippines, UK, USA
A. microphylla	48	China, Galapagos, Paraguay, Philippines
A. nilotica	1	Sudan
A. rubra	9	Japan
A. pinnata var. *pinnata*	46	Australia, Ivory Coast, Malagasy, Senegal, Mexico
Unclassified	1	Mexico
Hybrid*	7	Philippines, China
Total	359	

*Hybrids between *A. filiculoides* × *A. filiculoides*, *A. filiculoides* × *A. microphylla*, *A. microphylla* × *A. microphylla*, *A. microphylla* × *A. filiculoides*, *A. microphylla* × *A. mexicana*.

Legume-Rhizobium germplasm collection and conservation

There are about 650 genera and 18,000 species in family Leguminosae mostly found in the tropics (National Academy of Sciences, 1979). Many species yield seeds that are rich in protein and constitute valuable sources of food and fodder; others are important either as components of pasture or used as green manure or timber. Legumes are valued for their nitrogen-fixing ability. The nitrogen contribution of legumes can be vital for maintaining the sustainability for intensive production systems. Consequently, leguminous shrubs are becoming important in the alley farming techniques being developed in several parts of Africa as an alternative to the shifting cultivation system of land management.

Although thousands of species of legumes are known, only a few are economically exploited and still fewer are available in the form of germplasm. The work on collection of genetic resources of tropical non-grain legumes started only a few decades ago. The major collections are held by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia; the Centro Internacional de Agricultura Tropical (CIAT), Colombia ; International Livestock Centre for Africa (ILCA) in Ethiopia; International Council for Research in Agroforestry (ICRAF) in Nairobi and the University of Hawaii. Among all the collection centres, the largest and the most comprehensive collections are with CSIRO, CIAT and ILCA (Table 2).

At IRRI a Biofertiliser Germplasm Centre is being established in the Microbiology Department to preserve the genetic resources of leguminous green manures, *Azolla*, blue-green algae, and bacteria including rhizobia. In the coming years, collections of biofertiliser germplasm will be expanded, and characterisation and evaluation will be done. The collection is being made available to researchers, extension workers, and farmers all over the world. The importance of germplasm collection and conservation is manifested by the recent exploration by French scientists of hitherto unknown aquatic legumes, *Sesbania rostrata*, and species of *Aeschynomene* (*A. nilotica* and *A. afraspera*) that grow wild in the waterlogged soils of Senegal, Africa (Rinaudo et al., 1983; Alazard and Becker, 1987). These legumes are fast growing, produce nodules on both roots and stems, and can grow under flooded conditions. They have opened up new possibilities for integrating a green manure crop into rice farming system without disturbing current cropping systems very much. It has been found that growing and incorporating a 40 to 50-day old *S. rostrata* crop before wet season rice, can add up to 100 kg N/ha (Ladha et al., 1987).

Research on Legume-Rhizobium symbiosis has led to the establishment of collections of rhizobia in many places throughout the world. In 1974 the UNEP/UNESCO/ICRO Panel of Microbiology started the concept of Microbiological Resources Centers (MIRCENs) and the major goal was the conservation of Rhizobium genepools in developing countries. Since then several MIRCEN centres are operating (Table 3). The World Data Center (WDC) for microorganisms supported by UNESCO/UNEP published the World Catalogue of Rhizobium Collections in 1983.

TABLE 2. GERMPLASM COLLECTIONS OF FORAGE LEGUMES

Genus	CSIRO	CIAT	ILCA
Acacia	50	*)	100
Aeschynomene	450	850	100
Alysicarpus	250	250	150
Cajanus	300	50	100
Calopogonium	150	500	50
Canavalia	100	200	*)
Cassia	250	300	100
Centrosema	1200	1900	300
Clitoria	100	150	50
Crotalaria	300	250	150
Desmanthus	200	150	50
Desmodium	1500	2550	150
Dioclea	*)	200	*)
Dolichos	50	*)	*)
Eriosema	*)	100	*)
Erythrina	*)	*)	50
Flemingia	*)	50	*)
Galactia	100	550	*)
Glycine	100	*)	*)
Indigofera	450	200	150
Lablab	150	*)	150
Leucaena	600	150	100
Lotononis	100	*)	*)
Lotus	200	*)	*)
Macroptilium/Vigna/Phaseolus	1300	1250	750
Macrotyloma	150	50	50
Mucuna	*)	50	*)
Neonotonia	250	100	200
Phyllodium	*)	50	*)
Pseudarthria	50	50	*)
Pueraria	100	200	*)
Rhynchosia	300	400	150
Sesbania	150	50	*)
Stylosanthes	2000	3250	900
Tephrosia	250	150	100
Teramnus	100	300	50
Trifolium	1200	50	1050
Uraria	100	150	*)
Vicia	100	*)	*)
Zornia	100	950	250
Total	12750	15500	5250

*) = Fewer than 50 accessions

Source : R. Schultze-Kraft (1987) Germplasm collection and evaluation of tropical legumes. Paper presented in Symposium on Sustainable Agriculture—the role of green manure crops in rice farming systems. 25-29 May, 1987, IRRI, Los Baños, Philippines.

TABLE 3. RHIZOBIA CULTURE COLLECTIONS*

Institutions/ MIRCENs	Country	No. of strains
Porto Alegre	Brazil	650
Nairobi	Kenya	208
Hawaii	USA	2000
Beltsville	USA	938
		3796
Others Centres*	Argentina, Brazil, Chile, Colombia** Peru, Uruguay	5410

*No data available for large collections of Australia

**CIAT, Colombia—3000 strains, mainly of pasture tropical legumes.

Source : R. Schultze-Kraft (1987) Germplasm collection and evaluation of tropical legumes. Paper presented in Symposium on Sustainable Agriculture—the role of green manure crops in rice farming systems 25-29 May, 1987. IRRI, Los Banôs, Philippines.

Sexual hybridisation

Wei et al. (1986) reported the success of sexual hybridisation between two species of *Azolla* (*A. filiculoides* and *A. microphylla*). The hybrid was confirmed by esterase isozyme pattern. In some crosses, new sporophytes happened to be albino and could not grow in N-free medium. One hybrid which is now being tested in the field in Fujian in China showed hybrid vigour and exhibited cold temperature tolerance that was apparently inherited from one parent. The F_1, however, did not form megasporocarps.

At IRRI and the University of the Philippines at Los Baños, "hybrids" have been obtained between *A. microphylla* and *A. filiculoides*. But hybridisation has not yet been tested by biochemical means (Watanabe et al., 1987). A combination of interspecific hybridisation and change of algal partner would be useful for changing Azolla's characters for better agricultural use and wider application.

Blue-green algae

During the last thirty years, blue-green algae (BGA) have become recognised as a major group of prokaryotes. As pointed by Stanier, one hundred fifty years ago, BGA were left without much question to the botanists, in view of the classical definition of the term algae as encompassing all oxygenic phototrophs of simple general structure. As a result, research on BGA was basically concerned with two descriptive elements: taxonomy and ecology. The recognition of the prokaryotic nature of BGA has opened new fields of microbiological research on coenobacteria, the name coined by Stanier to emphasise the prokaryotic nature of BGA.

Interest in BGA arises from :

(1) The ability of a number of genera to fix atmospheric nitrogen, which has implications in the maintenance of the fertility of natural and cultivated ecosystems. In particular BGA are of importance in rice fields where their growth and N_2-fixing activity can be enhanced by inoculation and various cultural practices, thus providing a cheap source of nitrogen for the crop (Roger and Kulasooriya, 1980).

(2) The high nitrogen content of some genera, especially *Spirulina*, and the possible usage of certain strains as food or feed (Venkataraman, 1983).

(3) The possible usage of BGA as a source of useful biochemicals.

(4) Academic curiosity for organisms that constitute the largest and the most diverse and widely distributed group of photosynthetic prokaryotes.

For most eukaryotic organisms, and specially for cultivated plants, gene erosion is the major reason for establishing germplasm banks. For prokaryotic organisms, on the contrary, there is certainly very little risk of gene erosion. In particular, BGA are the most ancient living organisms on earth. They are ubiquitous, able to grow or survive in almost any environment including extreme ones and exhibit a very large morphological, ecological and genetic diversity. The major reason for establishing a collection of BGA comes from the difficulties in isolating and characterising strains. Once a strain has been isolated, there is very little chance to reisolate it from another ecosystem (or even from the same ecosystem) and to be sure of the identity of the material.

Because facilities are not yet available for a large culture collection at IRRI, only a restricted number of N_2-fixing strains (Table 4) is being maintained. The

TABLE 4. NUMBER AND ORIGIN OF THE COLLECTION OF BLUE-GREEN ALGAE IRRI, 1987

Genera	Africa		Asia		Europe	Other Regions	Total
	Senegal	Other	Philipp.	Other			
Anabaena	20	2	5	11	9	3	50
Aphanothece	0	1	1	0	0	0	2
Aulosira	1	1	0	1	0	1	4
Calothrix	14	2	5	3	0	1	25
Cylindrospermum	4	1	1	0	0	0	6
Gloeotrichia	1	0	3	0	0	0	4
Eischerella	0	3	7	0	0	0	10
Nodularia	2	0	1	1	0	0	4
Nostoc	20	6	13	13	2	5	59
Scytonema	6	0	1	1	0	0	8
Tolypothrix	0	0	0	4	0	0	4
Wollea	0	0	1	0	0	0	1
Westiellopsis	0	1	0	0	0	0	1
N_2-fixing	68	16	38	34	11	10	177
Nonfixing	16	0	0	1	1	0	18
Total	84	16	38	35	12	10	195

major purpose is to have available a range of strains for producing inocula for field inoculation experiments. Therefore, no special trials are made to purify the strains which are maintained as unialgal material. However, a few axenic strains obtained from other laboratories (mainly the Pasteur Institute) are maintained, for basic studies, in liquid medium and on agar slants. Unialgal strains are maintained in liquid medium and as dry powdered inocula.

CROP PLANTS

Until recently, issues relating to the collection, conservation and utilisation of crop genetic resources were primarily of interest to plant breeders and conservationists. After World War II, fears of large scale genetic erosion caused by the destruction of the habitats where genetic variability exists in nature, led to a stepping up of efforts in both *in situ* (biosphere reserves) and *ex situ* (gene banks) conservation. The Consultative Group on International Agricultural Research (CGIAR) established in 1974 an International Board for Plant Genetic Resources (IBPGR) for promoting coordinated efforts in the collection, conservation and utilisation of crop genetic resources. Of late, political interest and concern, particularly with reference to the question of ownership of gene banks has grown. The reasons for this development stem from the realisation that access to genetic variability is essential not only for avoiding genetic vulnerability to pests and diseases but also to take full advantage of recent progress in molecular biology and genetic engineering. Developing countries which constitute the most important centres of origin and diversity of economic plants, have to produce more and more food from less and less land in the decades and centuries ahead. This can be done only by increasing crop yield per day and more crops per year on a sustainable basis, thereby harvesting solar energy to the maximum possible extent. Increasing productivity and intensity of cropping are the twin pathways of achieving higher yield per day, which is the only meaningful way of measuring yield in the tropics and subtropics.

This will call for the efficient utilisation of genetic variability for tailoring new strains of crop plants characterised by higher yield potential and greater resistance to a broad spectrum of climatic and soil stresses in addition to pests. Developing countries, therefore, are concerned with the implications for the future of total privatisation of plant breeding research in developed countries with regard to easy and non-commercial access to the genetic resources collected from their countries and conserved in gene banks in developed countries. This concern resulted in the adoption in November, 1983 by member nations of FAO, with reservations by some countries, of a resolution on an International Undertaking on Plant Genetic Resources (IUPGR). The undertaking aims to achieve the following purposes :

1. to promote greater efforts in the exploration of plant genetic resources;

2. to facilitate the adoption of appropriate legislative and other measures for the preservation, evaluation and documentation of genetic material;

3. to allow access to samples of genetic resources and to permit their export where the resources have been requested for the purpose of scientific research, plant breeding or genetic resource conservation;

4. to strengthen international cooperation and to improve the capabilities of developing countries ;

5. to foster a coordinated network of national, regional and international base collections in gene banks under the auspices of FAO;

6. to develop a global information system on available crop genetic resources; and

7. to promote greater financial support and security to conservation work.

To assist in the implementation of the provisions of the international undertaking on plant genetic resources, FAO has also established a Commission on Plant Genetic Resources. This Commission, whose membership is open to all member nations and associate members of FAO, will monitor the operation and arrangements for the implementation of the international undertaking and take or recommend measures that are necessary or desirable to ensure the comprehensiveness of the global system of conservation.

As mentioned earlier, these initiatives on the part of FAO had their genesis in the growing apprehension among several developing countries that the introduction of plant breeders' rights and crop variety patenting may hinder the availability of useful genetic material to developing countries (Barton, 1982; Mooney, 1983). Under a convention signed by several countries in Europe, the breeders of a new plant variety will be eligible for royalty for at least 18 years in the case of trees and vines, and at least 15 years for all other plants. This convention is administered by the International Union for the Protection of new Varieties of Plants (UPOV) which is an inter-governmental organisation. The UPOV Convention of Plants was signed in Paris on December 2, 1961, and amended by an additional Act signed in Geneva on November 10, 1978. The objective of the convention is the protection of plant patent rights (Swaminathan, 1983).

A new plant variety for the purpose of patent rights must be clearly distinguishable by one or more important characteristics from any other variety whose existence is known at the time protection is applied for. Distinctions from existing varieties, homogeneity and stability are important for recognition.

The major aim of legislation relating to Plant Breeders' Rights (PBR) is to provide stimulus to private sector breeding and investment. Various views have been expressed on the positive and negative implications of PBR legislation (Brown, 1983; IBPGR, 1983). According to IBPGR, the issue of PBR in relation to genetic resources is of no great significance. What is urgently needed is greater effort in the collection and conservation of the basic sources of variation in wild and weedy species and primitive cultivars to prevent genetic erosion. However, IBPGR has also warned that "consent for the transfer of material under development may be more difficult to obtain than hitherto."

The importance of access to wild species and strains of rice for introducing genes for resistance to pests of commercial importance will be clear from the following recent experiments in rice :

1. Novel sources of resistance/tolerance to insect pests and viral diseases as a result of screening wild rices in the Entomology and Plant Pathology departments of the International Rice Research Institute (IRRI) are listed in Table 5. The only source of resistance to date to whorl maggot, *Hydrella philippina*, have been found in a wild species (Heinrichs et al., 1985).

TABLE 5. USEFUL TRAITS OF WILD SPECIES OF *Oryza*

Wild species	Chromosome number	Genome	Useful traits
O. perennis	24	AA	Tolerance to stagnant flooding and acid sulphate soil
O. nivara	24	AA	Resistance to grassy stunt virus and blast
O. sativa var. *fatua*	24	AA	Tolerance to cold temperature and acid sulphate soil
O. longistaminata	24	AA	Floral characters for out pollination Resistance to stem borer
O. barthii	24	AA	Resistance to bacterial leaf blight
O. officinalis	24	CC	Resistance to BPH, WBPH, and GLH
G. eichingeri	24,48	CC BBCC	Resistance to BPH, WBPH, and GLH
O. minuta	48	BBCC	Resistance to BPH, WBPH and GLH
O. latifolia	48	CCDD	Resistance to GLH, Sturdy stem
O. australiensis	24	EE	Resistance to BPH and drought
O. brachyantha	24	FF	Resistance to stem borer
Porteresia coarctatum	48	—	Tolerance to salinity

2. Resistance to biotype 2 of the grassy stunt virus has only been found in a perennial rice accession, Guan-ken *A/O. rufipogon/O. longistaminata* (Agwero et al., 1984).

3. Hill rice *Mijingem* from Bangladesh has more xylem vessels in its roots and is thus better able to withstand short drought periods than lowland cultivars with fewer xylem vessels (IRRI, 1986).

4. An insect pest of increasing significance in south and southeast Asia is the leaf-folder, *Cnaphalocrosis medinalis*. The primary sources of resistance to this pest are found in traditional varieties. The resistant traditional varieties, Muthumanikam and Yakadayan from Sri Lanka and Gora and Kalachikon from Cox's Bazaar district, Bangladesh were collected by IRRI field collectors.

It is, therefore, obvious that we have to take steps to preserve for current and future use a full spectrum of germplasm in all economic plants. Also, today's needs may be very different from those of the plant breeders in the 21st century, because of changing food habits and processing methods on the one hand, and projected climatic changes on the other.

In situ conservation through biosphere reserves and national parks is important not only for conserving biological diversity but also for preserving the ecological conditions under which variability is generated and maintained. However, *ex situ* methods of conservation are becoming even more urgent because of the widespread destruction of natural ecosystems. Recently Plucknett et al., (1987) have described the steps taken in recent years to establish gene banks for *ex situ* conservation. Such gene banks aim to maintain a representative sample of gene pools originating from different sources (Figure 1).

The existing gene banks fall under 3 major categories :

(1) Nationally organised, supported and controlled gene banks in developed and developing countries. Some of the largest collections under this category are at Leningrad in the USSR and in Fort Collins (National Seed Storage Laboratory) in the USA. In recent years, IBPGR and bilateral donors have supported the establishment of long-term seed storage facilities in developing countries. A gene bank where over 400,000 seed samples can be preserved for long-term conservation has recently been established by the Chinese Academy of Agricultural Science at Beijing with support from the Rockefeller Foundation and IRRI.

(2) Regional gene banks like the Nordic gene bank at Lund in Sweden and the Mediterranean gene bank at Bari in Italy.

(3) Gene banks maintained by international agricultural research centers (IARCs). These have become very important sources of availability of genetic variability because IARCs not only conserve germplasm but more importantly screen and describe the important genes contained in the collection. Nigel Smith (1987) has given information on the existing collections in IARCs (Table 6).

The use of land races in breeding new varieties is increasing and modern varieties represent the re-emergence of land races in new and novel combinations. They thus help to preserve valuable genes.

Figure 2 shows how modern varieties involve pyramiding of genes from a large number of primitive cultivars. The International Rice Germplasm Center at IRRI now has over 80,000 accessions consisting of *O. sativa* accessions (72,550), *O. glaberrima* strains (2,983), genetic testers and mutants (695) and populations of wild species (2,268).

IRRI also maintains all the wild species of *Oryza*, several of which have very useful traits which are now being transferred to the cultivated rice with the help of tissue culture and genetic engineering technology (Table 5). IRRI considers its germplasm centre as a public resource and hence makes seeds from the collection available free of cost to scientists all over the world.

TABLE 6. INTERNATIONAL AGRICULTURAL RESEARCH CENTERS WITH MAJOR CROP GERMPLASM COLLECTIONS WITHIN THE CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

Centre	Crop Genebank	Samples
International Rice Research Institute (IRRI)	Rice*	78,800
Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT)	Wheat	31,144
	Maize	11,100
	Barley	5,569
Centro Internacional de Agricultura Tropical (CIAT)	Common bean* (*Phaseolus vulgaris*)	30,790
	Lima bean* (*P. lunatus*)	2,527
	Runner bean* (*P. coccineus*)	1,179
	Cassava*	3,700
Centro Internacional de la Papa (CIP)	Potato*	6,500
International Institute of Tropical Agriculture (IITA)	Rice*	6,500
	African rice (*Oryza glaberrima*)	2,000
	Cowpea*	12,000
	Soybean	1,359
	Bambara groundnut (*Vigna subterranea*)	1,200
	Cassava	1,829
	Sweet potato	1,000
International Center for Agricultural Research in the Dry Areas (ICARDA)	Wheat	16,596
	Barley	14,215
	Lentil	5,906
	Chickpea	5,585
	Faba bean	3,293
	Pea	3,058
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	Sorghum*	24,600
	Pearl millet*	16,985
	Finger millet*	1,863
	Foxtail millet*	1,260
	Chickpea*	13,819
	Peanut*	11,448
	Pigeonpea*	10,104

*Base collection designated by the International Board for Plant Genetic Resources, Rome. Base collections, of which there may be more than one per crop, are major genebanks containing a large proportion of the genetic variability of the crop.

IMPLICATIONS OF THE TRANSITION FROM MENDELIAN TO MOLECULAR TECHNIQUES

Following the development of recombinant DNA technology, existing genetic resources could be used to a greater extent than is presently possible. Firstly, it will become possible to introduce specific genes into a target plant without causing large-scale disruptions in the existing selected and adapted genome. Secondly, it will greatly extend the horizons of sources of genes for transfer into any particular target species, extending this horizon beyond the current perimeter defined by the barriers of sexual hybridisation procedures. In this respect, existing genetic resources may be stored as seeds or tissues for subsequent DNA extraction, or as DNA libraries.

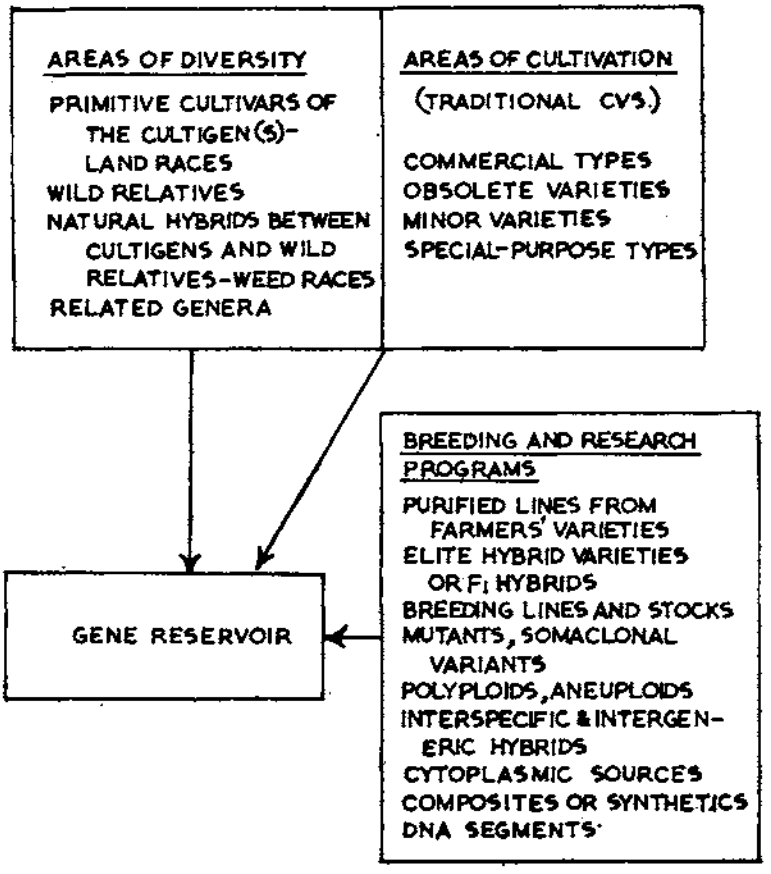

Fig. 1. The full spectrum of germplasm in a crop species (cultigen) and its sources.

A number of gene transfer systems are being developed in plants with varying degrees of success. The first proven DNA method for introducing genes into plants involves the Crown Gall tumor-inducing bacterium, *Agrobacterium tumefaciens*, which provides a natural vector system for 'foreign' DNA, inserted into the T-DNA segment of the bacterium's plasmid. Recently, alien genes have been introduced into cells of both monocotyledonous and dicotyledonous plants and stable transformation has occurred in many dicotyledonous species (Uchimiya et al., 1986; Spielmann and Simpson, 1986). Other established methods of DNA transfer include microinjection and electroporation.

The biggest limitation to the efficient exploitation of genetic resources through recombinant DNA techniqtes will be our inability to identify the appropriate gene to meet a particular challenge. Maintenance of a complete DNA library would allow gene transfer by a shotgun approach, followed by the selection of transformants possessing the required phenotype. This system would avoid the need

for precise molecular identification of the gene would be comparable to what a plant breeder does in his normal hybridisation-based plant breeding. Peacock (1984) considers that DNA libraries have no particular advantage over a seed 'gene library' because a seed is a collection of genes which is coordinated to a high degree. A DNA gene library, on the other hand, would present us with the total genetic information but not with coordinated information.

New opportunities for introducing *in vitro* methods of collecting germplasm in the field are also now becoming available (Withers, 1987). Peacock (1984), however, considers that an *in vitro*-based storage system for vegetatively propagated plants or for those with recalcitrant seeds is an extremely risky and expensive form of storage. In contrast, a seed gene library can safely perpetuate a range of genetic variation which will become increasingly available for incorporation into genes as our recombinant DNA methodologies become progressively more sophisticated.

Such transformation studies have also been successful with animals, an example being the transformation of mice with rat growth hormone genes using microinjection techniques (Parmiter et al., 1982). The insertion of donor DNA into one of the transposable sequences which are present in many *Drosophila* species has proved successful in achieving high levels of gene function in the right tissue.

DNA transfer techniques are not just limited to transfer of genetic resources between related species or genera. Fischoff et al. (1987) were able to determine the structure of the insect control protein gene from the bacterium *Bacillus thuringiensis* var. *kurstaki* HD-1. Truncated forms of the gene that express a functional insecticide protein were generated and successfully incorporated into tomato plants, using a plant expression vector for *Agrobacterium*-mediated transformation. Transgenic tomato plants were produced which expressed the insect control protein gene and were tolerant to the insect pest.

APPLICATION IN HUMAN BEINGS

The methods of DNA-mediated gene transfer will increasingly permit the introduction into cells of normally functioning genes to replace defective single genes. A DNA library of human genes can be envisaged for therapeutic purposes. In fact over 200 human genes have already been cloned, of which over 100 are associated with clinical diseases (Robinson, 1987).

Two types of gene therapy can be defined. Somatic therapy entails the production of defined genes *in vitro* and their introduction into the cells that require them, in a functional and normally regulated fashion. This is a form of replacement therapy that is in principle no different from all medical therapy. Germ-line therapy, on the other hand, requires the introduction of functional genes into gametes or fertilized eggs. When this approach becomes practical, it will produce genetic 'cures' which will be passed on to the offspring. This type of therapy may have to be closely regulated to prevent abuses (Robinson, 1987).

The greatest threats to the conservation of the genetic endowments of humankind come, on the one hand, from the potential now existing for the widespread deployment of nuclear weapons, and on the other, from evil minds like that of Hitler who exterminated millions of human beings for the sake of breeding a 'superior human race.' Scientists working for 'defence' establishments in perfecting biological methods of mass destruction of human life can also do immense harm. Our genetic heritage will be safe if human beings are left without genetic manipulation except for the provision of genetic counselling and gene therapy facilities where these will be helpful for enhancing the quality of human health and happiness.

LOOKING AHEAD : NEED FOR A GLOBAL GERMPLASM ETHIC

We can now develop an integrated conservation strategy ranging from *in situ* conservation of populations to conservation at the molecular level. Biosphere reserves and national parks are becoming important instruments for *in situ* conservation of biodiversity. The establishment of such biosphere reserves is particularly important in the main Vavilov centres of origin of crop plants. In November 1972, a Convention for the Protection of the World Cultural and Natural Heritage was adopted by the UNESCO General Conference. This convention provides the framework for international cooperation in conserving the world's outstanding natural gifts. IUCN (1982) has published an indicative

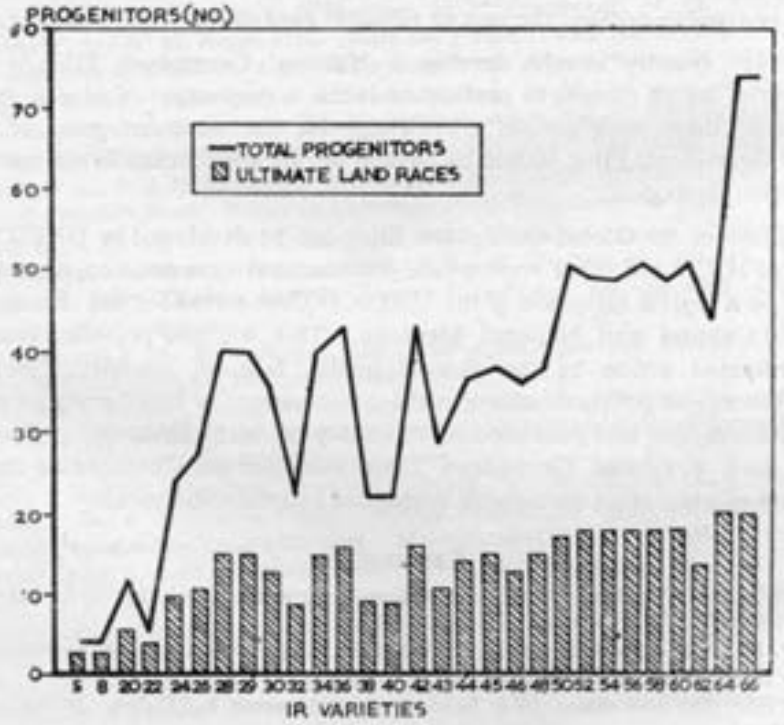

Fig. 2. Gene sources in IR varieties

inventory of natural sites of world heritage quality. The recent book 'Our World's Heritage' published by the National Geographic Society (1987) provides a glimpse of the glorious natural and equally glorious but occasionally horrible man-made heritage we possess.

Plant genetic conservation is unfortunately becoming an area of considerable controversy on the basis of ownership and patenting issues. While professionals and political leaders may quarrel, it is not surprising that in some of the world's less disturbed habitats indigenous tribal people as well as traditional farmers are practising a holistic germplasm ethic. Aldo (1966) whose birth centenary also falls this year proposed a land ethic for the protection of our land resources. What we need now is a similar global germplasm ethic for the conservation, and utilisation of genetic resources of economic plants and animals for the purpose of increasing human happiness and welfare everywhere.

A Global Germplasm Ethic should be based on the following foundations :

(a) Germplasm conservation should start with the inhabitants of each agro-ecological area. For example, tribal societies, indigenous people and forest dwellers should play a major role in the conservation of the biological endowments of the area where they live.

(b) Educational and research institutions in each area should take a lead role in generating public awareness and in developing effective monitoring and early warning systems to prevent the loss of valuable genetic material.

(c) Every country should develop a National Germplasm Ethic to provide opportunities for all citizens to participate in the conservation of genetic resources and sharing them with people everywhere for the common good of all. A National Germplasm Ethic should be backed up by appropriate *in situ* and *ex situ* conservation strategies.

Guidelines for the Global Germplasm Ethic can be developed by UNESCO with the help of IUCN and other appropriate international conservation organisations. This will be a logical extension of the UNESCO Convention for the Protection of the World Cultural and National Heritage. This will also provide a framework for coordinated action by the general public, farmers, scientists, development administrators and political leaders in the conservation of biodiversity so essential for the maintenance and enhancement of quality of life. Diversity is the essence of life. Such a Global Germplasm Ethic can, therefore, become an important instrument of promoting sustainable ecological and nutrition security.

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