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Genetic resources and plant breeding

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The need for genetic variability

Genetic variation is the starting point of plant breeding. Without it, no breeding progress would be possible.

Where do plant breeders find the genetic variability to work with? In most cases it comes from the diversity of cultivated varieties, or cultivars, which have evolved over the millennia in most crops to suit them to cultivation under a wide range of environments or agricultural systems.

Sometimes, plant breeders must go back to the wild ancestors of our cultivated plants to find the genetic building blocks needed to adapt future cultivars to new conditions or uses, or to enable them to give higher yields or better quality.

■ Collecting medic seed in Iraq.

How crops and crop variability evolved

All our crop and pasture plants developed from wild ancestors. Pre-agricutural man collected fruits and seeds from the most desirable of the wild plants and carried them wherever he went. This amounted to an unconscious process of selection towards plant types most useful to man, for example types with large or more easily harvested seeds, or with more palatable fruits. The process would have been in operation for hundreds of thousands, perhaps millions, of years before the beginning of deliberate cultivation.

With the advent of the neolithic revolution some 10,000 years ago, many of these plants were taken into agriculture. The rate of their evolution then quickened greatly. When selecting seed, tubers, cuttings, etc. for planting each successive new crop, man would wherever possible have chosen the most desirable types to propagate, because he already knew well that offspring tend to resemble their parents.

Nearly all plants intercross spontaneously, to varying extents, with their close relatives within the same species. Occasionally they cross with different but closely related species, and in certain combinations the offspring of such wider matings can be fertile.

Outcrossing to genetically different types creates great variability among the resulting progeny. Plant breeders now deliberately exploit this as a means of creating new combinations of the characteristics possessed by the parents, or occasionally, completely new characteristics. Even in the absence of deliberate breeding, natural crossing and the pressure of farmer selection in a primitive agriculture can bring about quite big changes over periods of centuries or millennia.

To the constant reassortment of existing plant characteristics allowed by natural crossing must be added a low rate of natural mutation, or "sporting". By this means, completely new characteristics can arise. If one or more of these occur at any time and happen to be of a type which is useful in agriculture, such as longer retention of the seeds in the heads at maturity, they can bring about dramatic changes in an evolving crop plant.

The modern development of lupins for cropping has been based on the selection and intercrossing of rare natural mutants selected from field populations of more primitive types, including mutants which are free of alkaloids, or which have non-shattering pods, permeable seed coats, earlier flowering and maturity, or flowers and seeds of colours which enable the crop types to be distinguished readily from their bitter ancestors. In selecting and inter-crossing these types, plant breeders have merely repeated in a short period what occurred much more slowly in our older established crop species some thousands of years ago.

The change from wild to crop plants has often been so great that the wild ancestors are unrecognisable as belonging to the same species. But although the superficial differences are large, the species have usually remained the same in their basic genetic apparatus. In most cases modern crop varieties can be crossed readily with their wild ancestors if the latter can be identified. Thus purely botanic and cytogenetic studies of the crop species and their relatives can be of great value to plant breeders.

The geography of crop plant variability

Agriculture evolved more or less independently in several parts of the world. Early agricultural communities exploited the plant species which occurred naturally in their own regions, or in neighbouring regions with which they had contact.

Thus, the early civilizations of the Near and Middle East were based on the cultivation of wheat and barley, both of which still occur there in wild forms. Various other species such as peas and the tares (vetches) of the Bible grew wild or as weeds in cultivated or fallow fields, and were later taken into cultivation as well.

The spread of agriculture based on wheat allowed other species to spread as weeds, and eventually to be selected for cultivation. Probable examples of this are oats and rye, both of which are native to Northern Europe.

Rice and soybeans evolved as crop plants in south-east Asia; sorghum and certain of the millets in Africa. The pre-Columbian civilizations of Central America were an independent source of what are now some of our most important crops and vegetables. These include maize, sunflowers, potatoes and sweet potatoes, tomatoes, various cucurbits, and several types of summer-growing beans.

Therefore each of our cultivated species has its own broadly defined region where it evolved as a crop plant, corresponding with the natural distribution of the parent species and the extent of the civilization or civilizations responsible for its domestication. These are what the great Russian botanist N. I. Vavilov (1887-1943), the father of the modern genetic resources concept, called the 'centres of origin'. The world's largest collection of plant genetic resources, at the N. I. Vavilov Institute in Leningrad, commemorates his pioneering efforts.

Not only may the old crop types and usually the parent species be found in these centres, but often there will be intermediate forms resulting from natural crossing between cultivated and wild types, which may persist as weeds or volunteers in a variety of situations.

Further factors influence the amount of genetic variation developed within each cultivated species. When plants are carried into different environments they usually must undergo natural evolution or deliberate selection to fit them to the new conditions. Therefore, the wider the spread of a species as a crop plant, the wider becomes its range of genetic variation.

Isolation plays an important part. Where there is little movement or trade in agricultural seeds, communities over the centuries have tended to evolve varieties with a high degree of adaptation to their local conditions. Such isolation is particularly marked in mountainous regions. With agriculture often confined to valleys with little or no communication among them, and with conditions in the individual valleys differing greatly according to their attitude and rainfall, or to the availability of water for irrigation, the diversity of adapted plant types has become very great. The nature of the terrain also affords protection against excessive cropping and grazing. Therefore isolated mountainous areas are usually the richest sources of genetic variation. This can apply whether or not they lie within a species' 'centre of origin'.

Effects of modern plant breeding and commerce

The situation described existed with little change up to the late 18th Century. However, the twin developments of modern plant breeding and of the commercial seed trade over the last two centuries have resulted in profound and accelerating effects on the world's stock of variation in its crop and pasture plants.

Breeders have been able to produce varieties which are more responsive to fertilisers, irrigation, better weed control, and other improved forms of management. For some highly developed agricultures, natural resistances to diseases and pests have become less important because of the availability of chemical treatments, so that breeders have been able to concentrate on yield and other characteristics important in commerce.

Most importantly, with improved communications and the rapidly spreading commercialisation of agriculture in all parts of the world, cultivation of the new 'high-yielding varieties' has been at the expense of the traditional local varieties. In many areas the latter are disappearing completely, unable to compete under the financial pressures of modern commercial agriculture.

To a degree the growing involvement of large transnational organisations in breeding and promoting new cultivars has hastened the process.

The need for genetic conservation

Plant breeders have long known of the dangers of the 'genetic erosion' that accompanies the loss of the old varieties, or land races as they are often known. Although often uncompetitive in modern agriculture, the land races are in many cases the only readily available sources of genetic factors (genes) for resistance to diseases, pests, and various adverse climatic or soil factors.

In the never ending race against the evolution of disease and pest organisms to overcome the resistances in plants, new and diversely-based genes for plant resistance are needed constantly. And as agriculture of necessity extends increasingly on to marginal land, so there is likely also to be a renewed need for plants naturally able to perform well under adverse agronomic conditions.

The problem of genetic erosion is greatest with the most highly developed crop species. The cultivars of these usually cannot survive at all in the wild or as volunteers, so that when the cultivation of a variety ceases, it is lost completely.

Pasture plants are less affected because they usually are able to persist in a weedy or semi-wild state. But even with these there is evidence of serious genetic erosion in the regions of origin. For instance, subterranean clover appears to have retreated substantially in Mediterranean and Western European countries under the pressure of increased cropping of old pasture land, and of fertilisation and replacement by 'improved' perennial species such as white clover. Similarly, the wild and semi-wild bitter lupins seem to be disappearing from many parts of their Mediterranean home.

Wholesale clearing of remaining undeveloped land throughout the world, particularly in the tropics, is also destroying the habitats of many plant species which are not yet economically exploited. In a time of rapidly changing technology, nobody can say which of these might have important roles to play in future.

The loss of plant species and varieties did not loom as a major problem in the early years of scientific plant breeding. Large reserves of genetic variation remained in the less developed regions which were still untouched by modern agricultural technology.

All that has changed. The population explosion and 'green revolution' of the last 20 years, together with increasing penetration by 'agri-business' into undeveloped as well as developed countries, has resulted in a rapid abandonment in nearly all parts of the world of the old in favour of the new high-yielding varieties.

It is a paradox that the very success of plant breeding is posing a threat to the basis of its future. Not only is the genetic base for future progress being lost, but the spread of single cultivars or closely related groups of cultivars over large areas has made cropping increasingly vulnerable to the breakdown of existing genes for disease and pest resistance.

The need for genetic conservation is now acute.

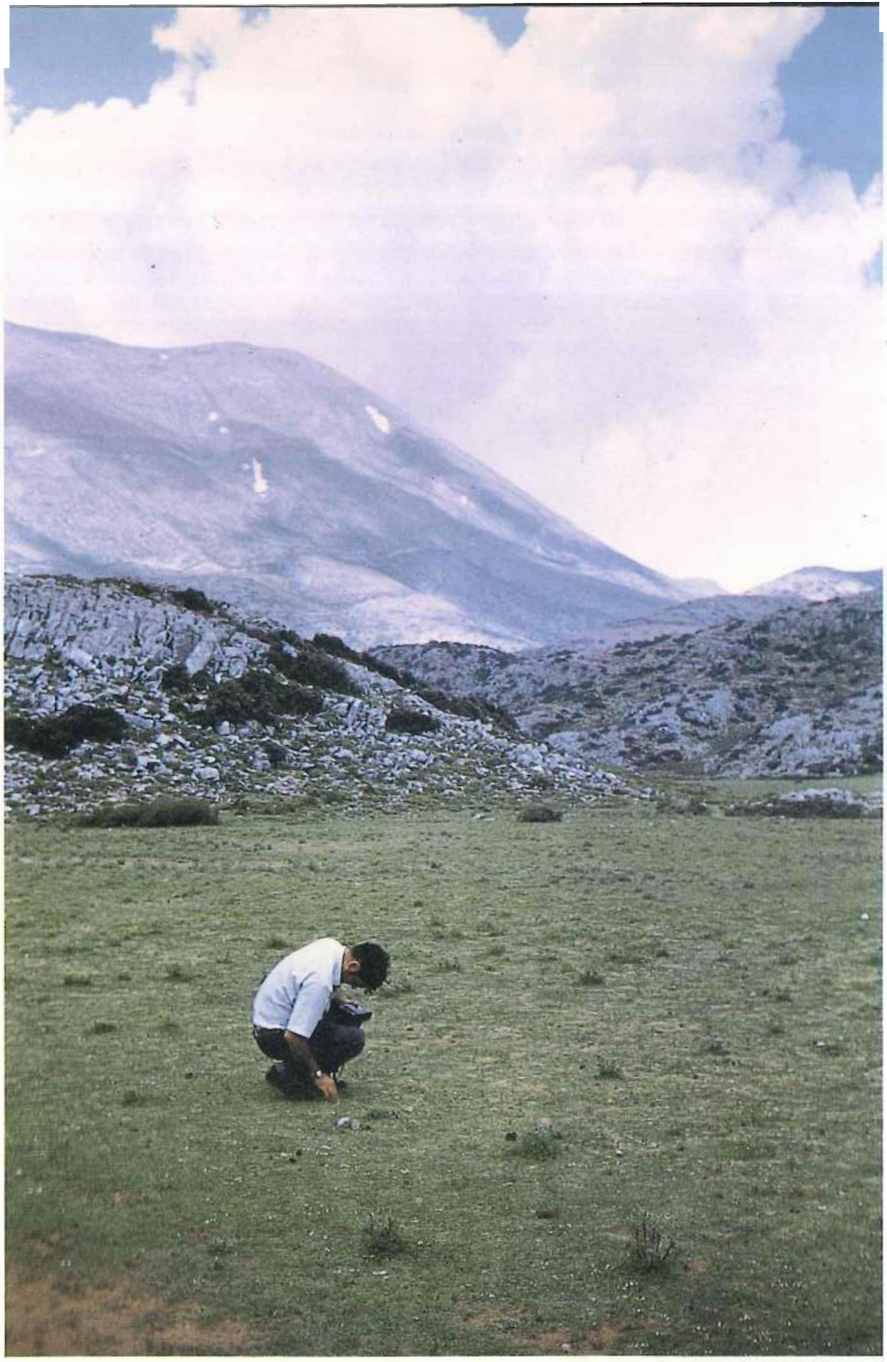
What is being done?

Following Vavilov's work in the 1920s and 1930s, researchers from a number of other countries—particularly the U.S.A.—became active in genetic collecting. However most of the early collections covered only a restricted range of the more important species. Many of the lines were inadequately studied and in some cases were lost later.

Major crops which came to be covered by international research institutes, such as wheat and rice, generally fared best. 'World collections' of these and some other crops eventually became established. These are centrally housed and maintained, and samples of all lines are available to other research bodies and plant breeders throughout the world. Australia maintains a national wheat collection at Tamworth, New South Wales, which directly services plant breeders in all States. It is financed by wheat industry funds.

Only in the last decade or so has there been general realisation of the extent of the genetic erosion problem.

The International Board for Plant Genetic Resources (IBPGR), which operates under the auspices of the Food and Agriculture Organisation of the United Nations, the World Bank and the United Nations Development Programme, is now developing a major programme to support and co-ordinate the collection, study and maintenance of seeds and other propagating



■ The late Dr J. S. Katznelson collecting sub. clover and medic seed in Crete.

materials throughout the world. The IBPGR has its major genetic resource centre at Bari, Italy, and co-ordinates the work of a series of other resource centres many of which are located in developing countries. Most of the developed countries have existing national programmes of their own, which co-operate among themselves and with the IBPGR to varying degrees.

Despite all the efforts to date, only a small proportion of the economic species or potential source regions have been adequately sampled. One of the problems in gaining support for the work has been the growing trend in developed countries for plant breeding to be done by commercial organisations. Understandably these are most concerned with work which will yield quick dividends, leaving genetic resources activities to public bodies whose budgets tend to be restricted.

Australia's role in genetic conservation

Australia is playing a major role in two areas.

The first is that of sub-tropical forage and pasture species, particularly legumes. This work is being done mainly in Queensland, and has entailed many collecting trips to nearly all sub-tropical countries of the world. The collections are maintained by the CSIRO Division of Tropical Pastures, Brisbane. Australia leads the world in this field, and the work is of major importance to many countries besides Australia.

The second area is that of temperate annual pasture legumes, another in which Australia (especially Western Australia and South Australia) is a world leader. Of the main species groups, South Australia has primary responsibilities for the annual medics, and Western Australia for subterranean clovers and the serradellas (*Ornithopus* species). Western Australia also maintains a substantial collection of wild lupins.

Western Australian plant researchers have been very active in recent years, both in collecting naturalised subterranean clovers and native saltbushes in Australia, and in collecting subterranean clover, serradellas, annual medics, lupins and saltbushes in various countries surrounding the Mediterranean. The main seed collecting trips by Western Australian scientists since 1960 are listed in Table 1.

There are now more than 5 000 distinct lines in the subterranean clover collection. The official collection is held at the Department of Agriculture, South Perth, but duplicates of most lines are held also at the University Field Station, Shenton Park. This is the only comprehensive collection of subterranean clovers in the world.

The strains are being sorted and studied progressively, and records kept for each of them of important characteristics such as number of days to flowering, contents of oestrogenic isoflavones, level of hard-seededness, winter vigour rating and resistance to clover scorch caused by the fungus *Kabatiella cautivora*, together with a wide range of visible distinguishing characters and details of the strains' origins.

The data are in the process of being computerised using the University of Colorado 'EXIR' programme. This sytem allows the strains to be sorted and listed according to any desired character of combination of characters. This greatly helps agronomists and plant breeders to identify strains which might be suitable for particular conditions or purposes.

The collections of other *Trifolium* species and yellow and slender serradellas and wild lupins held at the Department of Agriculture are smaller at present, but are the main collections in Australia, and for certain of the species may be the most comprehensive in the world.

MAJOR SEED COLLECTING TRIPS BY WESTERN AUSTRALIAN RESEARCHERS AND COLLABORATES, 1960-1981

Year	*Collector(s)*	*Countries*	*No of Collection sites*	*Main plants collected*
1960	A. J. Millington	Spain, Portugal	13	Sub. clover
1960-70	J. S. Gladstones *et. al.*	W. Australia	300	Sub. clover (naturalised)
1967	E. T. Bailey J. S. Katznelson	Turkey, Israel	500	Annual clovers, medics, grasses
1967	C. V. Malcolm	Algeria, Iraq, Iran, Israel, Tunisia, U.S.A.	330	Saltbushes salt-tolerant grasses, legumes
1968	J. S. Gladstones	S. Italy	105	Lupins, sub. clover, serradellas, medics
1973	J. S. Gladstones	Morocco, Tunisia, Spain, Portugal	438	Lupins, sub. clover, serradellas, annual medics
1973	C. V. Malcolm T. C. Swaan	W. Australia	150	Saltbushes
1974	C. M. Francis W. J. Collins J. S. Katznelson	Turkey	128	Annual clovers, medics
1975	C. M. Francis J. S. Katznelson	Greece, Crete	106	Annual clovers, medics
1975	B. J. Quinlivan C. Gomez A. Ramos	Spain	30	Sub. clover
1975	N. N. Roy	India	—	Rapeseed, mustards
1976	C. M. Francis C. Gomez	Spain, Portugal, Canary Is.	66	Sub. clover, lupins
1977	J. G. Paterson	W. Australia	250	Annual grasses (naturalised)
1977	J. S. Gladstones	N.E. Victoria	80	Sub. clover (nat.)
1977	C. M. Francis D. J. Gillespie	Sardinia, Hvar	163	Sub. clover, lupins, serradellas, annual medics
1978	J. S. Gladstones	Corsica, France, England	222	Sub. clover, lupins serradellas
1978	D. J. Gillespie	N. Italy, Corfu, Paros	25	Sub. clover, serradellas
1978	C. M. Francis M. Ewing M. Fituri	N.W. Libya	175	Annual medics
1979	C. M. Francis C. Gomez V. Moreno	Portugal, S.W. Spain, Madeira	168	Annual clovers, lupins, serradellas, annual medics
1980	C. M. Francis R. J. Parkin S. Al Kaisi	N. Iraq, Syria	127	Annual medics
1980	G. Gintzburger A. Hafid	Libya, Sardinia	60	Annual medics, medic rhizobia
1980	R. J. Parkin	Greece, Peleponesos, Is. Santorini	31	Annual clovers, medics

Some practical results to date

The collections by Western Australian scientists have contributed strongly to Australian agriculture already. Nungarin subterranean clover came from a cross between two locally naturalised strains collected in 1962. At least one further strain from the Western Australian collection is under consideration for direct commercial release in New South Wales.

Many crossbreds now under test come from crosses among the local strains and others collected later overseas. Some of the strains from Spain, Italy and Greece have been especially useful as new sources for breeding of resistance to Kabatiella, while Moroccan strains have been a source of hard-seededness. Certain of the midseason to late-maturing strains from Tunisia, France, Sardinia and Turkey are showing promise for possible future release in their own right.

A number of serradella lines collected in Morocco, Spain, Italy, Greece and Madeira have shown marked promise in early tests, both here and in New South Wales and Victoria, and are currently undergoing seed increase for larger-scale field trials. It is likely that one or more of them will eventually be released commercially.

Wild strains of the narrow-leafed lupin collected in Morocco, Spain, Portugal, Italy and Israel form the main basis for current Australian breeding of this species for improved yield and disease resistance. Several wild types from Spain, Italy and Morocco have been shown to carry useful degrees of resistance to *Phomopsis leptostromiformis*, the fungus responsible for periodic toxicity in lupin stubbles and lupinosis in stock grazing them. Cultivated-type derivatives from crosses with these lines are now undergoing initial field screening as a basis for selecting safer lupin cultivars for the future.

Also, several of the *Atriplex* (saltbush) species collected here and overseas have shown promise in tests for Western Australian grazing conditions.

Future developments

Australia-wide discussions have led to agreement in principle that primary responsibilities for maintenance of the Australian genetic resource collections be distributed among eight main centres, suitably located for the species concerned. Perth is to be the official centre for clovers and the serradellas. Unfortunately financial and organisational difficulties have so far prevented the scheme from coming into formal operation.

Nevertheless some progress has been made in Western Australia. We now have in operation at the Department of Agriculture a medium-term seed store which when fully developed will maintain storage conditions of approximately 5°C and 30 per cent relative humidity, and with enough space to store small to medium-sized seed samples of all lines in the genetic collections over the immediately foreseeable future.

These storage conditions allow seeds to be kept viable and free from insect attack for 10 to 50 years or more, depending on the species, several times longer than in the past.

Eventually, plant breeders hope that all genetic collections associated with the Department of Agriculture's plant breeding programmes can be computerised along lines similar to those now being developed for subterranean clover, including details of seed age, quantities, test germination percentages, and purposes for which samples have been withdrawn. Such a system, if it can be attained, will add greatly to the efficiency of the State's future crop and pasture improvement programmes.