PART VI

GLOBAL WARMING: IMPLICATIONS for BREEDING STRATEGY.

Introduction

Crop plants have been selected over a very long timescale of thousands of years, but the scientific bases of plant breeding and genetics are barely 90 years old. In that time, breeding has made great strides in using the available genetic resources to extend the ranges of many crops into adverse environments: hot or cold, dry or saline. It has provided the means to check, if not counter predations by pests and losses through disease. It has been possible, through breeding, to adapt and develop the useful properties of plants such as cooking quality in potatoes, feed quality of forage brassicas, baking quality in wheat and malting quality in barley. Although these achievements have been considerable, they have to be seen in perspective. Firstly, although strategic research into associated areas of biology such as genetics, biochemistry and pathology, has increased the precision and scope of breeding programmes, in most cases breeders do not manipulate individual genes and often do not have detailed knowledge of the genetic control of the characters they manipulate. This is inevitable because of the large number of genes expressed in the plant life cycle, one estimate is of 14,000 in soya bean. The situation is compounded by incomplete knowledge of plant metabolism e.g. the control of partitioning of dry matter or the influence of environmental stresses on amino acid metabolism (Stuart & Larker, 1980). Secondary metabolites that act at low concentrations can have complex roles such as nepetalactone, an insect antifeedant. Secondly, assuming that the genetic material that is required is available it can take from 12 - 20 years from making a cross between suitable parents to releasing a new variety. Thirdly, the genetic diversity within some of our important crop species, or at least in the cultivated material, is limited. Although it is possible to exploit sources of genetic variation such as germplasm collections from wild flora (e.g. rubber and coffee) or primitive agriculture (Simmonds, 1976; Asher, Thomas & Thomas, 1983; Giles, Ellis & Watson, 1981; Jennings, 1988) the introduction of the genetic material required for the enhanced expression of some attribute can present both technical and logistical problems. The logistical problems may include the necessary introduction of and subsequent selection against undesirable characters. The introduction to potato of genes from a wild species of *Solanum* to confer resistance to a pest may also introduce genes for high concentrations of alkaloids in the tubers or may re-introduce a daylength sensitivity for tuberization. Technical problems are presented in incompatibility of breeding systems, either through differing ploidy levels within a species (cultivated crops can differ from other plants in the same species in the sets of chromosomes carrying the basic genetic information) or from the more fundamental breeding barriers between genera, species and even varieties . Other technical problems relate to identifying not only the genes, but also the control sequences for expression of particular characters in order that genetic transfer will be effective.

The direct and indirect effects of global warming are likely to be far reaching for

agriculture. The effects of the expected changes will be complex, they cover the entire range of climatic variables. and it is clear from the discussion in Part I that significant changes in climate are likely to occur over the next few decades, a timescale which threatens to outpace development by traditional breeding methods. It is the rate of environmental change which harbours the most important implications for future breeding strategies.

The achievements and the limitations of plant breeding, show that breeding can have an important, central role in society's efforts to adjust to the environmental changes that are forseen. They also show that research and development are necessary if the sciences of genetics and breeding are to have the necessary tools to deal with the challenge. The purpose of this chapter then, is to consider only a few of the problems that will face breeders and to highlight some of the techniques that may help to solve these problems provided they are developed to an appropriate level.

It should be noted that a discussion paper on global warming submitted to the Plant & Soils Committee of the AFRC made no reference to plant breeding. That that was a vital ommission should become clear in this chapter.

VI.1 The Threat to Genetic Resources.

In the long term the effect of the activities of man and society that are leading to global warming will also have major effects on natural plant populations, potentially leading to rapid genetic erosion. This could be a most serious problem for plant breeding. Also, environmental changes will inevitably exert selection pressure on natural populations. Even a small temperature rise may have the potential to upset the balance between species in complex populations. Since 1974 a considerable effort has been made to organize collection and conservation of crop germplasm on an international scale (Lawrence, 1984). However, only a small proportion of the world's total plant species has been examined for their economic potential, and of these perhaps 6000 have been exploited in agriculture and industry (Simmonds, 1976). The degradation of tropical forests by over-exploitation is recognised as an important factor contributing to global warming. It is precisely these ecosystems which are least well understood and which constitute the largest reservoir of potential genetic resources.

It should be recognised that although the formation of "gene banks" or of collections of germplasm is a laudable aim and a worthy achievement, these can never be a substitute for the diversity in life-forms that occur naturally on this planet. For the species that are represented in such collections, the material is limited to include only the genetic and phenotypic diversity that has been recognised at present, and by definition it is stored in such a way as to minimise the opportunities for further mutation or re-combination of genes. For the species that are not represented in the collection, the position is even worse in that there is no protection whatever for the genetic material, and yet these species do include those that are adapted to severe environments, and to changing environments. They may also include others that are potentially useful for production of special substances e.g. drugs. Genetic resources are not renewable once lost and so, if they are to be used effectively and efficiently in the long-term, it will be important to maximise collecting strategies and the conservation of lifeforms. A final point to be noted is that gene banks require adequate support and maintenance. The predecessor to the current ICRISAT pigeon pea germ plasm collection was assembled under the Regional Pulse Improvement Project (RPIP) funded by USDA, India and Iran. When this ceased in 1970 the material was dispersed with the consequence that many of the accessions have died and are not adequately documented (Remanandan *et al.*, 1988).

The conclusion may seem a little out of place in a consideration of plant breeding in

agriculture, but it is an inescapable one that arises from a consideration of the resources available to the breeder. In all our attempts to adjust to an altering global climate and to feed an expanding population, efforts must be made to preserve natural communities with their diversity of species.

VI.2 Technology as an Aid to Plant Breeding.

Modern biotechnology is already being applied to assist plant breeders in their attempts efficiently to produce novel combinations of genetic material and in making selections. The phenomenon of global warming will present the breeder with a new set of challenges as new combinations of environmental conditions occur and he or she will, therefore, need to use all the available technology in order to meet these challenges. The techniques available range across a continuum fom tissue and cell culture through protoplast fusion to recombinant DNA (so-called "genetic engineering"). The techniques are often inter-dependent, so that subdivision into categories is artificial. However, each presents its own opportunities to the breeder, and each still requires further development either directly as in alternative vectors for gene transfer, or indirectly as with identification of the parts of a genome that will confer a particular character. The opportunities offered by new techniques have recently been usefully reviewed by Innes (1989) who also specified problems that must be solved before genetic engineering can be widely used by plant breeders. It is possible to apply some methods such as doubled haploids in barley or microtubers in potatoes to speed up the selection and multiplication stages. However, many important characters in otherwise well researched crops have not been analysed genetically, and their chromosome locations have not been mapped. The use of biochemical markers such as isozymes and, where developed, restriction fragment length polymorphisms (RFLP) to map important performance characters will allow selection to be much more precise.

VI.2.1 Tissue and Cell Culture.

Tissue and cell culture techniques are now used widely by plant breeders as aids in their programmes (Table VI.1, after Innes, 1989). The techniques are used in long-term storage

Table VI.1 **Cell and tissue culture as an aid to plant breeding.**

1. Genetic conservation.
2. Elimination of diseases and international exchange of germplasm.
3. Large scale speedy propagation.
4. Embryo rescue for difficult inter-specific and inter-generic crosses.
5. Protoplast fusion for difficult inter-specific and inter-generic crosses.
6. Novel characters from somaclonal variation.
7. Selection aids.
8. Haploid production from pollen or anther culture.

Anther and pollen culture can produce a high yield of haploid plantlets which, with chromosome doubling to produce doubled haploids, can give rise to completely homozygous individuals in a single generation. This is being used increasingly by breeders for a wide range of crops (Dunwell, 1985) so some of the characteristics that are desired in new varieties can be screened for in the resulting populations, e.g. the development of varieties of white mustard (*Sinapis alba*) and Indian mustard (*Brassica juncea*) to produce non-food industrial oil with a high content of erucic acid (Brune *et al.*, 1989). A second example using undifferentiated plant material is provided by a study recently funded by the E.C. to select peas resistant to herbicides. Hodgkin (1988) screened mature pollen to maintain increased resistance in *Brassica* to phytotoxic compounds from a fungal pathogen.

Somatic fusion offers the opportunity to transfer agronomically useful traits between plants with breeding barriers or incompatability mechanisms e.g. Serraf *et al.* (1989) transferred resistance to *Verticillium dahliae* from the wild species *Solanum kasianum* to the aubergine *Solanum melanogena*. Problems can still remain with hybrid sterility in the products of the process and in the regeneration of the normal plant from protoplasts (e.g. Jacobsen and Lehminger-Martens, 1989).

VI.2.2 Recombinant DNA Technology

Genetic transformation by non-conventional methods is strongly dependent upon the technology for tissue culture and also on the availability of suitable "vectors" to carry parts of a genome from one organism to another. Thus, in recent years the Ti plasmid of the bacterium *Agrobacterium tumefaciens* and the Ri plasmid of *A. rhizogens* have been used to transfer genes coding for resistance to antibodies and to herbicides. However, these bacteria will not infect all possible higher plants, and in particular they infect only a few monocotyledonous plants which include the cereals. There is evidence (Luo & Wu, 1988) of some success with more direct methods of transfer of DNA, but the techniques for moving DNA between organisms need further investigation and development.

Table VI.2 **Problems that require solution before genetic engineering can be widely used by plant breeders.**

1. Gene characterisation
2. Isolation of specific DNA sequences.
3. DNA cloning.
4. Transfer of DNA to more species.
5. Plant regeneration of more species especially temperate cereals.
6. Gene expression in the mature plant.
7. Sexual transmission of genetic traits.

Innes (1989) outlined the problems (Table VI.2) that need to be resolved before the technology of recombinant DNA can be a really useful tool for the plant breeder. Among the set of problems given, numbers 1,2 and 6 are particularly pertinent. Where a gene has been characterised for its effect and for the DNA sequence that comprises it, then that gene may be suitable for manipulation between organisms. It is becoming increasingly clear that proteins in the chromosomes of higher plants, play key roles in the regulation of genes; many genes seem to switched on by the formation of highly specific and very stable protein-DNA complexes. A study of how these transcriptional complexes work is required if there is to be an understanding of how previously inactive genes become active during the development of the plant (e.g. Thompson *et al.*, 1987).

Although the normal mechanisms of sexual reproduction allow genetic recombination in most higher organisms (they ensure that each individual is slightly different from its parents) there are other mechanisms of genetic recombination that are still poorly understood and that serve to rearrange the genome in "irregular" ways. One such mechanism is the action of transposable elements. These movable pieces of DNA were discovered in maize about 45 years ago, and have recently been found in a wide range of organisms from bacteria to man. These elements may offer a means of genetic manipulation and *A. tumefasciens* has been used with transposable elements to transfer sections of DNA from maize to tobacco (Baker *et al.*, 1986). However, the intensity of expression of the characters supposedly controlled by the transposable elements varies with the position of the element on the chromosomes of the donor plant as well as in the recipient (Fedoroff, 1986). This highlights the problems of gene-control that are associated with DNA recombination. A desirable gene must be set in the correct environment of other controlling genes. There is a great deal of work to be done before "genetic engineering" can become a regular aid to the breeder.

VI.3 Relations between Problems Outined in Parts II - V and the Contribution from Plant Breeding.

A primary difficulty for the breeder is that many of the most economically important characters are not under simple genetic control, but are polygenic in nature. This is almost certainly true of the genes controlling morphogenetic behaviour such as partitioning of dry matter, root growth etc. Here, RFLP could be particularly useful in identifying functional units of the genome and their action.

VI.3.1 Relations with Growth an Yield.

A major determinant of photosynthetic capacity (Section III.3 and Appendix D) is the activity of the enzyme Ribulose bi-phosphate carboxylose oxidase (RUBISCO). Seeman *et al.* (1986) observed differences in the activity of Rubisco within the species *Phaseolus vulgaris* which explained differences in photosynthetic performance from plant-to-plant, and which have been shown to be due to an inhibitor that binds to the Rubisco in place of the normal substrate. Identification of the inhibitor, then the gene responsible for it and the control sequence for that gene could be followed by selective removal of that part of the genome and that could allow enhanced photosynthetic performance to be achieved from the same amount of protein.

More complex problems will be presented by changes in partitioning between roots and shoots and between harvestable and non-harvestable parts under the influence of raised [CO_2] and temperature. Modifications to partitioning have been achieved in the past. Examples are the short-strawed or semi-dwarf wheats and rice. The principal physiological reason for improved yields was not the greater production of total dry matter, but in improved partitioning of that dry matter to the grain. Extension of this work to other species will require a better understanding of both the genome and the physiology of the plants.

Table VI.3

Recommended traits for grain sorghum and cowpea grown in order of priority in intermittent and terminal stress environments in modern agriculture (after Ludlow & Muchow, 1988)

	Intermittent stress	***Terminal stress***
1.	matching phenology to water supply	some
2.	osmotic adjustment in shoots and roots	some
3.	rooting depth and density	some
4.	developmental plasticity	increased leaf reflectance
5.	early vigour	some
6.	leaf area maintenance	re-mobilization of dry matter from pre-anthesis
7.	increased leaf reflectance	
8.	low lethal water status	

Adaptation to stress, principally water stress, is a probable requirement in the event of global warming. Physiologists can indicate the traits that they consider will increase grain production per unit of precipitation (Table VI.3) but the balance of costs and benefits of the adaptation require a modelling approach (Part VII). If breeders are to do better than select from random variation in these characters, then a better knowledge of the genetics of the crops will be required as most of the characters are almost certainly polygenic in origin.

VI.3.2 Breeding for Resistance to Pests and Diseases

As already described in the earlier chapters, the pressure from most pests and diseases will increase in the event of global warming, and so successful outcomes from breeding programmes against these hazards will be extremely important. All the modern biotechnology will be required to meet the challenge. Recombinant DNA techniques and protoplast fusion will be required to transfer resistance across species; alteration of ploidy levels will be

required to circumvent sterility barriers, and to allow effective selection in homozygous materials; tissue culture will permit extensive screening for some of the simpler characters, such as tolerance to pesticides or resistence to some diseases; and tissue culture followed by micropropagation will be required to shorten the generation times for new varieties, and to enhance the cost effectiveness of the breeder.

VI.4 Conclusions

1) The present levels of knowledge and expertise in tissue and cell culture and in recombination of DNA are sufficient to show the potential of these techniques to aid plant breeding and thereby to allow agriculture to adapt to a modified environment.

2) In order that future requirements for genetic material may be met it is important that collections of germplasm should be encouraged. Of necessity this must include the conservation of "wild" material which can only be done by safeguarding natural communities.

3) Knowledge of the genome of most crop species is scanty so that even with the best techniques for transference of genetic material, the problem remains - what to transfer? The genetical mapping and analysis of crop species should be encouraged.

4) Since many of the economically important characters are polygenic in origin, and since desirable characters may also bring penalties, it is important that there should be mathematical studies (Part VII) of the interactions between responses, so that the breeders may specify closely desired ideotypes before beginning breeding and selection.

5) The threat to yields and quality from improved conditions for pests and diseases coupled with an unsympathetic public attitude to chemical sprays, will make more urgent the breeding of resistant varieties.

6) Molecular biology provides an opportunity to improve our understanding of basic biological principles and pathways. These exciting new analytical tools could be particularly relevant to our response to global warming and they can be applied to populations of direct relevance to agriculture and to society.

7) For each of these several reasons, support should be provided for solution of the problems set out in Table VI.2. and for enhancement of the techniques indicated in Table VI.1.

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