PLANT BREEDING AND MOLECULAR FARMING

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Summary

Genetic engineering has had a profound impact on plant breeding because it is now possible to introduce genes into plants from any other organism. This is a new and powerful technology that cannot be considered a natural extension of traditional

breeding methods. Although the potential exists for developing plants that may be of benefit to humanity it is important to remember that genetic engineering methods are in their infancy. Two indicators of this fact are that genes cannot be directed to a selected site in the plant genome and the exact result of introduced genes is extremely variable and unpredictable. There is also a great deal of uncertainty about the impact of genetically engineered plants on other organisms in the agro-ecosystem, the broader environment and on human health. Although there is much scientific evidence indicating that we should be very cautions about the impact of genetically engineered plants, the regulatory systems for evaluating the risks are inadequate. Unless caution is employed with genetic engineering the natural biological systems that sustain us may be jeopardized. In addition to the effects on human health and the environment, genetically engineered plants may have a profound socioeconomic impact which, if left unchecked, could lead to a greater disparity between the rich and poor of the world.

1. Introduction

Since the earliest cultivation of plants by humankind some form of plant breeding has been practiced either consciously or unconsciously. Crop species developed from wild species as early farmers selected plants, fruits, and seeds with favorable characteristics such as flavor, and size of fruit and seeds. This process of selection over the millennia has led to the large variety of crop species available today. Modern plant breeding methods were developed after the rediscovery of Mendel's laws of genetics in 1900 (see Mendelian Genetics and its Development). These methods differ from the earlier selection methods because they involve the deliberate use of cross hybridization to combine genetic characteristics from different plants before selecting superior plants among the progeny. Many different breeding strategies have developed which differ according to whether the crop plants are naturally self-pollinating or cross-pollinating. Improvements to the yield and quality of crop plants made by traditional breeding methods generally result from new favorable combinations of genes derived from different genotypes within the species (see Traditional Plant Breeding for Yield Improvement and Pest Resistance).

With the development of biotechnology the introduction of genes to crop plants from other plant species and also from completely different organisms has become possible. There have been many proposals for using this technology for improving crop productivity and modifying plant products. These include the concept of molecular farming by which plants are genetically engineered to produce high value products such as pharmaceuticals or oils to be harvested and purified for commercial use. Some examples of genetically engineered crops include: crops which have genes for herbicide resistance (see Crop Protection through Pest Resistance Genes) which allow the crop to survive treatment with a specific herbicide while the weeds in the crop are killed; crops which synthesize proteins which are toxic to insects to prevent crop damage by insect attack; and crops which produce oils which are not naturally found in that crop species.

The development of genetically engineered plants (see Genetic Engineering of Plant Cells) poses serious potential risks as well as perceived benefits. The risks include the escape of artificial genes from crops to weed species or to other organisms such as bacteria. The escape of herbicide or insect resistance genes to weed species could create exceptionally aggressive or vigorous weeds and the transfer of antibiotic resistance genes to bacteria will provide more opportunities for the evolution of bacterial strains with resistance to all known antibiotics (see Biotechnology in the Environment: Potential Effects on Biodiversity). The impact of genetically engineered crops on biodiversity and other organisms in natural and agricultural ecosystems is largely unknown but potentially harmful (see Biotechnology and Agro-Biodiversity). Additionally, the risks to human health of ingesting new proteins which have not had a long history of safe consumption is largely unknown and there are no guaranteed procedures in place to evaluate the long-term impact of these proteins on the development of allergies or diseases (see Health and Genetic Engineering). Finally, the social impact of this new technology must be considered because there is a danger that this new technology may be of benefit to the more affluent, and yet a hazard to the disadvantaged (see Genetic Engineering Causes Concern: Social, Cultural and Political Impacts).

This is a new and powerful technology that requires extreme caution and thorough evaluation of both the environmental and social impact. Unlike the development of agricultural chemicals or many other technologies, genetically engineered plants are living, replicating organisms that once released cannot simply be recalled.

2. Traditional Plant Breeding

Plant breeding has been practiced since the beginning of plant cultivation by humankind. Early in the development of crop species, characteristics such as large fruit and seed size, resistance to seed or fruit drop, reduced woodiness or spininess, enhanced flavor, reduced dormancy, and visual attractiveness were selected both consciously and unconsciously by gardeners and farmers who chose the most favorable plants for consumption and propagation. This process of selection within the natural gene pool has produced the enormous variety of crop species available today. Most crops now bear little resemblance to the wild species they originated from, and it is clear that the vast majority of genetic improvement in crop plants has been made over the millennia prior to the modern plant-breeding era.

The rediscovery of Mendel's laws of genetics (see Mendelian Genetics and its Development) in 1900 were the catalyst for the development of modern plant breeding which is based on deliberate cross-pollination (hybridization) of plants with differing characteristics followed by deliberate selection of those progeny that have inherited the desirable characteristics from both parents. There are many different breeding strategies which differ according to whether the crop is naturally self-pollinated or cross pollinated and differ with respect to factors such the number of parents used and the generations at which selections are made. However the common feature of practically all modern plant breeding is that it is based on a system of hybridization followed by selection to produce a new cultivar or plant variety which is in some way superior to previous existing cultivars.

The purpose of most plant breeding programs is to improve either or both the yield and quality of a particular crop. Yield may be improved by increasing the total biomass of the plant or selecting for plants that partition a greater proportion of the biomass to the harvested portion of the plant. Other factors that may contribute to yield improvement include resistance to pests and diseases, tolerance to adverse environmental factors and improved seasonal adaptation (see Traditional Plant Breeding for Yield Improvement and Pest Resistance). Quality attributes include parameters such as grain protein composition, milling quality, starch, sugar and oil composition, fiber strength, digestibility, nutritional value, fruit color, shape and flavor.

Many of the major crops including wheat, rice, barley, soybean and cotton are self-pollinated. This allows new inbred cultivars to be produced by selecting one superior genotype from within a population and propagating seed from this individual to produce a genetically uniform cultivar. Because of this genetic uniformity the crop is uniform for characteristics such as height, product quality and time of maturity, which is advantageous in an industrial system of agriculture. However the disadvantage is that the crop is more vulnerable to environmental pressures. For example, a disease organism capable of infecting one plant will be capable of infecting the entire crop.

Other crops such as maize, sorghum, and many vegetable and forage species are cross-pollinated species in which cultivars are composed of a population of individual plants that are genetically related but not identical. These crops have more resilience to disease and environmental factors but lack the uniformity of self-pollinated crops. Cultivars of many perennial cross pollinated crops, including many fruit and forest tree species, are made genetically uniform by selecting and propagating a single superior plant.

Many cross-pollinated crops have been modified to produce hybrid cultivars that are genetically uniform and often high yielding. Seeds for hybrids are produced by using one highly inbred genotype to pollinate a different highly inbred genotype. All plants within the hybrid cultivar are genetically uniform but unlike self-pollinated cultivars, they cannot truly breed so that plants grown from the seed of hybrid crops do not resemble the original crop. Farmers who choose to grow hybrid cultivars must plant newly purchased seed for each crop whereas it is possible to use farm-saved-seed for most self-pollinated and cross-pollinated crops.

Over the latter half or the twentieth century it has been estimated that for many crops, including wheat, maize and soybean, the yields per hectare have doubled because of improvements in plant breeding and agronomic practices and that at least 50% of the yield improvements are attributable to genetic improvements. There are also many examples of improvements in crop quality, including successful selection for improved malting quality in barley, selection for high protein content and improved baking quality in wheat, and improved nutritional quality in grain and forage legumes. Developments in plant breeding and agronomy in the 1960s, led by the Nobel laureate Norman Borlaug, resulted in green revolution in which semi-dwarf and hybrid cultivars, in combination with the application of soluble nitrogenous fertilizers, produced substantial yield increases in many areas of the world. There has been much debate about the actual benefits of the green revolution technologies and although increased production has been achieved in many areas, this has been accompanied by substantial losses of crop genetic diversity and displacement of many poor subsistence farmers who could not afford to purchase seed and fertilizer inputs.

The improvements that continue to be made to crop plants by conventional hybridization and selection techniques are generally due to new favorable combinations of genes derived from different genotypes within a particular crop species. However it is also possible to introduce genes into crops from different plant species, and in recent years genes from entirely different organisms have been introduced into crop plants (see Genetics and Molecular Biology).

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Biographical Sketch

Philip Davies graduated with First Class Honors in Agricultural Science from the University of Adelaide in 1984 and received a PhD in genetics from the Australian National University in 1989. His academic interest has been in the application of genetics and cell culture to crop improvement. Since 1984 he has held positions in Australian universities and government research organizations. He has conducted studies in the fields of cell culture, protoplast fusion, genetic transformation, somaclonal variation, cytogenetics and doubled haploid production. His current work involves the application of doubled haploid technology to cereal breeding programs.