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FROM THE GREEN REVOLUTION TO THE GENE REVOLUTION

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ABSTRACT

Crop improvements have been one of the most important human endeavors in history, for a very good reason - survival. Initially such improvements were achieved by repeated selections for quantity and quality of food as guided by experience only. Further advancement was made by our forefathers who recognized that both animals and plants could be selected and crossed to reproduce and upgrade species. The knowledge of genetics guided the development of the breeding program from its infancy to maturity, eventually leading it into the era of the green revolution and gene revolution. The inital breeding program was based on the principles of genetics. By classical manipulation of chromosomes, many new varieties or species of important crops were created through hybridization, pure line selections and mutations. The contribution of the breeding techniques reached their peak in improving crop productivity in the 1960's. The achievements were so dramatic, it is referred to as the green revolution. These operations have limitations such as sexual incompatibility. To overcome these limitations the tissue culture techniques were developed in the 1950's. This led to the development of protoplast fusion in the 1970's. The contributions made by these new technologies have been enormous and more importantly they paved the way for the current advancement of biotechnology. The application of biotechnology to crop improvement ushers us into a new era of the gene revolution.

INTRODUCTION

In China, one of the most widely circulated sayings is "Agriculture is the foundation of the country and food is the top priority for the people". This signifies the importance of agriculture in our daily life. In history, the elevation of the living standard of farmers, in most cases, was always coupled with the technical advancement associated with agriculture. Thus, it is understandable that crop improvements have been one of the most important human endeavors, for a very good reason - survival. Initially such improvements were achieved by repeated selections for quantity and quality of food as guided by experience only. Further advancement was made by our forefathers who recognized that both animals and plants could be selected and crossed to reproduce and upgrade species. The knowledge of genetics has guided the development of the breeding program since its infancy, eventually leading it into the era of the green revolution and gene revolution.

The initial breeding program was based on the principles of genetics. By classical manipulation of chromosomes, many new varieties or species of important crops were produced through hybridization, pure line selections and mutations. The contribution of the breeding techniques reached their peak in improving crop productivity in the 1960s. The achievements were so dramatic, they were referred to as the "Green Revolution". These approaches have limitations such as sexual incompatibility. To overcome these limitations the tissue culture techniques were developed in the 1950s. This led to the development of protoplast fusion in the 1970s. The contributions made by these new technologies have been enormous and more importantly they paved the way for the current advancement of biotechnology. The current advancement and application of biotechnology to crop improvement ushers us into a new era of the gene revolution. To date we have produced more than 35 transgenic plants.

PLANT BREEDING AND GREEN REVOLUTION

Plant breeding strategies vary according mainly to the mode of pollination of the crop. A description of these strategies is presented below.

Pure-Line Selection

Most of the wild relatives of modern crop plants show considerable variability for many traits. Pure-line selection involves selection from the extremes for the phenotype desired. In genetic terms, a selected and inbred population is more homozygous than its wild relatives. Pure-line selection generally involves three distinct steps. In the first step a large number of selections are made from the genetically variable original population. In general, the number of initial selections should be as great as consideration of time, expense, space and competitive plant breeding projects will permit. The second step consists of growing progeny rows from the individual plant selections for observational purposes. After obvious elimination, the selections are grown over a shorter or longer period of years to permit the observations of performance under different environmental conditions for making further eliminations. The final stage starts when the breeder can no longer decide among lines on the basis of observation alone and he/she must turn to replicated traits to compare the remaining selections with each other and with established commercial varieties in relative yielding ability and other aspects of performance. This stage of evaluation lasts at least three years. If a large number instead of a single pure-line is likely to be retained such procedure is usually referred to as mass selection.

One of the most important features of pure-lines is the great precision with which they produce themselves. Associated with this are some potential problems in unmasking some harmful genes as well as eliminating some desirable genes.

Hybridization

In contrast to pure-line selection, the most frequently employed plant breeding technique is hybridization. Hybridization demonstrated that crops such as maize could be inbred for six or seven generations until finally there was no further reduction in vigor and size. Thus they become highly inbred varieties. When these highly inbred plants were hybridized with other inbred varieties, very vigorous, large-sized, large fruited plants were produced. This led to the origin of hybrid maize and resulted in the most significant in American agriculture at that time. The term "heterosis" was used to describe this phenomenon.

The first step in hybrid production is to generate homozygous inbred lines. This is normally done by means of self-pollinating plants where pollen from male flowers fertilizes female flowers on the same plants. Once the pure lines are generated they are outcrossed. A problem with such hybridization is that the farmer must buy new hybrid seed crops each year, and cannot use part of his own crop as seed for the following year.

Another useful breeding technique is backcrossing. Backcrossing makes it possible to transfer specific genes from one plant variety to another. In this way, desirable characteristics of one variety can be combined with those of another variety. This trick circumvents the problem of trying to select simultaneously for many traits in the same variety.

Mutations

Instead of relying on the introduction of genetic variability from the wild species gene pool, mutations induced either by chemicals or radiation is another alternative. The mutant obtained will be tested and selected further to meet standards of an established cultivar, or used as a donor in a crossing program. This method is applicable for both modes of pollination. By and large, this method has not been used widely in breeding programs.

Green Revolution

The success in using the principles of plant breeding and agricultural practices to improve crops reached the peak when high-yielding wheat and rice strains were cultivated in the 1960s. The doubling or tripling of productivity of these important crops in Asia signaled a new agricultural revolution in the developing countries. This breakthrough in food production was termed the "Green Revolution" to describe the social, economic and nutritional impact of the new high-yielding wheat and rice strains. Dr. Norman Porlaug was awarded the Nobel Peace Prize in 1970 for his role in the breeding of new high-yielding strains of wheat. Since that time the Green Revolution has been both praised and damned. In the 1960s, as use of the new strains spread rapidly in Asia, claims were made that many underdeveloped countries would soon be self-sufficient of cereal grains. These new high-yielding strains were highly responsive to fertilizer and irrigation; both required energy intensive investments. Thus, in the early 1970s, poor weather, high energy costs and global economic constraints slowed the progress of the revolution considerably. The Green Revolution, as many other scientific advancements have made impacts as well as have been associated with limitations.

TISSUE CULTURE, PROTOPLAST FUSION AND SOMACLONAL VARIATIONS

Tissue Culture

In contrast to animal cells, plant cells are totipotent, each living cell is capable of regenerating into an entire plant identical to the one from which the living cell was obtained. The term "tissue culture" was used to describe any type in vitro culture of plant parts; callus, organ, embryo, anther, cell suspension, protoplast and many others. It was developed in the 1950s. Tissue culture techniques proved to be more valuable in commercial mass production of uniform progenies than in crop improvements. There are exceptions. One of the outstanding examples are the new tobacco cultivars produced by anther culture.

Protoplast Fusion

Protoplasts are plant cells without cell walls. Because of this property they can be studied as a single cellular entity like a microorganism. The isolated protoplasts can be used for fusion, DNA uptake, to study cell walls and other investigations. In 1972, the first parasexual hybrid of tobacco was produced by protoplast fusion. This was followed by the fusion of cells from potato and tomato to create the novel "pomato". Nevertheless, no new crop with the desired agronomic traits has been produced by protoplast fusion to date.

Somaclonal Variation

One of the properties of tissue culture is that the progenies produced by this technique are highly variable. This induced variability is termed somaclonal variation and is frequently used as a means to generate mutations. Such variability includes chromosome number changes, chromosome structure rearrangement, DNA amplification and deamplification, rearrangement and mobilization, single gene mutation and alteration of gene expression. By using this approach, for example, herbicide resistant mutants were selected. It was estimated that in vitro tissue culture produced ten times more somaclonal variation than can be induced by chemical treatments. Thus, it serves as a reliable approach to induce mutations.

BIOTECHNOLOGY AND THE GENE REVOLUTION

Biotechnology offers new ideas and techniques applicable to agriculture. It is the use of technologies based on living systems to develop commercial processes and products. Because of the rapid development of this technology agriculture has moved from a source-based to a science-based industry. For example, plant breeding has been dramatically broadened by the introduction of genetic engineering techniques based on knowledge about plant structure and function. In 1982 direct gene transfers became possible using recombinant DNA technologies. The newly acquired ability to transfer genes among organisms without sexual crossing provides breeders new opportunities to improve the efficiency of production and to increase the utility of our agricultural crops. Plants with new traits such as herbicide resistance have been genetically engineered using genes from unrelated organisms. Scientists are also trying to improve the quality of our agricultural products by altering the nutritional value of proteins and oils. However, it should be emphasized that the biotechnology is not a substitute or replacement of the traditional breeding methods Rather, it can improve on past, traditional methods. The major differences between traditional breeding and biotechnology lie neither in goals nor processes, but rather in speed precision, reliability and scope.

By using the recombinant DNA technology many transgenic organisms have been engineered since 1985. Table 1 lists nearly 30 transgenic plants produced to date. The list is growing rapidly because the technology for inserting and expressing genes in plants is in hand, and more and more genes are being identified, together with the traits they control.

The majority of plant biotechnology research thus far has focused on developing plants that reduce losses caused by insects and diseases, resist frost damage, and tolerate certain herbicides. Insect resistance research has centered on inserting a gene into plants or bacteria obtained from the bacteria *Bacillus thuringiensis* (BT). The gene produces a toxin that is fatal to insects. Efforts have concentrated on the use of BT because it has been used commercially in agriculture for 25 years and dissipates rapidly in the environment.

Herbicide resistance research has focused on developing tomato and tobacco cultivars that are resistant to herbicides such as glyphosate (Roundup Brand-name, Monsanto, St. Louis, MO). Environmental groups have expressed concern about the benefits from this research since it is not clear whether it will lead to increased or decreased use of herbicides. The commercialization of these plant technologies may be 5 to 10 years away as a result of economic incentives, environmental regulations. and public acceptance. For example, a major economic consideration will be whether or not the cultivars produce fruit that meet the standards of the processors.

Table 1. Transgenic Plants Produced

Monocotyledonous plants	
Asparagus	Millet
Corn	Rice
Dicotyledonous plants	
Legumes	Special crop
Alfalfa	Cotton
Clover	Flax
Peas	Lotus
Soybean	Sugarbeet
	Sunflower
Solanaceae	Woodyplants
Eggplant	
Petunia	
Potato	Pear
Tobacco	Poplar
Tomato	Walnut
Vegetable crop	Special plant
Cabbage	Arabidopsis
Carrot	
Celery	
Cucumber	
Lettuce	
Rape	

Plant technologies that involve multigenic traits such as nitrogen fixation and stress tolerance are even further away. Researchers are concerned because plants that are engineered to produce nitrogen may use so much energy in doing so that yields may fall dramatically. Much more needs to be learned about genetic structure, gene function, and gene regulation before these goods are achievable and marketable.

CONCLUDING REMARKS

Crop improvement represents our continuous efforts in seeking new ways as well as in solving problems associated with traditional methods to improve crops. For example, the protoplast fusion technology was developed to overcome the sexual incompatibility barrier. The application of genetic principles in breeding programs has been very successful. It formulated the basis for the "Green Revolution". This was further complimented by the development of tissue culture and protoplast fusion techniques. The combination of breeding programs and tissue culture techniques has opened many avenues for crop improvements which were not possible previously. The current advancement of biotechnology has ushered the agriculture research into a new era of transgenic organisms. Thus, we have advanced from the hybrid organisms to the transgenic organisms or, from the green revolution to the gene revolution.