

China: Agricultural Biotechnology Opportunities to Meet the Challenges of Food Production

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Crop improvement using biotechnology has now become a reality. Globally, commercial production of transgenic crops has increased rapidly in the last few years (James 1998). There is considerable research and development (R&D) in agricultural biotechnology in China. The challenges, opportunities, and constraints to biotechnology R&D are reviewed here, especially those related to crop improvement and production in China.

Challenges

Increasing food production has always been the highest agricultural priority in China because of the huge population of the country. It is projected that the population of China will reach 1.6 billion by the year 2030. Demand for food production will increase by at least 60 percent to keep pace with population growth. This rapid population increase and vast urbanization will result in loss of valuable farmland and other natural resources. The only viable approach to increasing food production, therefore, is to increase the productivity of existing farmland. Statistics show, however, that the total production rates of the major grain crops has been decreasing in the last decade (Ministry of Agriculture 1996), because yield potentials of the newly released cultivars and hybrids have not been realized.

There is also a huge demand for quality improvement of food products, especially the grain quality of cereal crops. Quality improvement of rice, for example, was largely neglected in breed-

ing programs in recent years. High yield cultivars and hybrids is frequently associated with poor quality; most of the widely used cultivars and hybrids have poor cooking and eating qualities, and thus are disfavored by producers and consumers.

Another major problem is degradation of the environment. We have seen increasingly frequent natural disasters such as floods, drought, insect pests, and diseases, and also expanding areas of soil desertification, salinity, and acidity. Extensive applications of chemicals have created a vicious circle in which the excessive use of the chemicals has resulted in a rapid deterioration of the environment, and this deterioration has made crop production even more dependent on chemicals.

The greatest challenge is to increase food production and improve product quality in an environmentally sustainable manner.

Developments in Biotechnology Research in China

Infrastructure

In the last 15 years there have been rapid developments in China in scientific infrastructure and also research programs in biotechnology and molecular biology of various crop plants. Infrastructure developments include the establishment of National Key Laboratories in the general areas of agricultural biotechnology and crop genetics and breeding, in north, central and south China. These laboratories are well equipped for

biotechnology and molecular biology research. In addition, there are open laboratories supported by the Ministry of Agriculture, the Ministry of Education, and the Chinese Academy of Sciences. These laboratories have provided good opportunities for biotechnology research.

Financial Resources

During the same period, regular funding channels were formed at the central government level, which support basic and applied research. This includes the establishment of the National Natural Science Foundation of China and The Chinese Foundation of Agricultural Scientific Research and Education. Major research initiatives and programs were also established at the state level and by various ministries. The most important programs for biotechnology R&D are the National Program on High Technology Development (also known as the 863 Program) and the National Program on the Development of Basic Research (also known as 973), both of which included agricultural biotechnology as a major component. Programs were set up to promote young scientists by awarding special grants from the National Natural Science Foundation, the 863 Program, and also various ministries. Similar systems, although smaller, were also developed by local governments in many provinces.

International funding channels also opened to Chinese scientists during this period, including those of the Rockefeller Foundation, McKnight Foundation, the International Foundation for Science, and the European Union-China collaboration programs. The availability of financial support has enhanced research capacity and has promoted the development of young scientists. Some of the programs have a training component as well.

Scientific Advances

Rapid advances have been made in molecular biology and biotechnology research in China in the 1990s. These include genomic studies in rice and other cereals, development of molecular marker technologies, identification, and mapping and molecular cloning of a large number of agriculturally useful genes. These studies have re-

sulted in powerful tools for crop improvement (for example, marker-assisted selection) that can be applied to develop new cultivars and hybrid parents.

Transformation technologies have also been firmly established in many laboratories for most of the crop species, including major cereal crops such as corn, rice, and wheat that are often considered difficult to transform. Transgenic plants can now be routinely produced for crops such as rice, corn, wheat, cotton, tomato, potato, soybean, rapeseed, and other crops, using *Agrobacterium*, particle bombardment or other methods.

The most up-to-date molecular technologies necessary for varietal development are now in place in China.

Opportunities

Genome mapping and biotechnology research in recent years offer powerful tools in crop improvement including genetic transformation and molecular marker-assisted selection. These techniques have opened enormous opportunities to meet the challenges of food production. These opportunities according to individual traits are described below:

Disease resistance: More than 20 genes for resistance to various plant diseases have been isolated in recent years (Baker and others 1997). Analyses of the DNA sequences indicate that the genes share many structural characteristics in common, despite the fact that diseases are caused by a variety of pathogens such as fungi, bacteria, viruses, and nematodes. The genes were isolated from a wide range of plant species including monocotyledonous and dicotyledonous species including tomato, rice, tobacco, and barley. These have provided a rich source of disease-resistance genes for improving resistance by genetic engineering.

Large numbers of genes have been tagged and mapped using molecular markers in many crop species (for examples see Zhang and Yu 1999). Closely linked markers flanking both sides of the genes were identified in many cases. These closely linked markers can be used as the starting points for isolating the genes using the map-based cloning approach. These markers can also be used as selection criteria in breeding programs to monitor the transfer of the genes, which is referred to

as marker-assisted selection. New crop lines with improved resistance have been obtained using both approaches.

Insect resistance: Genes for resistance to various insects have been identified in many crop species and their wild relatives, including gall midge and brown planthopper resistance in rice, and pink borer resistance in cotton. A number of insect resistance genes has also been genetically tagged and mapped using molecular markers (Zhang and Yu 1999). These genes can be directly used in crop breeding programs using marker-assisted selection.

An important strategy in the development of insect resistant crop varieties is utilization of exogenous genes, including genes coding for endotoxin of *Bacillus thuringiensis* (*Bt*) and proteinase inhibitors from various sources (Krattiger 1997). Some of the genes have demonstrated strong insecticidal activities under both laboratory and field conditions. Several genes have now been widely used in transformation studies. Many insect-resistant transgenic cotton, corn, and rice plants have been produced from these transformation studies, which have now been advanced to the stage of commercial production (James 1998).

Large-scale utilization of the insect resistance genes in crop production will not only reduce labor and costs of production, it will also have long-term beneficial effects on the environment. These insect-resistant crops may have a major role to play in sustainable agricultural systems.

Tolerance to abiotic stresses: Drought, soil salinity, and acidity are among the most important threats to agricultural production that cause severe yield losses of all major food crops worldwide. In China, the northwest region is prone to drought, so water supply is a major limitation for crop production; in south and central China, soil acidity is a major limiting factor that reduces crop yield; salinity occurs in large areas in the east coastal region.

Drought resistance has been the subject of many studies in several major food crops including rice, corn and sorghum (Nguyen, Babu, and Blum 1998). Although many quantitative trait loci (QTLs), which explain certain genetic variations in drought tolerance in experimental populations, have been identified by molecular marker map-

ping, they are unlikely to have a major role to play for improving the drought tolerance of crops.

There have also been QTL studies on the tolerance of rice to acidic soil conditions, especially with respect to aluminum and ferrous iron toxicity (Wu and others 1999), showing that major gene loci may be involved in increasing the tolerance of rice plants. This may present an opportunity for using genes from rice itself to improve the tolerance of rice varieties to acidic soils.

A more promising line of research is the use of gene coding for citrate synthase, the enzyme for biosynthesis of citric acid (de la Fuente and others 1997). Transgenic sugar beet plants with elevated expression of this gene show an enhanced tolerance to aluminum, and also increased uptake of phosphate in the acidic soil as a result of excretion of citrate. This indicates that genetic engineering may be able to produce plants that can grow better in acidic soil even with reduced application of phosphate fertilizers. This work may have tremendous implications in crop improvement, especially for crops grown in tropical and subtropical regions.

Product quality: Biotechnology may have much to offer in the improvement of product quality. In rice, for example, the poor cooking and eating qualities of high-yielding cultivars and hybrids represent a major problem for rice production in China. Research has established that the cooking and eating qualities are to a large extent dependent on three traits: amylose content, gelatinization temperature, and gel consistency. It was recently shown that all three traits are controlled by the waxy locus located on chromosome 6 (Tan and others 1999).

The waxy gene was isolated from maize and rice (Shure, Wessler, and Federoff 1983; Wang and others 1990). Rice plants transformed with the waxy gene both in sense and antisense configurations showed reduced amylose content, thus demonstrating the usefulness of the transgenic approach in improving cooking and eating qualities. Moreover, the waxy locus has also been clearly defined in the molecular linkage map, and markers residing on the waxy locus and closely linked markers that flank the waxy locus on both sides were identified (Tan and others 1999). Thus, improvement of the cooking and eating qualities

can therefore be achieved using marker-assisted selection.

Another example is the recent success in engineering the entire biochemical pathway for provitamin A biosynthesis (Al-Babili and others 1999), which significantly enriched vitamin A content in the endosperm of rice grains. This will be a great help to the poor peasant farmers to balance the micronutrients in their diets and hence alleviate malnutrition.

Increasing yield potential: Several of our major crop species have gone through two great leaps in yield increase in the last several decades: increasing harvest index by reducing the height by making use of the semidwarf genes, and utilization of heterosis by producing hybrids. Reduced rates of yield increase have been observed in a number of major food crops in the last 10-15 years (Ministry of Agriculture 1996). Increasing yield potential has therefore been a common concern in essentially all crop breeding programs.

Two approaches have been reported in the literature. The first approach is called "wild QTLs," in which efforts are devoted to bringing QTLs for yield increase from the wild relatives to enhance the yield of cultivars. The argument for such an approach is that only a portion of the genes that ever existed in the wild species was brought to cultivation in the processes of domestication, leaving most of the genes unused. With the help of molecular marker technology, it should therefore be possible to identify genes that can increase the yield of cultivated plants. Xiao and others (1996), for example, reported two QTLs from a wild rice that showed significant effects in increasing the performance of an elite rice hybrid. This has generated considerable interest in identifying genes for agronomic performance from wild relatives that are potentially useful for varietal improvement.

The second approach is to modify certain physiological processes by genetic engineering. Gan and Amasino (1995) reported a system conceived to delay leaf senescence by autoregulated production of cytokinin. The construct was designed by fusing a senescence-specific promoter isolated from *Arabidopsis* with a DNA fragment from *Agrobacterium* encoding isopentenyl transferase (*IPT*), an enzyme that catalyzes the rate-limiting step in cytokinin biosynthesis. The

strategy for such a system is that the gene would be turned on at the onset of senescence leading to the synthesis of cytokinin, and the production of cytokinin would in turn inhibit the process of senescence, thus repressing the expression of this construct itself. Such a system would, therefore, be able to produce cytokinin for delaying senescence, and at the same time preventing overproduction of cytokinin, because overproduction of this hormone is detrimental to the plant. Transgenic tobacco plants carrying this construct showed a significant delay in leaf senescence, bringing about a large increase in the number of flowers, number of seeds, and biomass, indicating the possibility of increasing plant productivity by delaying leaf senescence. It is interesting, therefore, to determine if this system can provide a general strategy for yield increase in crop improvement.

There are many opportunities for biotechnology to contribute to sustainable food production, to achieve higher yields, better quality, and less dependence on chemicals, making crop production more environmentally friendly.

Field Testing of Transgenic Crops in China

According to statistics from the Ministry of Agriculture, transgenic research has been conducted in 47 plant species in China using 103 genes. A national committee for the regulation of biosafety of genetically improved agricultural organisms was established in 1996 to promote biotechnology in a healthy environment. This committee accepts applications twice a year for biosafety evaluation of genetically improved agricultural organisms such as crop plants, farm animals, and microorganisms.

By mid 1998, the committee had received 86 applications, of which 75 were for field testing of transgenic crops. Permission for 53 of the applications was granted for commercial production, environmental release, or small-scale field testing (Chinese Society of Agricultural Biotechnology 1998a, b). The crops used for transgenic research were rice, wheat, corn, cotton, tomato, pepper, potato, cucumber, papaya, and tobacco. A variety of traits were targeted for improvement including disease resistance, pest resistance, herbicide resistance, and quality improvement. In a

few cases, transgenic crops have been grown for large-scale commercial production. We expect that the area planted in transgenic crops will increase rapidly in the next few years.

Constraints

Intellectual Property Rights

One of the major constraints relates to intellectual property rights (IPR). China does not yet have effective IPR in place for large-scale biotechnology research to develop new genetically improved crops. Most of the genetically improved crop plants that have been developed so far involve complex IPR issues. There is a major shortage of experts in China with knowledge of IPR, and experience in dealing with these issues. China urgently needs help in training people in IPR. Scientists and breeders do not fully understand IPR, which are not always recognized and honored. Education is therefore urgently needed on these issues.

Delivery Systems

Another major constraint is the lack of delivery and extension mechanisms that take the products of biotechnology research to the farmers. China had a network system to dispense agricultural technologies, seeds, and other related materials. With the development of a market economy, the old distribution systems are gradually losing their effectiveness, and are now evolving into profit-driven seed companies undergoing the processes of privatization. Although this may be a good movement in itself, it may take several years for the system to become effective, because the funding situation does not appear to be promising at the moment. Governmental support mainly goes to the research component, and there is not enough funding to support initiatives and startups of seed companies.

Scientific and Technical Constraints

There are also a number of scientific and technical constraints to the application of technology in crop improvement. One of the constraints is the lack of understanding of the mechanisms gov-

erning the traits that are very important in crop improvement. Drought causes severe yield loss worldwide, and it will continue to be among the most damaging stresses in crop production. Tolerance of the crop to drought as a trait, however, has not been well defined, and it is still not clear what aspects of plant morphology or physiology are the most important for drought tolerance. Research is still needed to define a clear target for improving drought tolerance.

There is also a huge need for germplasm. Germplasm has not been found for a number of important traits such as resistance to fungal diseases and resistance to a number of pests in crop species, for example, sheath blight of rice, scab disease of wheat, and yellow wilt of cotton. These have become the most devastating diseases worldwide, as have borer insects of a number of crops that cause heavy damage. International collaboration, coordinated by CGIAR centers, may have a crucial role to play in germplasm identification, exchange, and utilization.

Perspectives

Recent developments in genome mapping and genetic engineering have provided a knowledge base, identified germplasm resources, provided useful genes, and offered effective tools for crop improvement. Integration of the knowledge, the tools, and the genetic resources into breeding programs will greatly increase the efficiency of new varietal development.

Molecular Marker-Assisted Selection

It is expected that molecular marker-assisted selection will have a major role to play in future genetic improvement of many crops. This is not only because the technique itself has provided a highly efficient tool for speedy and precise selection, but also because it possesses several distinct advantages. First, it does not require the isolation of the targeted gene, which often takes years and considerable resources to accomplish. Second, most of the gene constructs such as those commonly used in many transformation studies are now covered by IPR, hence are not freely available for varietal development. Third, the progeny developed by marker-assisted selection

in general does not suffer from adverse effects such as over- or underexpression and transgene silencing, which are now frequently reported with transgenic plants. The performance of the progeny resulting from marker-assisted selection is therefore much more predictable than those from transformation. The large number of genes that have been precisely tagged and mapped will provide a rich source for marker-assisted breeding.

Gene Isolation

The most common practice for obtaining new genes is map-based cloning. Molecular markers that are closely linked to genes of interest can serve as the starting point for cloning the genes following the map-based cloning approach. It can be expected that the process of gene isolation using this approach will be greatly accelerated with advances of the international effort in DNA sequencing. It is highly likely that all the genes that are accurately mapped with closely linked markers can be quickly isolated with the availability of the sequence information.

The recent development in DNA-chip technologies may also provide a powerful tool for large-scale isolation of new genes in the near future (Lemieux, Aharoni, and Schena 1998). It can be expected that large numbers of genes will become available for crop improvement in the next decade.

Biotechnology will soon play a major role in crop improvement in China. The area planted to cultivars, developed using modern biotechnology, will increase steadily in the years to come. Biotechnology will contribute significantly to food production and food security in China in the coming century.

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