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Guest editorial

GMO Biosafety Research in China

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Over the years, genetically modified organism (GMO) development and regulation in China have regularly attracted international attention. In the early 1990s, China became the first country to commercialize a genetically modified (GM) crop with planting of a virus-resistant transgenic tobacco variety on a relatively large scale, while other parts of the world were debating about the risks of GMOs. A few years later, the GM tobacco was removed from cultivation because of strong pressure from outside of the country. This situation was not changed until late 1997, when an insect-resistant cotton variety was approved by the GMO Biosafety Committee in the Ministry of Agriculture for commercial cultivation in five provinces. This paper will give an overview of GMO development and biosafety research in China.

DEVELOPMENT AND ADOPTION OF AGRICULTURAL GMOs IN CHINA

Research in agricultural biotechnology dates to the early 1980s, and rapid development of transgenic crops started in the mid-1990s. In March of 1986, the State Council launched a national program for developing high-tech, the 'National High-Tech Research & Development Program' (generally referred to as the 863 Program), in which agricultural biotechnology and medical biotechnology shared roughly the same budget of approximately RMB 2.86 billion in the area of biotechnology over a 15-year period from 1986 to 2000. This indicates the important position of agricultural biotechnology considered by the government. In addition, other national and ministerial competitive grants also encouraged research and development in agricultural biotechnology. Government-funded programs continue in the new century. However, investment from private sectors is still small.

According to a survey made in 2001, there were over 130 organisms under research by scientists nationwide (including scientists at non-agricultural systems) and more than 200 candidate genes were used to transform these organisms. Among these were over 60 plant species being studied, and 121 genes used for transformation. One of the most visible and successful achievements is the development and commercial application of transgenic insect-resistant cotton (*Bt* cotton). Commercial planting of the new cotton variety was first approved by the Ministry of Agriculture (MOA) in 1997 after years of field trials in different locations. By the end of year 2001, an accumulated area of 1.0 million hectares was planted with the new *Bt* cotton varieties developed by Chinese scientists. About the same area of cotton land was planted with Monsanto's *Bt* cotton varieties. The adoption of *Bt* cotton varieties has provided a 70–80% decrease in the use of insecticides, compared to alternative insect management strategies. In a survey of farmers in Shandong and Shanxi provinces, the economic benefits were estimated to increase to an average of RMB 2130/ha (about $250/ha) including savings from reduced cost of labor and insecticide use (Jia et al., 2001).

To ensure that agricultural biotechnology is used effectively and appropriately, the MOA has developed and implemented biosafety regulatory systems since 1996, covering from laboratory research to commercialization. Between March 1997 and February 2002, the MOA approved 501 cases of GMOs for field trials or commercialization from a total of 695 applications for GMO biosafety evaluation. Commercial approval has been granted to 59 applications that include insect-resistant cotton, shelf-life altered tomato, virus-resistant tomato, virus-resistant sweet pepper, color-altered petunia, nitrogen-fixing bacteria, and vaccines for animal use. The shelf-life altered tomato variety has been planted in a very small area in Hubei province. Virus-resistant tomato, sweet pepper and color-altered petunia varieties have not yet been registered, and are not yet commercially available. No transgenic staple food and oil crops have been approved for commercial use in China yet. In China, there is a variety registration system. A transgenic variety granted a biosafety certificate for commercial use has to go through a procedure for variety registration before its real commercial production in the field and its being put on the market.

In addition, GM crops under development and waiting for product testing or commercialization include rice improved for disease resistance, insect resistance or herbicide tolerance, as well as disease-resistant cotton, insect-resistant corn, herbicide-tolerant soybean, disease-resistant rapeseed, disease-resistant potato, quality-improved potato, and insect-resistant poplar.

GMO BIOSAFETY RESEARCH

GMO biosafety research has been conducted by the developers of GM crops since the early 1990s. The GMO developers have allocated more funding to biosafety since 1997, when the MOA implemented its GMO regulations. In 1996, the government supported biosafety research as a part of the 863 High-Tech Program. In recent years, governmental funding has increased significantly for biosafety research, and funding from other sources has expanded as well. For example, there are four projects in the National Transgenic Crops Program from 2000 to 2002, 6 projects in the 863 Program from 2001 to 2003, a big project in the National Fundamental Science program (generally referred to as the 973 Program) from 2002 to 2007, and a project in the National Key Program from 2001 to 2003. These projects deal with food and environmental safety, GMO detection methodology and technical standards for GMO biosafety assessment, covering from basic biosafety issues to specific questions relevant to a targeted GMO product, from monitoring of long-term effects to questions to be urgently answered. The current projects deal with GM crops, microbes and animals, but most of them are plant oriented.

What is specific to the Chinese philosophy concerning these biosafety research projects? Historically, risks to the environment presented by crop plants are low. In these projects, we think what we need to do is to collect scientific data and understand the scientific basis for safe use of GMO products. For example, we are trying to prove if a GM crop variety, when released in the field, is as safe as its conventional crop variety, according to modern biological knowledge and experience. We are not trying to prove how risky it may be, by strange imagination or by inventing some special phenomena that do not occur in nature. Therefore, the biosafety research of transgenic crops focuses on the recognized risks such as the stability of the genetic modification, gene transfer to related plants, weediness potential, non-target effects, and development of risk management strategies including procedures and methods to minimize the risks and their consequences that may be resulted from the cultivation of transgenic crop varieties.

INSECT-RESISTANT COTTON

Cotton is the most important cash crop in China. In 2001, 13 insect-resistant transgenic cotton varieties were planted in 12 provinces. A series of biosafety studies have been conducted during the past five years on the ecological impact of *Bt* cotton varieties, which are described below.

Field performance

Although field performance is not a biosafety issue, it has been evaluated repeatedly in China. In Northern China, four generations of cotton bollworm (CBW, *Helicoverpa armigera* (Hübner)) occur each year. The first generation grows on wheat or other crops. The second to fourth generations cause damage to cotton. During 1997 to 2001, CBW control by *Bt* varieties was highly satisfactory. The percentage of terminal and square damage in *Bt* cotton was less that 1%, while an average damage of 40–90% occurred in non-*Bt* cotton plants in different generations, seasons and locations (Jia, 1998; Wu et al., 2001). However, a much lower efficacy was reported with a variety that was developed at an earlier stage (Xia et al., 1999).

Biodiversity of arthropod community

Field impact of *Bt* cotton on non-target insects and insect predators was evaluated in 1997-2001 (Wu et al., 2001). All types of arthropods were collected using a portable suction device and identified to species if possible. Shannon index was used to measure biodiversity of the ecosystem. The diversity of pests (phytophages) was significantly higher in *Bt* cotton without spray than non-*Bt* cotton without spray or non-*Bt* cotton with regular spray in July and early August, while no difference was found among different treatments for the diversity of natural enemies (predators and parasitoids) and neutral insects (scavengers/decomposers and transient species).

Further results indicated that predator populations in *Bt* cotton were significantly higher than that in non-*Bt* cotton with regular spray. Non-target insect pests such as plant bugs, *Lygus pratensis* (L.), *Lygus lucorum* (Meyer-Dur), *Adelphocoris suturalis* (Jak.), *Adelphocoris fasciaticollis* (Reuter) and *Adelphocoris lineolatus* (Goeze), occurred more abundantly in *Bt* cotton fields, due to decreased use of insecticides for CBW control. However, the population density of cotton aphids, *Aphis gossypii* (Glover), was 443 to 1646 times lower in *Bt* cotton plants than that in non-*Bt* cotton plants with regular spray of both pyrethroid and organophosphorus insecticides (Jia et al., 2001).

Impact on silkworm

The impact of a cotton variety expressing a *cry1Ac* gene, a cotton variety expressing *cry1A* and *CpTI* genes, and a corn variety expressing a *cry1Ab* gene has been evaluated in a recent study. Growth, development and cocoon quality of silkworm, *Bambyx mori* (L.), were compared after feeding on pollen from the above mentioned transgenic varieties, and on pollen from non-transgenic cotton and corn varieties as well as non-pollen treatments. The authors conclude that the adverse effect of transgenic insect-resistant cotton and corn pollen on the growth and development of the mulberry silkworm is negligible (Li et al., 2002).

Resistance management

Resistance management for insect-resistant crops remains a serious concern in China because of the difficulty for small farmers to use a high dose/refuge strategy. China has to develop its own strategy for resistance management. For this, *Bt* cotton is a good example. Cotton cultivation in China has been categorized into five ecological regions: the South China, the Yangtze river valley, the Yellow river valley, the Liaohe river valley and the Northwest regions. Baseline data have been obtained on the IC50 (50% inhibition concentration) of CBW larvae grown into third instars among 23 sample populations in the above five ecological regions (0.011 $mg.ml^{-1}$–0.057 $mg.ml^{-1}$) (Wu et al., 1999). Lines of CBW that are resistant to Cry1Ac and Cry1Ab have been obtained after selection with *Bt* cotton plants and Cry1Ac protein. The initial frequency of resistant alleles in different populations varies between 0–0.13%, and the competitiveness of resistant individuals, resistance monitoring under natural field conditions, the genetic basis and evolution for CBW resistance to the *Bt* plants have been studied in several qualified laboratories. Based on these studies, several resistance management strategies for *Bt* cotton had been developed. One of the options is to use the unique multi-cropping system as a natural refuge in Northern China (different crops planted in the same or neighboring field) and pyramid two dissimilar insecticidal genes in the same crop variety. The value of this strategy for delaying resistance development is still under evaluation, while preliminary results have shown that the natural refuges could be effective (Wu et al., 2001) and that a two-gene (*cry1A* and *CpTI*) transgenic tobacco plant could significantly delay the resistance development of CBW in comparison with one-gene (*cry1A*) plants (Zhao et al., 1999). It is predicted that the currently registered *Bt* cotton varieties may be effectively used for 10 years at least (Jia, 1998).

GM RICE

Rice is a staple food for China and many other Asian countries. The genus Oryza contains two cultivated species and 20 wild species. The rice in this article generally means *O. sativa*, which is cultivated worldwide, and China is considered one of the centers of origin of this species. Rice has been classified into two subspecies indica and japonica. In China, rice is cultivated annually. However, rice plants can grow vegetatively and continuously under favorable conditions. Tiller buds on the basal nodes can re-grow after harvest. Some farmers grow these ratoon plants for a second harvest. Hybrid rice is common in southern China. In making hybrid seeds, a larger and longer stigma that extends outside the spikelet is a good trait of the sterile line, but this will increase the opportunity for outcrossing (more than 5%). Intraspecific and interspecific crossing has been reported. Considering these complicated situations, GM rice has faced a big challenge to pass the biosafety assessment for commercialization by the MOA biosafety committee.

In public-sponsored 973 and 863 biosafety research projects, gene flow and its ecological consequences have been considered a major issue in GM rice environmental biosafety research. Artificial and natural outcrossing, introgression and ecological impact have been under evaluation in experiments that use GM rice with marker gene(s) for the purposes to understand gene flow (1) from crop to crop, especially to sterile lines of cultivated rice; (2) from crop to wild relatives (three wild species found in China, a perennial common wild rice *O. rufipogon*, *O. officinalis*, and *O. myeriana*); and (3) from crop to wild grasses in rice fields (barnyard grass *Echinochloa crusgalli* var. *mitis* and others).

Other studies on ecological impacts of transgenic rice, corn, cotton, soybean, other crops, pseudomonads, and fishes are also in progress, and some of these studies have been conducted for years. In most of these researches on environmental safety of agricultural GMO field releases, the principle of substantial equivalence has been followed as a starting point for further studies. One of the big challenges facing us is lack of necessary baseline information about the ecological impact of conventional agricultural practices and sufficient data to allow effective comparison between the transgenic crop variety and its conventional counterpart. It is in this area and monitoring of long-term ecological effects that we have a strong interest in international collaborations.

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