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Agricultural Biotechnology Development, Policy and Impact in China

China is developing the largest plant biotechnology capacity outside North America and an impressive list of genetically modified (GM) crops under trial. However, underlying these achievements is a growing concern among policy-makers about the impact of the global biotechnology debate on China's agricultural trade. Like many other developing countries, it has now to address serious questions on the future of biotechnology in the country.

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I

Introduction

Biotechnology has the potential to address problems not solved by conventional research. At the same time, biotechnology may speed up research processes and increase research precision [Conway 2000]. Proponents of biotechnology consider that genetically modified organisms (GMO) have the potential to be healthier, and more productive than organisms derived through conventional means. Equally, advocates argue the technology has the potential to revolutionise medicine and agriculture, and to contribute to the tackling of rural poverty and management of environmental problems. Conversely, critics of biotechnology claim that genetically modified (GM) crops will affect human health and damage the environment and may do very little to alleviate poverty and income insecurity in developing countries.

In spite of highly conflicting views about the merits of biotechnology, GM crops have developed and spread rapidly since the early 1990s. The total area planted with GM crops worldwide increased from 1.7 million hectares in 1996 to 44.2 million hectares in 2000 and is expected to have continued to grow by more than 10 per cent in 2001 [James 2002]. An estimated 5 million farmers from industrial and developing countries grew biotech crops in 2001. Most GM crops are planted in US, accounting for more than two-third of the global total in 2001 [James 2002].

Although only 3 per cent of the total global area of GM crops was in China in 2001, we estimate that at least 4 million farmers planted Bt cotton, as the average farm size is only about 0.5 hectare with several crops. In the same year, Bt cotton area reached 1.48 million hectares, the fourth largest GM crop area sown, after the US, Argentina, and Canada. Although commercialisation of major food crops has proceeded at a cautious pace in China, the official policy of the Chinese government has been to promote biotechnology as one of the national priorities in technology development since the 1980s [SSTC 1990; Huang, Rozelle, Pray and Wang 2002]. The Chinese government views agricultural biotechnology as a tool to help China improve the nation's food security, raise agricultural productivity, increase farmer incomes, foster sustainable development, and improve its competitive position in international agricultural markets [MOA 1990].

A recent survey of China's plant biotechnologists by the authors and their collaborators confirms this objective [Huang, Rozelle, Pray and Wang 2002]. It shows that China is developing the largest plant biotechnology capacity outside of North America. The list of GM crops in trials is impressive and differs from those being worked on in other countries. The first commercial release of a GM crop in the world occurred in 1992 when transgenic tobacco varieties were first adopted by Chinese farmers.[1] GM varieties for four crops have been approved for commercialisation in China since 1997. These include GM varieties of cotton, tomato, sweet pepper, and petunia. Cotton varieties with the Bacillus thuringiensis (Bt) gene to control bollworm have spread widely. GM varieties of crops such as rice, maize, wheat, soybean, peanut and others are either in the research pipeline or are ready for commercialisation [Chen 2000; Li 2000; Huang, Rozelle, Pray and Wang 2002].

However, despite these achievements there is growing concern among policy-makers about the impact of the ongoing global biotechnology debate on China's agricultural trade, particularly import restrictions in EU countries. Policy-makers are also concerned about biosafety issues, and potential opposition derived from consumer concerns with the environmental and food safety of biotechnology products. Under these circumstances, while GM crops have continued to be generated in public research institutes and while the number of imported GM crop varieties submitted for field trial and environmental releases has been rising, securing approval of GM crops, particularly food crops, for commercialisation has become more difficult since 1999.

China, like many other developing countries, now faces a dilemma as to how to proceed on the further commercialisation of GM crops. The objectives of this paper are to review the status of biotechnology applications in China's agriculture and current findings on the impact of plant biotechnology.[2] In order to achieve these objectives, the paper is organised as follows: In the next section, a general review of agricultural biotechnology development in China is provided. The third section discusses the priority and products of agricultural biotechnology. The impact of biotechnology are discussed in the fourth section. The final section provides concluding remarks and areas for policy actions.

II

Agricultural Biotechnology in China

Agricultural biotechnology research and development in China is predominantly financed and undertaken by the public sector. Several supra-ministries and agencies are involved in the design of research strategies, priorities, and the approval and allocation of budgets. The supra-ministries and agencies include the ministry of science and technology (MOST), the State Development Planning Commission (SDPC), and the ministry of agriculture (MOA) among others [Huang, Wang, Zhang and Zapeta 2001]. Several research institutes within the Chinese Academy of Agricultural Sciences (CAAS) and the Chinese Academy of Sciences (CAS) as well as within public universities, initiated agricultural biotechnology research programs in the early 1970s. The research focus of biotechnology at this time was on cell engineering, tissue culture, and cell fusion and emphasised crops such as rice, wheat, maize, cotton, and vegetables [KLCMCB 1996].

However, the most significant progress in agricultural biotechnology was made following the development of transgenic techniques after 1983. The pace of biotechnology research increased significantly after China started a bold national policy supporting biotechnology programmes coordinated by MOST in 1986. Since then agricultural biotechnology laboratories have been established in almost every agricultural academy and major university. Chinese research institutes and laboratories have generated advanced biotechnology applications that have been utilised in medicine, chemistry, environment, the food processing industry, and agriculture.

Bt cotton is one of the most often cited examples of the progress of agricultural biotechnology in China. Ten transgenic cotton varieties and four Bt cotton hybrids with resistance to bollworms had been produced by Chinese institutions by 2000 and have been approved for commercialisation in China since 1997 [BRI 2002]. Huang, Hu, Pray, Qiao and Rozelle (2002) estimated that since the first Bt cotton variety was approved for commercialisation in 1997, the total area under Bt cotton reached 0.7 million hectares in 2000. Our recent survey shows that Bt cotton area reached 1.48 million hectares in 2001, accounted for 31 per cent of China's cotton area. In addition, other transgenic plants with resistance to insects, disease or herbicides, or plants that have been quality-modified have been approved for field release and are ready for commercialisation. These include transgenic varieties of cotton resistant to fungal disease, rice resistant to insect pests or diseases, wheat resistant to barley yellow dwarf virus [Cheng, He and Chen 1997], maize resistant to insects or with improved quality [Zhang et al 1999], soybeans resistant to herbicides, transgenic potato resistant to bacterial disease, among others [MOA 1999; NCBED 2000; Li 2000].

Progress in plant biotechnology has also been made in recombinant microorganisms such as soybean nodule bacteria, nitrogen-fixing bacteria for rice and corn, and phytase from recombinant yeasts for feed additives. Nitrogen-fixing bacteria and phytase have been commercialised since 1999. In animals, transgenic pigs and carp have been produced since 1997 [NCBED 2000]. China was the first country to complete the shrimp genome sequencing in 2000. Chinese researchers also announced the successful sequencing of the rice genome in 2002 [Yu, Hu, Wang et al 2002], at the same time as another in separate international project.

There are about 150 laboratories at the national and local level located in more than 50 research institutes and universities across the country working on agricultural (plant and animal) biotechnology. At the same time multiple sources of funding (MOST, SDPC, MOA, and local provinces), combined with the large number of biotechnology research institutes and laboratories, and the lack of coordination and collaboration between research institutes both at the national and the provincial level, has led to large overlaps in agricultural biotechnology research programmes and has contributed to unnecessary and inefficient duplication of efforts, particularly at the local level.

Research Capacity and Investment

A recent survey [Huang, Rozelle, Pray and Wang 2002] shows that China is developing the largest biotechnology capacity outside of North America. To create a modern and internationally competitive biotechnology research and development system, China has made great efforts to improve the innovative capacity of its national biotechnology programmes since the early 1980s. In contrast to the stagnating (or even declining) patterns of agricultural research expenditure and research staff recruitment in the late 1980s and the early 1990s [Huang and Hu 2001], R and D investments and the numbers of research staff in biotechnology institutes has increased significantly since the early 1980s. Based on our primary survey of 29 research institutes working in the plant biotechnology field, the number of researchers more than doubled in past 15 years (Table 1). Total investment in plant biotechnology in real terms nearly doubled every five years [Huang, Wang, Zhang and Zepeda 2001], and reached $ 112 million (converted from Chinese RMB or yuan to US donors using the purchasing power parity rate in 1999 [Huang, Rozelle, Pray and Wang 2002]. Expenditures of this level demonstrate the seriousness of China's commitment to plant biotechnology. Government research administrators allocated about 9.2 per cent of the national crop research budget to plant biotechnology in 1999, up from 1.2 per cent in 1986. China's level far exceeds the 2-5 per cent levels of other developing countries [Byerlee and Fisher 2000].

III
Priorities and Products of Agricultural Biotechnology Research

In 1985, MOST developed a five-year Biotechnology Development Outline (BDO). The BDO proposes policy measures and research priorities in each research field. Huang, Wang, Zhang and Zepeda (2001) summarised research priorities for plant biotechnology identified in various Biotechnology Development Outlines over the past 15 years in China (Table 3). Since the mid-1980s cotton, rice, wheat, maize, soybean, potato and rapeseed have been consistently listed as priority crops for biotechnology research funding. The total area sown to these crops was over 100 million hectares, accounting for more than two-third of the total sown crop area in China in the 1990s [SSB 2000].

Cotton has been consistently selected as a top priority crop not only because of its importance by sown area and its contributions to the textile industry and trade, but also because of the serious problems with the associated rapid increase in pesticide applications to control insects (i e, bollworm and aphids). Per hectare pesticide expenditures in cotton production in China increased considerably over recent decades, reaching 834 RMB yuan (approximately US $ 100) in 1995. This amount is

Table 1: Numbers and Composition of Plant Biotechnology Research Staff in Sampled Institutes, 1986-99

Year	Professional Staff	Support Staff	Total Staff
1986	285	356	641
1990	409	399	808
1995	535	433	968
1999	691	514	1205
1999a	969	688	1657

Note: All data are from 22 biotechnology research institutes except for those with 1999a that includes 29 institutes in 1999. These 29 institutes account for about 80 per cent of research staff, about 85 per cent of research expenditure, and more than 90 per cent of research output in China's plant biotechnology.

Source: Huang, Wang, Zhang and Zepeda 2001.

much higher than comparable expenditure for grain crop production but lower than in horticultural production [Huang, Qiao, Zhang and Rozelle 2000]. Cotton production alone consumed about US $ 500 million annually in pesticides in recent years.

Rice, wheat and maize are the three most important crops in China. Each accounts for about 20 per cent of the total area planted. Production and market stability of these three crops are a primary concern of the Chinese government as they are central to China's food security. National food security, particularly related to grains, has been a central goal of China's agricultural and food policy and has been incorporated into biotechnology research priority setting.

Genetic traits viewed as priorities may be transferred into target crops. Priority traits include those related to insect and disease resistance, stress tolerance, and quality improvement (Table 2). Pest resistance traits have top priority over all traits. Recently, quality improvement traits have been included as priority traits in response to increased market demand for quality foods. Quality improvements have been targeted particularly for rice and wheat, as consumer income rises in China. In addition, stress tolerance traits – particularly resistance to drought – are gaining attention, particularly with the growing concern over water shortages in northern China. In addition, northern China is a major wheat and soybean production region with significant implications to China's future food security and trade.

In 1997 there were 57 applications for field trial, environmental release, and commercialisation (Table 3).[4] Of these China approved 46 requests for agricultural biotechnology products. The total number of approved cases for field trials, environmental release or commercialisation reached 251 in 1999. Of the 251 approved cases from 18 crops, 92 cases were approved for field trials, 74 for environmental release and 33 for commercialisation.

Among the approved releases for commercialisation, 16 approvals were granted to Bt cotton (varieties developed by CAAS and by Monsanto), five to tomatoes with resistance to insects or improved shelf-life, a petunia with altered flower colour, and sweet pepper resistant to diseases.

Products in the Research Continuum

There are over 120 different genes and more than 50 different plant varieties that have been used in plant genetic engineering in China since the middle 1980s [Huang, Rozelle, Pray and Wang 2002]. Plant biotechnology research has emphasised the development of new varieties for major crops seemed as high priority by the Chinese government such as cotton, rice, wheat, maize, soybean, potato and rapeseed. Traits introduced into these crops include insect resistance, disease resistance, herbicide resistance, stress tolerance and quality improvements [Wang, Xue and Huang 2000]. The main achievements were summarised in Huang, Wang, Zhang and Zepeda (2001) and are introduced below.

Newer research focuses on the isolation and cloning of new disease and insect-resistance genes, including the genes conferring resistance to cotton bollworm (Bt, CpTI), rice stem borer (Bt), rice bacterial blight (Xa22 and Xa24), rice plant hopper, wheat powdery mildew (Pm20), wheat yellow mosaic virus, and potato bacterial wilt (cecropin B) [MOA 1999; NCBED 2000]. These genes have been applied in plant genetic engineering since the late 1990s. Significant progress has also been made in the functional genomics of arabidopsis and in plant bioreactors, especially in utilising transgenic plant to produce oral vaccines [BRI 2000b].

Table 2: Research Focus of Plant Biotechnology Programmes in China

Crops/Traits	Prioritised Areas
Crops	Cotton, rice, wheat, maize, soybean, potato, rapeseed, Cabbage, tomato
Traits	
Insect resistance	Cotton bollworm and aphids Rice stem borer Maize stem borer Soybean moth Potato beetle
Disease resistance	Rice bacteria blight and blast Wheat yellow dwarf and rust Soybean cyst nematode Potato bacteria wilt Rapeseed sclerosis
Stress tolerance	Drought, salinity, cold
Quality improvement	Cotton fibre quality Rice cooking quality Wheat quality Maize quality
Herbicide resistance	Rice, soybean
Functional genomics	Rice, rapeseed and arabidopsis

Source: Authors' survey.

IV Biosafety Management and Regulations

The principles that have been set out by the Chinese government for biosafety management are summarised in the following section [Huang, Wang and Keeley 2001]. Firstly, government policy emphasises biotechnology development, while paying equal attention to biosafety management. Second, prevention of negative ecological or health effects is essential whether in risk assessment trials, or after commercialisation in processing, utilisation or waste management stages. Third, there should be cross-sectoral coordination to promote biosafety. This means not only between agricultural, environmental and health sectors, but also those responsible for import and export management and international trade. Four, biosafety management should be based on scientific principles with clear assessment standards adopted and detailed collection of monitoring data for released biotechnology applications. Five, consumers have a right to know whether products are genetically modified or not, hence new labelling regulations for key commodities. The public should be made aware of the differences between genetically engineered and conventional products. Six, biosafety assessment is made on a case-by-case basis. Genetic information exchange during processes of genetic manipulation is complex, so specific analysis and assessment must be taken for every particular product.

Biosafety Management System

At present, biosafety management is implemented at 3 levels: national, ministry and research institute level. The MOST represents the national level and is responsible for the general management of

Table 3: Agricultural Biotechnology Testing in China, 1997-2000

	1997	1998	1999	July 2000	Total
Total (plants, microorganisms, animals)					
Submitted	57	68	126	102	353[a]
Approved	46	52	94	59	251[a]
Approvals for Plants					
Field trials	29	8	28	na	45[b]
Environmental release	6	9	30	na	65[b]
Commercialisation	4	2	24	1	31[a]

[a] From 1997 to July 2000.

[b] From 1997 to July 1999.

Sources: Huang, Rozelle, Pray and Wang (2002), Huang, Wang, Zhang and Zepeda (2001).

biosafety. Recently, a new division for biosafety management has been set up within the National Centre of Biological Engineering Development (NCBED). It is responsible for the administration of new regulations, for promoting academic exchange on biosafety, and coordinating different ministries involved with biosafety issues [Huang, Wang and Keeley 2001].

At the ministry level, the MOA is in charge of the formulation and implementation of biosafety regulation. In turn within the MOA, the Biosafety Office for Agricultural GMOs is responsible for the managing applications, and applying the guidelines. The Biosafety Committee on Agricultural Biological Engineering (BCABE) composed of officials from MOA and scientists from different disciplines including agronomy, biotechnology, plant protection, animal science, microbiology, environmental protection and toxicology, nominated by the MOA, is responsible for the detailed biosafety assessment of experimental research, field trials, environmental release and commercialisation of GMOs. The ministry of public health is responsible for the food safety management of biotechnology products. The appraisal committee consisting of food health, nutrition and toxicology experts, nominated by MPH, is responsible for reviewing and assessing GM food as it has been designated a new resource food. The State Environmental Protection Agency and MOA assume responsibility for environmental safety.

Within every biotechnology or research institute, there is usually a biosafety management group led by the director of the particular research institute. The group is in charge of the reviewing application documents and biosafety related consulting services. The Biosafety Division of Agricultural Genetic Engineering (BDAGE) under the Centre of Science and Technology Development, MOA, takes responsibility for accepting and pre-reviewing applications for biosafety assessment.

Since 2001, the government has been planning to set up a biosafety management system at provincial and county levels in order to enhance local capacity to manage these novel technologies. The policy to set up local biosafety committee has been effective from March 2002 though it will take a few years to achieve the policy goal. This implies, after fully implementation of the policy, that there will be 31 biosafety committees and government offices at provincial level and about 2,500 at county level. Establishment of the lower level biosafety management system will require substantial human capacity building investment.

The first biosafety regulation in China, 'Safety Administration Regulation on Genetic Engineering' was issued by MOST in 1993. The regulation consists of general principles, safety classes and evaluation, application and approval, safety control measures, and legal responsibilities. MOST required the related ministries to draft and issue corresponding biosafety regulations on biological engineering. Following this the MOA issued the Implementation Regulations on Agricultural Biological Engineering in 1996.

In May 2001, the state council issued new biosafety guidelines: Agricultural GMO Safety Regulations. These regulations have been supplemented by three detailed implementation guidelines, effective from March 20, 2002. There are several important changes to existing procedures included in these guidelines, and also details of regulatory responsibilities after commercialisation. These include the addition of an extra pre-production trial stage prior to commercial approval; new processing regulations for GM products; labelling requirements for marketing; new export and import regulations for GMO products; and local and provincial level monitoring guidelines.

In addition to this China is a signatory to the Cartegena Protocol on Biosafety. Responsibility for negotiation and implementation falls with the State Environmental Protection Agency (SEPA). SEPA is currently preparing an all-embracing national level set of biosafety regulations and a biosafety law which will encompass the MOA regulations. Biosafety assessment however will continue to be managed by the MOA where institutional capacity resides. This is clearly felt to be the most realistic option in the Chinese context given resource constraints and the complexity of the issues.

With regard to food safety policy, 'The Food Health Law of the People's Republic of China' was issued by the ministry of public health (MPH) in 1982, and amended in 1995. This is a general law for food health monitoring and management, and a major legal basis for other food health related regulations and standards. Transgenic food has been included in the wider category of 'novel foods' in China, so the management of GM food has been added to the existing Management Regulation of Novel Foods, which was issued in 1990 by MPH. According to this regulation, any trial production or commercial production of a new food must be approved by MPH.

The system of biosafety regulation in China has clearly become progressively more detailed and sophisticated. However, several problems have emerged in the practice of regulation, for example, the monitoring system and consulting service at local and farm levels is relatively weak, in addition to this, collaboration and coordination between ministries needs to be further strengthened.

V

Impacts of Plant Biotechnology

Studies have suggested that GM cotton, soybean, and corn varieties have increased yields and profits and decreased pesticide use of farmers in the US [Gianessi and Carpenter 1999; Fernandez-Cornejo, Klotz-Ingram and Jans 1999]. Few ex post studies of farm level impact of biotechnology so far have been published about countries outside the US. This section summarises recent studies on the farm level impact of biotechnology using Bt cotton production in China as a case study.

In response to rising pesticide use and the emergence of a pesticide resistant bollworm population in the late 1980s, China's scientists began research on GM cotton, launching the nation's most successful experience with GM crops. Starting with a gene isolated from the bacteria, Bacillus thuringiensis (Bt), China's scientists modified the cotton plant using an artificially synthesised gene identified through sequencing techniques. Greenhouse testing began in the early 1990s. Following a decline in the area sown to cotton due to pest losses in the mid-1990s, the commercial use of GM cotton was approved in 1997. During the same year, Bt cotton varieties from publicly funded research institutes and from a Monsanto joint venture (with the US seed company Delta and Pineland and the Hebei Provincial Seed company) became available to farmers. The release of Bt cotton began China's first large-scale commercial experience with a product of the nation's biotechnology research programme.

For many commentators the response of China's poor farmers to the introduction of Bt cotton is convincing evidence that GM crops can play an important role in poor countries [Huang, Rozelle, Pray and Wang 2002]. From only 2,000 hectares in 1997, Bt cotton's sown area grew to around 7,00,000 hectares in 2000. By 2001, farmers planted Bt varieties on more than 30 per cent of China's cotton acreage. Currently, Bt cotton in China is the world's most widespread transgenic crop programme for small farmers.

One major benefit of Bt cotton for farmers is that they are able to substantially cut pesticide use. In 1999, based on our 282 household surveys in Hebei and Henan provinces with series bollworm attacked, Bt cotton farmers reduced pesticide use by an average of 49.9 kg per hectare per season (Table 4). This reduced costs by $ 762 per hectare per season. A new survey in Henan province in 2000 further confirms this finding — a large decline in pesticide use though the amount of pesticide reduction is less than that in Hebei and Shangdong because the extent of bollworm attacks vary among the locations (Table 4).

The reduction of pesticide use, in turn, meant that farmers also significantly reduced labour for pest control. After holding the incidence of pests, pesticide price, and farmer's age and education constant, regression analysis finds that Bt cotton adopters use significantly less pesticides when pesticide use is measured by the number of sprayings, the quantity of pesticide used, or total cost [Huang, Hu, Pray, Qiao and Rozelle 2002].

The decrease in pesticide use has improved the pest control measures and increased production efficiency. In all locations and in both 1999 and 2000, the yields of Bt cotton are higher than non-Bt cotton (Table 4). Because the price of Bt and non-Bt varieties were the same, the yield increase and costs savings enjoyed by Bt cotton users reduced the cost of producing a kilogram of cotton by 28 per cent, from $2.23 to $1.61 in Heibei and Shangdong in 1999 [Pray et al 2001]. Multivariate production efficiency analysis demonstrates that the results are statistically valid [Huang, Hu, Qiao, Rozelle and Pray 2002].

China's experience with Bt cotton demonstrates the direct and indirect benefits of its investment in plant biotechnology research and product development. According to a recent study, the total benefits from the adoption of Bt cotton in 1999 were $334 million [Huang, Rozelle, Pray and Wang 2002]. Ignoring the benefits created by foreign life science firms, the benefits from the main variety created and extended by one of China's publicly funded research institutes were $197 million. Farmers captured most of the benefits since government procurement prevented cotton prices from declining (which would have shifted some of the benefits to consumers). Hence, the social benefits from research on one crop, cotton, in only the second year of its adoption were enough to fund all of the government's crop biotech nology research in 1999. As Bt cotton spreads, the social benefits from this crop will easily pay for all China's past biotech expenditures on all crops.

Our research shows that farmers reduced use of toxic pesticides, organophosphates and organochlorines, by more than 80 per cent and that this reduction appears to have improved farmer health. The survey asked farmers if they had suffered from headaches, nausea, skin pain, or digestive problems after applying pesticides. If the answer was 'yes', it was registered as an incidence of 'poisoning.' In 1999 survey, only 5 per cent of Bt cotton growers reported poisonings; 11 per cent of the farmers using both Bt and non-varieties reported poisonings; while 22 per cent of those using only non-Bt varieties reported poisonings (Table 5). The surveys in Henan in 2000 even had more strong evidence showing the health and environmental benefits of Bt cotton to the cotton farmers. None Bt cotton growers reported poisonings, while 29 per cent of cotton farmers who planted only non-Bt varieties reported poisonings (Table 5).

Finally, field interviews also show that insect biodiversity appears to have been enhanced by the adoption of Bt cotton. Local government authorities in Hebei province in 1997 found 31 insect species in Bt fields of which 23 were beneficial while non-Bt fields contained 14 species of which 5 were beneficial [Pray, Ma, Huang and Qiao 2000].

VI
Concluding Remarks

Agricultural biotechnology is considered by Chinese policymakers as a strategically significant tool for improving national food security, raising agricultural productivity, and creating a competitive position in international agricultural markets. Alongside these aims, China also intends to position itself as a world leader in biotechnology research. This objective is closely linked to the perception of policy-makers that there are risks associated with reliance on imported technologies to guarantee national food security. Despite the growing debate worldwide on GM crops, China has developed agricultural biotechnology decisively since the mid-1980s. By 2001, China had the fourth largest sown area of GM crops in the world. Research and development has continued apace, and China now has about 20 genetically modified plants that are in the pipeline for commercialisation.

The institutional framework for supporting agricultural biotechnology research programme is complex both at national and local levels. However, the coordination among institutions and consolidation of agricultural biotechnology programmes will be essential for China to create an even stronger and more effective biotechnology research programme in the future. The growth of government investment in agricultural biotechnology research in China has been remarkable. In contract to

Table 4: Yield and Pesticides Application on Bt and Non-Bt Cotton, 1999-2000

	Yield (kg/ha)		Pesticide use (kg/ha)	
	Bt cotton	Non-Bt Cotton	Bt cotton	Non-Bt Cotton
1999	3371	3186	11.8	60.7
2000	2237	1901	18.0	48.5

Sources: Data for 1999 are from 282 households survey in Hebei and Shangdong provinces, data for 2000 are from 147 households survey in Hebei province. Cotton production in Henan in 2000 was seriously affected by flood such had much lower yields than in 1999.

Table 5: Impact of Bt on Farmer Poisoning 1999-2000

		Farmers Planting Non-Bt Cotton Only	Farmers Planting Both Bt and Non-Bt Cotton	Farmers Planting Bt Cotton Only
1999	Farmers	9	37	236
	Number of poisonings[a]	2	4	11
	Poisonings as per cent of farmers	22	11	5
2000	Farmers	31	58	58
	Number of poisonings[a]	9	11	0
	Poisonings as per cent of farmers	29	19	0

a: Farmers asked if they had headache, nausea, skin pain, or digestive problems when they applied pesticides.
Source: See Table 4.

stagnating expenditures on agricultural research in general, investments in agricultural biotechnology have increased significantly since the early 1980s. While the number of researchers increased rapidly over the past 15 years, investment measured as expenditure per scientist more than doubled.

Examination of the research foci of agricultural biotechnology research reveals that food security objectives and farmers' current demands for specific traits and crops have been incorporated into priority setting. Moreover, the current priority setting for investments in agricultural biotechnology research has been directed at commodities for which China does not have relative comparative advantage in international markets such as grain, cotton and oil crops. This implies that China is targeting its GMO products at the domestic market. The emphasis on developing drought resistant and other stress tolerant GM crops also suggests that biotechnological products are not only being geared at high-potential areas, as critics argue but also at the needs of poorer farmers.

The review of the Bt cotton impact studies shows that there is evidence that small farmers obtain increased incomes from adoption of Bt cotton. More significantly the use of Bt cotton has substantially reduced pollution by pesticides in the regions where it was adopted. Incidents of poisonings through farmers' and farm labourers' exposure to pesticides have declined markedly. Some argue that insect biodiversity also appears to have been enhanced by the adoption of Bt cotton.

Although China is still struggling with issues of consumer safety and acceptance, many competing factors are putting pressures on policy-makers to decide whether or not to continue with the commercialisation of transgenic crops. The demand of producers (for productivity-enhancing technology) and consumers (for cost savings), the current size and rate of increase of research investments, and past success in developing technologies suggest that products from China's plant biotechnology industry are likely to become widespread inside China. The Chinese experience suggests that more developing countries should seriously consider allowing the cultivation of GMOs such as Bt cotton, where they offer an effective way of controlling serious cotton pests, reducing pesticide use, and improving the health of farmers and farm workers. In addition developing country governments should be open to potential benefits from adoption of other biotechnological innovations while taking due consideration of their social, environmental and food safety impacts.

Notes

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1 Chinese farmers have not been allowed to grow GM tobacco since 1995. This policy measure is a response to strong opposition from tobacco importers from the USA and other countries.

2 The issues related to biotechnology development and impacts can also be found in several papers written by the authors with their collaborators, including Huang, Wang, Zhang and Zepeda (2001), Huang, Rozelle, Pray and Wang (2002), Huang, Wang, Zhang and Keeley (2001), Pray, Ma, Huang and Qiao (2001), Huang, Hu, Rozelle, Qiao and Pray (2002), and Huang, Hu, Pray, Qiao and Rozelle (2002).

3 Applications were made after the creation of the Office of Genetic Engineering Safety Administration (OGESA) which was established in the MOA in 1996.

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