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From Lab to Field: The Development and Impact of Agricultural Biotechnology in China

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Abstract: Over the past three decades, researchers in China's agricultural biotechnology laboratories have developed hundreds of novel crop varieties suited to China's growing conditions and agricultural challenges. Among them are varieties designed to more effectively resist pest and disease outbreaks, require less water or fertilizer, and supply higher nutritional value than their predecessors. Many of these crops have been developed using transgenic techniques, which allow for highly specific transfer of genetic material through methods other than conventional cross-breeding. These techniques have generated controversies in some parts of the world. Despite their widespread application in China's laboratories, only one transgenic crop, insect-resistant cotton, is widely planted on farms. In a new book entitled Agricultural Biotechnology: Origins and Prospects, the origins of China's emerging agricultural biotechnology research system are introduced. How the impact of China's investment, both locally and globally, depends on factors beyond the laboratory are explained: the funding and performance of both biotechnology and conventional agricultural research, the strength of China's biosafety oversight, the effectiveness of seed delivery channels, and public acceptance of the technology in China and abroad.

Key words: biotechnology; China; rural development; transgenic crops

从实验室到田间：中国农业生物技术的发展及其影响

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摘　要：在过去的三十年间，中国从事农业生物技术研究的科技工作者已经培育了数百个适合中国自然生长条件并满足其它不同农业需求的新型农作物新品种。其中，有的可以更有效地抵抗害虫和病害爆发，有的可以节约水分和肥料，有的则具有更高的营养价值。许多这样的作物品种是通过转基因技术培育而成，也就是有目的地将供体的遗传物质转移到受体作物中，而毋需通过传统的杂交育种手段。这样一种转基因技术在一些国家引发了广泛的争议。在中国，尽管转基因技术研究在实验室内正在广泛开展，但到目前为止，只有转基因抗虫棉真正在农业生产上发挥着作用。在名为中国“农业生物技术：兴起和前景”的新书中，笔者首先介绍了目前在中国正蓬勃开展的农业生物技术研究产业，然后详细论述了中国对农业生物技术的投资在中国国内和全球范围内所产生的影响，这种影响如何依赖于实验室之外的一些因素：传统农业研究和生物技术方面的所获基金支持及其成效，中国对于生物安全性所持谨慎态度的影响，种子流通渠道的效率，以及国内外公众对转基因产品的接受程度。

关键词：生物技术；中国；农村发展；转基因作物

Over the last thirty years, China has developed one of the largest public research programs in agricultural biotechnology in the world. Scientists are now applying both advanced genomics and highly specific transgenic (also known as genetic engineering or genetic modification) techniques to perform specific transfers of desirable genes into crop plants, expanding upon the range of genetic combination that can be produced by conventional cross-breeding methods. Hundreds of novel varieties have been

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developed, including strains that can more effectively resist pests, tolerate drought or salt stress, or supply higher nutritional content. Many of the crop design efforts are tailored to the contemporary challenges facing China's agricultural sector. These encouraging trends, combined with recent discoveries in underlying plant science and biotechnology fields, suggest that China is emerging as a major center of innovation in agricultural biotechnology research.

In the book *Agricultural Biotechnology in China: Origins and Prospects*, to be published in 2007 by Springer[1], we begin by chronicling how and why China's leaders built an agricultural biotechnology research enterprise from the ground up. We then explore the potential implications of China's agricultural biotechnology programs for scientists, farmers, and consumers in China and around the world.

1 Rationale for China's Agricultural Biotechnology Investment

Technological solutions to agricultural challenges are nothing new in China. Since the earliest days of agriculture, farmers have sought to improve crop productivity and reduce daily toil, often by developing new tools and techniques. From the iron ploughshares of the Han dynasty to the early ripening rice pioneered during the Song dynasty to high-yielding hybrid crops of the twentieth century, breakthroughs in agricultural technology throughout China's history have enabled cultivated land to expand, states to emerge, and population to grow. China's arable land is very limited, especially given its population of 1.3 billion. As a result, farmers have grown adept at cultivating marginal lands (see Fig.1), while seeking technologies that enhance productivity.

Fig.1 Since China's arable land is limited, farmers have developed cultivation methods for farming even on difficult terrain

The twentieth century ushered in new yield-enhancing technologies for agriculture, many of them based on advances in the fields of biology and chemistry. Techniques for breeding hardier crops and developing chemical fertilizers and pesticides favored agricultural productivity growth in many parts of the developed and developing world, especially in the Americas, Europe, and Asia. These techniques were also spread widely in China through the country's extensive agricultural research system, which was established in its present form by the late 1950s.

Since the start of China's economic reform and opening in 1978, China's farmers have faced a new set of challenges. The agricultural sector would have to support the world's largest and growing population, without exacting the environmental toll of previous technologies. In particular, chemical pesticides have harmed the health of farmers who applied them and left residues in commercial food products and the environment. Together with chemical fertilizers, they have also polluted groundwater and soils. Meanwhile, economic growth has been placing increasing demands on water resources and land for development purposes, while favoring a shift in consumer tastes toward meat and high-value crops that require more land and agricultural inputs to sustain.

These challenges have coincided with national aspirations to build an internationally recognized and competitive science and technology research enterprise. Although biotechnology had been among the top priorities of science and technology planners prior to 1978, sustained funding for agricultural biotechnology was first granted under the National High Technology Development ("863") Program in March of 1986[2,3]. While other state- sponsored research initiatives also provided support for agricultural biotechnology research (and some exclusively focused on transgenic crops), the 863 Program administered by the Ministry of Science and Technology has remained among the largest and most influential. Most of the early efforts were focused on research with direct commercial applications with the aim of spurring growth in priority sectors. The government made significant investments in laboratory infrastructure and supporting facilities. By the late 1990s, however, research funds were expanded to support fundamental research in plant biology and biotechnology, which focused on advancing basic knowledge in part to sustain technology development over the long term. Funding from international organizations, such as the Rockefeller Foundation, also provided support for many of China's first biotechnology researchers in the late 1980s and 1990s. In the book, we describe the impact of these domestic and international initiatives on building biotechnology research capacity in China.

2 Research Progress and Farm-level Impact

Increased support at the national level has helped to foster the emergence of agricultural biotechnology research on the mainland. This development relied heavily on the expertise of scientists returning from overseas training. By the mid-1980s, scientists based at Peking University, China Agricultural University, the Institute of Microbiology at the Chinese Academy of Sciences, and several other institutes at the provincial level had produced China's first transgenic crops. Transgenic virus-resistant tobacco was the first of these crops to be commercialized in the early 1990s. Although commercial approval was later revoked due to concerns about its acceptance in overseas markets, work on many other transgenic crops continued to gain momentum during the 1990s[4]. Research agendas also expanded focus on non-transgenic applications of agricultural biotechnology, which rely on conventional breeding rather than direct transfer of one or more genes to produce desirable genetic combinations.

So far, several varieties of transgenic insect-resistant cotton (also known as Bt cotton) are the only transgenic crops accepted by regulatory authorities to have been widely planted on farms. Developed in China by scientists at the Chinese Academy of Agricultural Sciences, Bt cotton was among the first crops to receive official commercialization approval from China's first biosafety committee in 1996[5]. Around the same time, Bt cotton developed by the multinational company Monsanto also received approval. Taken together, Monsanto and CAAS Bt cotton varieties had expanded to cover over 3.5 million hectares, or 60 percent of China's cotton planting area, by 2006[6]. Studies by the Center for Chinese Agriculture Policy of the Chinese Academy of Sciences document significant increases in cotton yield and farmer incomes, along with reductions in pesticide sprayings and associated farmer health problems, based on comparisons of adopting and non-adopting households[7,8,9]. These observed benefits may help to explain why the technology was rapidly adopted, often by smallholder farmers with an average farm size of less than one hectare[7].

Aside from Bt cotton, very few other transgenic crops have been approved for commercial planting in China, nearly all of them around the end of the 1990s. This near-standstill in approvals has coincided with growing opposition to transgenic technology in some parts of the world. China's biosafety authorities responded by reexamining and modifying its biosafety framework to include more comprehensive monitoring for risks and provisions for labeling products containing transgenic material. Meanwhile, laboratory research has continued apace, with hundreds of crop varieties receiving approval for controlled environmental release trials since 1997. One of the most prominent candidates in trials has been varieties of insect-resistant and blight-resistant transgenic rice[10]. Although several varieties have completed the final stages of field trials, successive votes by the biosafety committee have refused approval on the basis that additional studies are needed. In contrast, non-transgenic varieties do not face the same stringent approvals, and enhanced varieties are reaching farmers in many areas.

3 From the Laboratory to Farmers' Fields: Many Challenges Remain

Although scientists have made great strides in the laboratory, matching scientific advances to rural needs is a complex and delicate endeavor. First, research must be responsive to the challenges facing farmers, and the technology's developers must have adequate funding and support to engage in research. Second, seed delivery channels must make the new technologies developed in laboratories accessible and affordable to farmers, while maintaining providers' incentives to offer improved seeds. Third, farmers and consumers are only likely to accept more controversial applications, such as transgenic crops, if they are certain the crops are safe and offer an advantage over conventional varieties. This assurance requires a sophisticated and well-enforced biosafety regulatory system, as well as quality assurance mechanisms to verify seed and product quality. These challenges are described in detail in the book, so we mention only a few salient points here.

Although biotechnology research in China is growing strong, its impact on rural areas depends on the responsiveness of biotechnology research agendas to agricultural needs and its integration within the broader agricultural research system. China has an extensive agricultural research system with established expertise in soil science, agronomy, breeding, and other related disciplines, which will be essential to overcoming many of the country's agricultural challenges. Indeed, if the conditions of the agro-ecosystem or varieties used are not suitable to local growing conditions, the tools and techniques of biotechnology are of little use. However, initial increases in biotechnology research funding were not accompanied by corresponding increases in funding for agricultural research more broadly. More recently, these trends have shown signs of reversal, as indicated by recent funding increases for agricultural research and emphasis on greater integration of research agendas for agriculture and related biotechnology applications.

The introduction of the laboratory into the crop improvement process is fundamentally changing the origins of seeds in China's agricultural system. For most of history, farmers saved seeds each season for replanting the following year, and varieties were freely disseminated among neighbors. Today, as laboratories develop seeds with certain advantages over saved varieties, new paths for delivering seeds to farmers are emerging. Since seeds are easily reproducible, companies often need a mechanism for recovering revenues so that they can continue to develop and provide enhanced varieties. In the case of Bt cotton, CAAS and Monsanto initially had to compete with numerous small seed companies that reproduced and distributed counterfeit Bt cotton seed[11]. The situation was complicated by the effects of market reforms on China's seed delivery channels and the extension system, which were both expected to rely more on commercial revenues instead of state allocations for core funding. Such institutions had few incentives to promote a technology that could threaten their own business. Further market reforms and clarification of institutional mandates are needed in order for China's seed delivery system to provide efficient, well-managed channels for moving suitable products from laboratories to farms.

Finally, more controversial applications of biotechnology, such as transgenic crops, may entail unforeseen risks that merit the tighter scrutiny of regulatory authorities. Although China established a biosafety regulatory system in the mid-1990s, and strengthened it in the early 2000s, the discovery of unapproved transgenic crops or unlabeled derived products suggests that the system still has many gaps. A robust biosafety system is the most convincing proof a country can offer to demonstrate its capacity to manage transgenic crops, both to its citizens and its trade partners. Moreover, as international media reports of public opinion on transgenic crops increasingly reach Chinese citizens through open media channels, the demand for evidence of the safety of transgenic methods, as well as information on the technology in general, can be expected to rise. Scientific literacy initiatives, combined with strong biosafety oversight, may help to ease any potential concerns that China's regulatory authorities are not capable of safely managing the technology.

4 Future Prospects for Agricultural Biotechnology

At present, China's investment in agricultural biotechnology shows no signs of slowing. This trend raises the urgency of addressing the challenges listed above in order to maximize the benefits of research programs, while minimizing any risks that may be associated with the introduction of new crops, particularly those developed with transgenic techniques. In the book, we evaluate the prospects for overcoming these challenges. Finally, we conclude with several insights into how China's emergence as a major research center might influence the development of agricultural biotechnology—and the adoption of transgenic crops—both in China and around the world.

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