# Postprint: Current Status and Issues in China's Bio-seed Industry Development

**Authors:** Peijuan Chi, Hualing Xie, Zhao Ping, Chen Fang, Wu Ning, Tian Zhixi, Yang Weicai, Yang Yanping, Yang Yanping

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## Abstract

The biological seed industry is a strategic core industry. Currently, biotechnology combined with digital technology is propelling the seed industry into an intelligent era, with the breeding paradigm shifting from "experimental selection" to "computational selection". The biological seed industry has become an R&D-intensive industry, with a highly concentrated market dominated by large multinational corporations. China and the United States lead globally in scientific and technological output in the biological seed industry, ranking among the top two worldwide in terms of the number of published papers and authorized patents. In terms of core competitiveness, the United States is a global leader, possessing absolute advantages in original basic research and core technologies; in recent years, China has made considerable progress in the application of breeding technologies, but still requires breakthroughs in basic theoretical research, core technology development, and the cultivation of market-dominant varieties.

## Full Text

## Development and Issues of Biotech Seed Industry in China

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**Affiliations:** National Science Library, Chinese Academy of Sciences; Department of Information Resources Management, School of Economics and Management, University of Chinese Academy of Sciences; Institute of Genetics and Developmental Biology, Chinese Academy of Sciences

**Abstract**

Biotech seed industry is a strategic core industry. The integration of biotechnology and digital technology has propelled the seed industry into an intelligent era, transforming the breeding paradigm from "experimental selection" to "computational selection." The biotech seed industry has become research and development-intensive, with markets highly concentrated under the control of large multinational enterprises. China and the United States lead global scientific and technological output in this field, ranking top two worldwide in both published papers and authorized patents. In terms of core competitiveness, the United States stands as the global leader with absolute advantages in original basic research and key technologies. While China has made substantial progress in breeding technology application, breakthroughs are still needed in basic theoretical research, core technology development, and cultivation of commercially dominant varieties.

**Keywords:** biotech seed industry, breeding technology, innovation competitiveness, industrial competitiveness

## Introduction

Agriculture is the foundation of the nation, and seeds are the foundation of agriculture. The seed industry is critical for ensuring food security and national security. According to the Food and Agriculture Organization of the United Nations, improved varieties have been a major factor in significantly boosting global crop yields, contributing to 50% of yield increases in the 20th century. Biotech seed industry is a strategic and foundational core industry that utilizes various biotechnologies to cultivate new biological varieties, involving breeding technologies such as hybrid breeding, molecular marker-assisted breeding, transgenic breeding, gene editing breeding, and genomic selection breeding.

In recent years, China's biotech seed industry has achieved considerable development, effectively ensuring stable domestic supply of grain and important agricultural products. However, it faces a series of challenges. For instance, China imports large quantities of feed grains such as soybeans and corn, with significant yield gaps compared to developed countries. Some high-quality fruit and premium vegetable seeds remain dependent on imports, as do core livestock and poultry breeds such as dairy cows and white-feathered broilers. To ensure food security and win the battle for seed industry revitalization, China urgently needs to enhance the competitiveness of its biotech seed industry through scientific and technological innovation.

This study adopts an intelligence research methodology to examine global biotech seed industry development trends from a whole-industry-chain perspective, analyze the global competitive landscape of seed industry scientific and technological innovation, and focus on dissecting the current status and bottlenecks of China's biotech seed industry development, providing references for China's biotech seed industry development strategy.

## Global Innovation Trends in Biotech Seed Industry

### The Global Seed Industry Enters the Intelligent Breeding Era Marked by Convergent Development of Gene Editing, Synthetic Biology, and Artificial Intelligence

The global seed industry has evolved through three eras—primitive breeding, conventional breeding, and molecular breeding—and is now entering the 4.0 era: the intelligent breeding era. This transition has dramatically improved breeding precision and efficiency. In recent years, important breeding technologies such as gene editing breeding, genomic selection breeding, and design breeding have developed rapidly. The proportion of related published papers among total biotech breeding papers has increased annually [Figure 1: see original paper]. Simultaneously, multiple countries have relaxed regulation of gene-edited products. For example, the United States and Japan have approved several gene-edited agricultural products for market release, including high-oleic soybean oil, $\gamma$-aminobutyric acid-enriched tomatoes, red sea bream with increased muscle mass, pufferfish with doubled growth rates, and waxy corn with high amylopectin content.

Intelligent breeding has emerged as a new frontier in seed industry development, with the breeding paradigm shifting from "experimental selection" to "computational selection." In recent years, several developed countries and regions have strengthened forward-looking intelligent breeding deployment. Between 2018 and 2021, Japan invested 1.148 billion yen (approximately 58 million RMB) to develop foundational technologies for gene editing and data-driven breeding. In 2021, the United States invested $25 million (approximately 170 million RMB) to establish the Center for Research on Programmable Plant Systems (CROPPS) to advance the new field of digital biology. The Netherlands invested approximately €50 million (approximately 360 million RMB) in the same year to launch the Plant-XR artificial intelligence breeding program. Major breeding companies are also vigorously promoting intelligent breeding R&D. For instance, seed giants such as Syngenta and BASF have collaborated with genomic big data company NRGene to develop intelligent breeding technologies.

### Development of Biotech Seed Industry as High R&D Investment and High Market Concentration

With the integration of biotechnology, digital technology, and the seed industry, biotech seed industry has become R&D-intensive. In 2018, the combined R&D investment of the world's top 10 seed enterprises reached $4 billion, with average R&D expenditure accounting for approximately 15% of sales—comparable to the pharmaceutical industry. According to AgFunder, a U.S. venture capital platform, the global agricultural biotechnology industry attracted $2.6 billion in venture capital investment in 2021, with funding primarily flowing to gene editing, synthetic biology, and digital genomics. International seed industry competition has intensified, and after multiple rounds of mergers and acquisitions, the market is highly concentrated under the control of large multinational

corporations such as Bayer, Corteva, Syngenta, and BASF.

## Global Scientific and Technological Competitiveness in Biotech Seed Industry

### China and the United States Lead Global Scientific and Technological Output

Over the past 30 years, the pace of scientific and technological innovation in biotech seed industry has accelerated, with both annual paper publications and authorized patents showing upward trends. The United States and China far exceed other countries in paper publications and authorized patents, placing them in the first tier . China ranks first globally in paper publications and second in authorized patents, with significant growth momentum—surpassing the United States in annual paper publications by 2010 and in annual authorized patents by 2020. The United States ranks second in paper publications and first in authorized patents, with authorized patents accounting for 51.6% of the global total, demonstrating outstanding technological innovation capability. In addition to China and the United States, developed countries such as Japan, Germany, and France also possess strong innovation capabilities, ranking among the top 10 globally in both metrics.

### U.S. Dominance in Basic Breeding Theory and Core Technology Innovation

Basic breeding theory research is the source of seed industry innovation, and its representative core papers exert broad influence on applied research and technology development. By defining core papers as those ranking in the top 1% in both patent citations and paper citations in the breeding technology field (with manual screening), analysis reveals that the United States published 62% of global core breeding papers, primarily concentrated in transgenic breeding, molecular marker-assisted selection breeding, genomic selection breeding, and gene editing breeding. Beyond the United States, countries such as Japan and Belgium also possess advantages in breeding theoretical innovation, while China shows almost no major theoretical breakthroughs. Simultaneously, the United States holds 80% of global core patents, maintaining a monopoly position in breeding technology development, while China's core patents amount to only 1/28 of the U.S. total—a massive gap.

### Outstanding Industrial Strength and Innovation Capability of Global Seed Giants

After several rounds of mergers and reorganizations, the global seed industry has formed a tripartite structure dominated by Bayer, Corteva, and Syngenta. In 2020, Bayer, Corteva, and Syngenta ranked as the top three global seed companies by sales, accounting for 23%, 17%, and 7% of global seed sales respectively. In terms of innovation capability, these three companies hold 41.7%, 27.5%, and 3.9% of global core patents respectively, with the former two collectively

holding 69.2% of global core patents—demonstrating exceptional performance.

## Current Status and Issues of China's Biotech Seed Industry

### China's Seed Industry Competitiveness Needs Improvement, and Enterprises Have Not Yet Become Innovation Leaders

*(1) Large but Not Strong Market with Low Concentration*

During the 13th Five-Year Plan period, China's average annual seed output value reached 120 billion RMB, making it the world's second-largest seed market. Chinese seed enterprises Syngenta and Longping High-Tech rank among the global top 10 by revenue. However, compared with developed countries, China's industrial competitiveness still shows significant gaps. First, China's crop seed import-export trade has long been in deficit, with a 49,300-ton deficit in 2020, requiring substantial imports of high-quality forage seeds. Second, Chinese breeding enterprises are numerous but small, with low market competitiveness and concentration. In 2020, excluding Switzerland-based Syngenta (acquired by China National Chemical Corporation), Chinese biotech seed companies achieved sales of 77.7 billion RMB, with only one company exceeding 2 billion RMB in sales. The combined revenue of these domestic enterprises is roughly equivalent to Bayer's seed sales alone ($10.3 billion, approximately 70 billion RMB). The top 10 domestic enterprises account for less than 15% of China's market share, while Bayer and Corteva together command 40% of the global market.

*(2) Enterprises Have Not Yet Played the Leading Innovation Role, with Low R&D Investment and Weak Core Competitiveness*

Enterprises have not become the main innovation drivers in China's biotech seed industry, holding only 36% of China's core patents, with the majority coming from universities and research institutions. This misalignment of innovation 主体 functions leads to slow commercialization of advanced breeding technologies. Chinese enterprises' R&D investment is relatively low, totaling 5.6 billion RMB in 2020, representing 7% of sales, while the world's three major seed giants typically invest over 12% of sales in R&D. Chinese enterprises also lack technological innovation capabilities, with leading companies Syngenta and Longping High-Tech collectively holding only 4% of global core patents, compared with 69.2% held by European and American giants Bayer and Corteva.

### Insufficient Core Scientific and Technological Competitiveness in China's Biotech Seed Industry, with Lagging Commercialization of Gene Editing and Other Breeding Technologies

*(1) Lack of Original Innovation in Basic Research and Need for Optimized Technology Layout*

Biotech seed industry innovation heavily relies on superior gene mining and breeding technology innovation. China lags behind developed countries in su-

perior gene mining, lacking independently discovered key genes with major industrial value. Crop germplasm resource utilization rate is only 3%-5%, and breakthroughs in molecular regulatory mechanisms of complex traits remain elusive. China has few theoretical innovations in breeding technology, with most original technologies coming from Europe and the United States. China's research layout for important breeding technologies also lags behind the United States. By 2021, papers in gene editing breeding, genomic selection breeding, and design breeding accounted for only 18% of China's total breeding technology papers, compared with 34% in the United States. Particularly, China's genomic selection breeding and design breeding papers represent only 2% and 5% respectively, far behind the U.S. figures (both at 13%).

*(2) Core Patent Holdings Far Behind the United States, with Key Patents Controlled by Foreign Entities*

China holds only 7% of global core patents related to biotech seed industry, while the United States accounts for 80%. In terms of patent layout, European and American countries have already mastered core patents for foundational biotech seed industry technologies such as gene editing. China has only a small number of core patents in applied R&D of foundational technologies, making it difficult to bypass foreign core patents in breeding technology development, and product industrialization will face intellectual property constraints.

*(3) Lack of Breakthrough New Varieties with Major Application Prospects*

China's independently bred varieties account for over 95% of major crop planting areas, but most varieties lack innovation and market competitiveness, with serious homogenization and few dominant varieties that can be widely promoted. In 2020, only nine crop varieties in China had promotion areas exceeding 10 million mu, and the combined promotion area of top 10 varieties for major crops such as rice, wheat, corn, and soybeans did not exceed 32% of total promotion area. Additionally, China's commercialization of gene-edited products lags behind the United States and Japan. The U.S. and Japan have approved five gene-edited agricultural products for market, while China has only issued its first and only agricultural gene editing biosafety certificate for a domestically developed high-oleic acid gene-edited soybean. According to the European Commission's New Genomic Techniques data platform, 150+ gene-edited products will enter the global market in the next 5-10 years, with China's potential market entries accounting for less than 16% of the U.S. figure.

**Relatively High Breeding Technology Level for Staple Grains, with Room for Improvement in Other Species**

*(1) Secure Supply of Staple Grains like Rice and Wheat, with High Rice Breeding Level*

In terms of supply, China's average self-sufficiency rates for rice and wheat over the past five years have exceeded 100%, ensuring overall supply security. Yield levels are 1.5 and 1.6 times the global average for rice and wheat respectively.

In breeding technology, rice has reached internationally leading levels, with core patents ranking first globally at 29.6% of the world's total in rice. Wheat breeding level needs further improvement.

*(2) Expanding Supply-Demand Gap for Feed Grains like Corn and Soybeans, with Significant Breeding Technology Gap with the United States*

In supply terms, China's average self-sufficiency rates for corn and soybeans over the past five years were 96% and 15% respectively, with extremely high soybean dependence on imports consistently exceeding 80 million tons. In yield levels, China's corn and soybean yields are 59% and 58% of U.S. levels, indicating substantial room for improvement. In breeding technology, China's core patents for corn and soybeans do not exceed 40 each, less than 1% of the U.S. holdings, while U.S. core patents account for 89.0% and 93.6% of the global total respectively, demonstrating absolute advantage.

*(3) Basic Self-Sufficiency in Most Livestock and Poultry, but Breeding Technology Level Far Behind Major Countries like the United States*

In supply terms, China's average self-sufficiency rates for pork, beef, mutton, and chicken over the past five years were 95%, 80%, 94%, and 99% respectively, with basic self-sufficiency except for beef. However, overall livestock production levels are low, particularly for beef cattle and dairy cows. In 2020, China's carcass weights for pigs, beef cattle, sheep, and chickens were 81%, 65%, 104%, and 85% of global averages respectively, with dairy cow milk production at about 65% of global average. In breeding technology, China holds 22.1% of global core patents in livestock breeding, second only to the United States at 36.7%, but with far fewer overseas patent layouts than the U.S. and other developed countries. In germplasm supply, China remains dependent on imports for core germplasm of mainstream livestock breeds such as great-grandparent pigs and white-feathered broiler grandparent stock, lacking specialized beef and dairy cattle breeds.

*(4) High Vegetable Production Level but Large Breeding Technology Gap with Developed Countries*

In supply terms, China ranks first globally in vegetable production, accounting for approximately 52% of global total output, with average self-sufficiency exceeding 100% over the past five years. China is a major vegetable exporter with annual net exports of about 9 million tons, representing approximately 15% of global export trade. Production levels are 1.3 times the global average. However, in breeding technology, China holds only 14 core patents in vegetables, accounting for merely 2.2% of the global total, far behind the United States (263) and the Netherlands (187). In germplasm supply, China's import dependence for seeds of carrots, spinach, onions, premium tomato varieties, and sugar beets exceeds 90%.

**Policy Recommendations**

*(1) Strengthen Top-Level Seed Industry Design and Optimize Breeding Research Layout*

To ensure food security in the new era, China must comprehensively optimize top-level seed industry design. First, strengthen basic research layout by enhancing innovation capabilities in germplasm resource identification and superior gene mining, and intensifying basic theoretical research in biotech seed industry to ensure a continuous source of breeding innovation. Second, strengthen research layout for important breeding technologies, attaching great importance to developing gene editing breeding, genomic selection breeding, and design breeding to expand competitive advantages in the new round of seed industry transformation. Third, strengthen germplasm supply research layout, focusing on breeding innovation for agricultural products with large supply gaps such as forage and feed grains to achieve self-sufficiency as soon as possible.

*(2) Strengthen Development of Key Biotech Seed Industry Technologies and Vigorously Develop Intelligent Breeding Technologies*

China's core scientific and technological competitiveness in biotech seed industry lags far behind Europe and the United States. Key foundational technologies such as gene editing primarily originate from Europe and the United States. China should strengthen core technology R&D to develop proprietary intellectual property rights for new gene editing tools and synthetic biology technologies to avoid IP constraints on core technologies. Facing the imminent intelligent breeding era, major European and American countries and large breeding enterprises have strengthened intelligent breeding technology development and data platform construction. China started late in this area and should accelerate forward-looking layout in computational breeding, establish an independent and controllable biological data platform and core instrument equipment guarantee system, and promote the application of emerging biotechnologies, big data, and artificial intelligence in breeding.

*(3) Further Optimize the Breeding Innovation Chain and Guide Enterprises to Play the Leading Innovation Role*

China's biotech seed industry innovation chain suffers from misaligned functions among various entities. China should encourage universities and research institutes, agricultural research institutions, and enterprises to focus on original basic research, applied basic research, and product development respectively, creating a clear division of labor and efficient collaboration in the biotech seed industry innovation chain. In enterprise cultivation, China should formulate differentiated support policies: on one hand, accelerate the cultivation of flagship leading enterprises by promoting mergers and reorganizations among seed companies, supporting enterprises in establishing large-scale R&D platforms and innovation consortia, and driving the aggregation of resources, talent, and capital toward enterprises. On the other hand, actively nurture a batch of specialized platform

enterprises targeting cutting-edge core technologies, encouraging outstanding researchers to participate in innovation and providing specialized technologies or services at key points in the industrial chain.

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**CHI Peijuan** is a librarian at the National Science Library, Chinese Academy of Sciences. Her research focuses on strategic intelligence and evaluation studies in agriculture and biology. E-mail: chipj@mail.las.ac.cn

**YANG Yanping** is a professor at the National Science Library, Chinese Academy of Sciences, and a master's supervisor at the School of Economics and Management, University of Chinese Academy of Sciences. Her research focuses on agricultural science and technology strategy. E-mail: yangyp@mail.las.ac.cn

*Note: Figure translations are in progress. See original paper for figures.*