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Development Strategy of Internet Plus Modern Seed Industry

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Abstract: The seed industry is the chip of agriculture, and its modernization is a significant symbol of agricultural modernization. The Internet Plus Modern Seed Industry is an important application scenario of modern agriculture and a concentrated embodiment of scientific and technological innovation in the seed industry. Based on the Internet plus modern seed industry's concept definition and main characteristics, coupled with field investigation and expert consultation, this study examines the characteristics, supporting technologies, and typical applications of application scenarios for different subjects, such as government departments, scientific research institutions, and breeding bases, to determine the challenges and demand for infrastructure, data sharing, key technologies, and the commercialization system of the Internet plus modern seed industry in China. In addition, we propose a development strategy, a technical roadmap, and major demonstration projects to provide a scientific reference for the development of the modern seed industry. Specifically, we urgently require major demonstration projects for big data platforms providing germplasm resources, new infrastructure for Internet plus modern seed industry bases, more Internet plus modern seed industry data-sharing platforms, and expanded big data intelligent services for the seed industry. Moreover, the intelligent equipment research, development, and manufacturing and the commercialized breeding software industries should be encouraged to comprehensively promote the intelligent development of the modern seed industry.

Keywords: Internet plus; modern seed industry; application scenarios; commercialized breeding; major demonstration project

1 Introduction

The seed industry is the chip of agriculture; as such, its foundational, strategic, leading, core, and guiding roles in agricultural development have become increasingly prominent. There is an urgent need for the seed industry to prioritize development and lead breakthroughs for high-quality agricultural development, cultivation of new driving forces for growth in the industry, and the acquisition of agricultural competitive advantages. At the beginning of the 21st century, the United States, Israel, the European Union, and others preliminarily realized the integration of the seed industry with new-generation information technologies such as big data, artificial intelligence (AI), cloud computing, and the Internet of Things (IoT). Consequently, these nations have achieved greater technological innovation and breakthroughs in breeding technology research and development (R&D), seed reproduction, commercial breeding, and expansion of the seed industry chain. Compared with developed countries,

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China is still in the primary stage of seed industry development, focusing on hybrid breeding and molecular technology-assisted breeding. Although mobile Internet, AI, blockchain, big data and other technologies have also been applied in key seed industry links, such as breeding R&D, seed production and marketization, and a series of technical achievements have been achieved, on the whole, China's Internet Plus seed industry technology R&D started late. The level of development is relatively insufficient, and a crop intelligent design and breeding technology system applicable to China's unique agricultural situation has not been established, which prevents its seed industry from moving toward the era of intelligent breeding 4.0.

Scientific and technological innovation are the essence of seed industry competition, which, in turn, determines the independent innovation and development of the industry [1]. Domestic and foreign studies on scientific and technological innovation in the seed industry mainly focus on key breeding technologies, new variety creation, commercial breeding platform innovation, etc. The first type of research concerns the breeding development stage. After the three landmark stages of domestication, genetic, and molecular breeding, breeding technology gradually developed to the stage of intelligent design breeding, thereby promoting the transformation and upgrading of the modern seed industry [2,3]. Second, research has been conducted on breeding technology innovation. With the deep integration of new-generation information technology, intelligent equipment technology, and biotechnology (e.g., big data, cloud computing, and AI), breeding technology is also gradually moving toward more precise, intelligent, and intelligent engineering design and breeding. High-throughput access facilities and equipment technology [4,5], sensor technology [6,7], phenotype intelligent analysis [8,9], and multi-recombination big data analysis technology [10,11] are widely used in breeding. The best genotype for a breeding target can be obtained to efficiently and accurately breed new varieties, which greatly shortens the breeding cycle, improves breeding efficiency, and effectively promotes the transformation and upgrading of the seed industry [12]. Third, previous studies have explored variety innovation. In general, since the Ministry of Agriculture accepted the first application of new varieties of agricultural plants on April 23, 1999, the number of applications and authorizations for new varieties in China's seed industry has increased steadily and breeding innovation ability has been gradually enhanced [13]. The Jingke 968 [14], Jinghua No. 12 [15], and other excellent varieties have been bred and achieved remarkable results in the national adaptability test, demonstrations, and promotion. Fourth, in terms of commercial breeding platform innovation, international seed companies such as the Syngenta Group, the Bayer Corporation, and the BASF Corporation have successively built the AgriEdge Excelsior platform, FieldView platform, and xarvioTM platform, respectively, to realize storage of massive amounts of breeding data, efficient analysis of complex data, and scientific management of large systems and provide simple, efficient, and accurate services. As early as 2005, China also started to prepare for the establishment of the National Agricultural Science Data-sharing Center to effectively revitalize, mine, rescue, and preserve China's agricultural science and technology resources and achieve data sharing and integrated application [16,17].

The existing literature on China's modern seed industry mainly focuses on the penetration of modern biotechnology in the breeding field; in particular, modernized breeding of different varieties. However, few studies have explored the penetration of Internet, big data, AI, etc. into the modern seed industry, and the exploration of application scenarios is unclear. Specifically, little attention has been paid to Internet Plus modern breeding technologies (e.g., IoT technology, phenotype group big data analysis technology, crop phenotype, environment big data technology, and breeding big data storage management and application technology); the application technology system and technology path of the modern Internet Plus seed industry remain unclear. Therefore, there is an urgent need for research based on the current status and needs of China's Internet Plus modern seed industry to put forward an application technology system and roadmap and study its future development path.

2 Major application scenarios of the Internet Plus modern seed industry

Leveraging the development of new-generation information technology with big data, cloud computing, blockchain, IoT, 5G, and other technologies as the core, China's seed industry is integrating mobile Internet, AI, blockchain, big data, edge computing, and other new-generation information technologies with modern biotechnology such as molecular markers, transgenes, gene editing, molecular design, and breeding. It has cultivated application scenarios for different subjects, (e.g., government management departments, scientific research institutions, and breeding enterprises) with the aim of comprehensively improving the digitalization and intelligence level of different links throughout the industrial chain, including seed breeding, promotion, supervision, and service. Additionally, it has promoted the development of breeding specialization, production standardization, service integration, management informatization, and technical equipment precision. Further, it

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provides effective support for accelerating seed industry revitalization, achieving self-reliance in seed industry science and technology, and establishing independent and controllable seed sources.

2.1 Concept and characteristics of the Internet Plus modern seed industry

According to China's effort in strengthening its seed industry and the author's team research and exploration of commercial seed breeding systems, big data of plant phenotype omics, and intelligent design breeding in recent years, the Internet Plus modern seed industry explored in this study centers on the needs of relevant subjects in the industry chain (e.g., breeders, seed enterprises, government agencies, and production entities). To this end, it combines the latest theoretical innovations in life science, information science, etc., relying on the cross-integration and collaborative innovation of life technology (e.g., molecular markers, whole genome sequencing, gene editing, and biosynthesis) and information technology (e.g., big data, AI, blockchain, and sensor technologies). Moreover, it explores the transformation and upgrading of the entire chain of the seed industry via digitalization, networking, cloud-based transformation, and intelligent upgrading and aims to realize the digitalization of modern seed industry variety innovation, intelligent production and management, and an ecological industrial system to achieve a new form of industry—seed industry 4.0—with flexible user service. Thus, the Internet Plus modern seed industry has the characteristics of promoting the precision of breeding technology, restructuring the ecological seed breeding system, supporting the digitalization of business management, and realizing intelligent user service. Accordingly, it plays a vital role in promoting the integrated, high-quality development of the entire seed industry chain that includes breeding, promotion, management, and service, facilitating turnaround in the industry and promoting China's transformation from a big to a powerful player in the seed industry.

2.2 Development status and application scenarios of the Internet Plus modern seed industry

2.2.1 Major research and development status of China's Internet Plus modern seed industry

In recent years, the Chinese government, research institutions, and seed enterprises have gradually increased the integration of new-generation information technology with breeding, seed production, industrialization, and other aspects to achieve a series of technological innovations and breakthroughs.

Biotechnology and information technology have been gradually integrated**.** In terms of breeding technology R&D, based on big data technology, we conducted multi-omics research that combines genomic data with phenotypic group, transcriptome, and metabolome data. The functions of a large number of unknown genes were quickly decoded, providing an important technical and theoretical basis for an intelligent breeding design. For example, in 2020, Huazhong Agricultural University integrated genome, transcriptome, phenotypic group, metabolome, epigenome, genetic variation, and genetic mapping results from the same maize population; built a comprehensive maize database (ZEAMAP); embedded a "browser" and "search engine" for genomes; and achieved high integration, rapid retrieval, and intelligent analysis of relevant genome data [18]. In 2016, the Institute of Botany of the Chinese Academy of Sciences developed Crop 3D, the first crop high-throughput three-dimensional phenotype monitoring platform based on lidar technology in China, which integrates four sensors: lidar, high-resolution camera, multispectral, and thermal imaging. This platform can not only extract conventional parameters (coverage, vegetation index, leaf temperature, etc.) but also monitor the entire growth period of crops through quantitative measurement efficiency, as well as assist in indoor breeding screening, crop modeling, and stress response analysis [19].

Information technology equipment has been gradually applied to seed production. With regard to R&D in seed breeding technology, China has developed information and automatic systems and equipment and applied them to field experiments, seed production, and seed processing, which has greatly improved the efficacy of breeding experiments and seed production. For example, since 2017, the Ministry of Agriculture and Rural Affairs has promoted information technology equipment in 117 national and regional breeding bases for improving varieties, integrating pest monitoring and early warning with green prevention and control, soil moisture monitoring and early warning with irrigation, agricultural machinery and unmanned aerial vehicle (UAV) equipment, new IoT, UAV remote sensing and driving, and other technologies. These have been combined with automatic and intelligent detection instruments and equipment, such as seed testing and yield measurement, which has helped bases such as the conventional rice and wheat breeding bases in Huachuan County, Heilongjiang Province and Huaxian County, Henan Province, respectively, to achieve qualitative leaps in their capacity to provide improved varieties. Another example is the Beidou-based agricultural machinery, which is capable of automatic navigation

and can precisely measure operations. Specifically, it utilizes control key technology developed by the National Engineering Research Center for Information Technology in Agriculture (NERCITA), which has broken through the bottleneck of automatic navigation technology to achieve adaptive operation of agricultural machinery in complex working conditions and established a mechanized operation-intelligent monitoring technology system that oversees the entire process.

Support is now provided for the entire process of information management and breeding traceability. As regards R&D on commercial breeding technology, in 2016, NERCITA closely combined information technology (e.g., the IoT with commercial breeding technology), integrated and applied computer and geographic information systems, AI, and other technologies, and developed China's first Internet Plus commercial breeding big data platform with fully independent intellectual property rights—the Golden Seed Breeding Cloud Platform—to provide resource management of germplasm, test planning, a character collection application (APP), variety breeding, regional tests of varieties, pedigree management, data analysis, a breeding traceability service of breeding that covers the entire process based on electronic tags, etc [20]. At present, the Golden Seed Breeding Cloud Platform has carried out cooperation, application, and promotion in breeding units such as Yuan Longping Agricultural Hi Tech Co., Ltd., Sichuan Agricultural University High Tech Agriculture Co., Ltd., and China Agricultural University. Huazhi Rice Biotechnology Co., Ltd. developed a modern breeding software platform called Huazhi Breeding Housekeeper. The platform covers eight core modules including germplasm inventory, breeding activities, variety testing, molecular breeding, mobile applications, and system management. It can provide management services such as breeding materials, cross matching, field testing, breeding data analysis, and comprehensive variety evaluation.

2.2.2 Main application scenarios of China's Internet Plus modern seed industry

The current Internet Plus modern seed industry mainly focuses on the needs of different subjects, such as government management departments, breeding research institutions, breeding bases, and seed market. It has built Internet Plus platforms, including China's seed industry big data platform and a national crop germplasm resource sharing service platform, with four application scenarios (as shown in Table 1).

Table 1. Main application scenarios of Internet Plus modern seed industry.

Application mode	Support technologies	Service subject	Main features	Typical applications
Big data platform of seed industry supervision	Big data technologies such as data collection, cleaning, storage, analysis, mining, and precise retrieval and visualization	Government management departments and relevant law enforcement departments	Can realize real-time collection and acquisition of multi-source heterogeneous, massive big data in the seed industry; process and provide decision support for massive data; realize convenient visualization of seed industry big data; and sharing and co-construction	China Seed Industry Big Data Platform
Germplasm resource management platform	Database technology, radio frequency identification devices (RFID), etc.	Breeding research institutions, breeding companies, government management departments	Can realize the digitalization and information management of germplasm resources, share information on germplasm resources, and facilitate the mining and utilization of germplasm resources	National Crop Germplasm Resources Sharing Service Platform
Seed industry IoT	QR code, sensor network, video surveillance, mobile communication, RFID and other technologies	Breeding institutions and breeding bases	Can realize the information perception of breeding/the breeding environment, conduct intelligent analysis of seedling growth information, and oversee the entire process automatic management of seedling growth	Top Cloud
Socialized service platform of seed industry	Big data technology, cloud computing, AI, etc.	Seed enterprises, breeding institutions, large growers, and other seed demanders	Can provide financing and trading services based on electronic trading information system; meet the individual needs of various subjects in the seed industry market; and provide precise services such as seed industry consultation, policy consultation, and seed industry product trading	China Seed Trading Network, China Agricultural Technology Promotion Information Platform

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For government management departments: The big data platform for seed industry supervision is supported by the analysis, mining, and visualization of the big data of the seed industry and provides accurate data information services covering various seed industry data such as variety approval, registration, protection, and promotion. The platform can realize variety traceability, including seed quality traceability, market subject traceability, one-stop information queries, and business handling. Given the collection, processing, analysis, and utilization of seed industry data as its core, it is characterized by a large amount of data, strong decision support ability, convenient service, and support for public welfare. Regarding practical applications, China's seed industry big data platforms use the Internet, big data, and other information technologies to integrate the data on seed industry management at the national, provincial, municipal, and county levels in accordance with the principles of unified data format, data interface, and data application. Thus, it seeks to disclose information, strengthen supervision, and optimize services to open up variety approval, registration, protection, seed production, and operation license information related to seed industry management, such as seed market supervision. Through the interconnection of seed industry information and public sharing of data, it has made varieties traceable, improved seed quality and market subjects, effectively solved the information island phenomenon in China's seed industry, and provided technical support for comprehensively improving the level of seed industry management.

For breeding research institutions: The germplasm resource management platform is used for the digital management and utilization of crop germplasm resources and genetic materials, such as grain, cotton, oil, and vegetables. The data of the germplasm resource management platform include germplasm investigation, introduction, preservation, monitoring, identification, evaluation and utilization data, crop variety pedigree, regional testing/demonstrations/validation data, and crop fingerprint and DNA sequence data. It establishes a unique identification for each seed through bar code or electronic label technology for proper storage of breeding resources and breeding of excellent varieties. From the perspective of practical applications, China has established a platform that enables the sharing of national crop germplasm resources and developed germplasm resource information system for Chinese crops. Its main users include government decision-making departments, new variety protection and approval institutions, researchers of germplasm resources and biotechnology, breeders, germplasm bank management, introduction and investigation personnel, farmers, and enterprises of feed, wine making, pharmacies, food, beverages, tobacco textiles, and environmental protection. In addition to the functions of data generation, maintenance, query, report printing, and data connection and transformation, the National Crop Germplasm Resources Database System also realizes the mathematical statistical analysis of large samples, crop pedigree analysis, graphic analysis, multi field classification statistics, etc., which can provide germplasm information for the national agricultural production and scientific research institutions.

For breeding base: The seed industry IoT, which is based on two-dimensional code, sensor networks, video monitoring, mobile communication, RFID, and other information technologies, uses temperature, humidity sensors, optical sensors, carbon dioxide sensors, seed testing systems, intelligent germination equipment, automatic transplanting machinery and equipment, and other equipment to establish an IoT system covering three layers of perception, transmission, and application. It can display the breeding and related environment parameters in real time, automatically control the breeding process, and realize the automation, digitization, and intelligence of the entire breeding process to ensure that the seedlings have a good and suitable growth environment. It can significantly reduce the labor cost of breeding and promote the improvement of the quality and efficiency of breeding. At this stage, many practices have been carried out in the typical scenarios of the seed industry IoT for breeding and breeding bases. For example, the seed testing system, leaf shape measuring instrument, crop canopy analyzer, intelligent light incubator, etc., which were independently developed in China, can conduct all-round detection from the roots, stems, leaves, and fruits of seeds, thereby providing the most suitable environment for seedling production. Meanwhile, the platform can be used with intelligent agricultural machinery and APP to achieve networking and intelligent crop variety breeding. Qionglai City, Sichuan Province, has successfully promoted seed testing, yield measurement, plant character monitoring instruments, etc. to build it the Silicon Valley of China's seed industry.

For seed markets: The socialized service platform of the seed industry is an intelligent service platform that serves the entire chain. It covers pre-production, in-process, post-production, packaging, sales, and other links and gathers upstream and downstream enterprises in the form of service products to connect and communicate with service organizations through the platform to promote the reasonable flow of seed industry service resources. It applies advanced big data, cloud computing, AI, and other information technologies for personalized information pushes and provides personalized and comprehensive information services for seed trading parties, service

providers, and the public. The platform can summarize and organize the seed and seedling supply and collected demand information, regularly update and publicize it, timely provide first-hand information for farmers, cooperatives, planting companies, etc. in the production area, and offer relevant quality, technology, traceability, and other services for customers who need it. With continuous updating and development of information technology, it is necessary to increase the construction of network seed channels in the future. Through the construction of technology platforms, and with the help of the current perfect network payment, logistics, and traceability fidelity systems, the flattening and disintermediation of seed sales channels can be boosted.

3 Development demand of China's Internet Plus modern seed industry

Although China has started to apply Internet Plus information technology and intelligent equipment in the modern seed industry, it is still in the initial exploration stage. It remains reliant on foreign countries for some technical equipment, and some scenes are only used for demonstration, which has not yet been widely promoted or applied in China. There is still a need to further strengthen the digital upgrading of China's seed industry infrastructure, the co-construction and sharing of germplasm resource information, as well as other practical needs.

3.1 Missing germplasm resources and information collection equipment and the need to further strengthen seed industry informatization and digital infrastructure

Compared with the United States, Germany, and other advanced countries' seed industry development, the degree of seed industry informatization in China is not high, and the facilities and equipment needed for the development of seed industry informatization need to be further improved. Taking the remote sensing technology required in breeding and seed reproduction as an example, UAV low-altitude remote sensing technology has the advantages of high throughput, positioning accuracy, efficiency, and flexibility. Breeding information collection based on this type of sensing can more deeply analyze crops' genetic characteristics, tap into the potential characteristics of crop growth, and effectively improve breeding efficiency [21]. However, at present, the popularization rate of agricultural remote sensing in China remains low. Most of the existing collection equipment is located in modern agricultural demonstration areas, agricultural informatization demonstration bases, or used in laboratory breeding in qualified scientific research institutions and has yet to be popularized in breeding and breeding bases. Therefore, it is urgent to strengthen the informatization transformation of modern seed industry infrastructure on the basis of existing agricultural informatization and digitalization; to create an Internet Plus seed industry infrastructure layout featuring interconnection, joint construction and sharing, and the trinity of provinces, cities and counties; promote the application of UAVs, intelligent sensors and other phenotypic information acquisition technology and equipment in the seed industry; and create a standardized and networked seed industry information monitoring infrastructure for modern breeding. Additionally, the development of multiple species provides data and computational support.

3.2 Existence of obstacles in seed industry data sharing, and urgent need to further strengthen the mechanism of germplasm resource information-sharing

At present, the degree of sharing and utilization of crop germplasm resources in China are insufficient. On the one hand, the information-sharing mechanism of crop germplasm resources is imperfect, which makes it difficult to effectively use excellent germplasm resources. At present, scientific researchers mainly learn about and obtain relevant crop germplasm information by searching the extant literature or through germplasm exchange between scientific research institutions, or self-collection of germplasm. Therefore, crop germplasm resource information-sharing services cannot fully satisfy the needs of scientific research and agricultural promotion [22]. Due to the limitations of the domestic breeding system and mechanism, insufficient support for sharing services, the lag in the construction of policies and regulations, and a lack of sharing standards and rules, the breeding process faces constraints such as the lack of connectivity of data resources and frequent occurrence of data islands, which pose certain obstacles to the data analysis work throughout the process of breeding, leading to difficulties in achieving data information exchange in the breeding decision-making process. On the other hand, the construction of the crop germplasm resource sharing platform lags, information from germplasm research is not smooth, and the phenomenon of repeated research is widespread. Therefore, it is urgent to develop a scientific and reasonable germplasm resource benefit-sharing mechanism, integrate the national crop germplasm resource data-sharing platforms, optimize the germplasm resource information-sharing service level, improve the sharing efficiency of germplasm resources, and boost the utilization efficiency of crop germplasm resources. In this way, we can better

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protect and utilize the rich crop germplasm resources in China and improve the overall strength and level of the national agricultural innovation system. Therefore, it is urgent to establish a seed industry big database based on the integration of existing germplasm resources under the top-level design framework, establish and improve the agricultural data resource sharing mechanism based on the agricultural big data-sharing platform, focus on refining the agricultural data sharing evaluation and incentive mechanism of relevant government departments and units, and urge relevant departments to participate in agricultural big data co-construction and sharing with the system.

3.3 Persistent bottlenecks in the key technologies of Internet Plus modern seed industry and the need to further break through the key breeding technology and equipment

China's agricultural sensors as a whole have obvious deficiencies in its research of basic principles, new material applications, core manufacturing process innovation, and other fields, and it is difficult for sensor accuracy to meet the actual application needs. Consider the sensor application in the seed industry IoT system as an example. At present, in addition to the relatively mature air temperature and humidity, light, and carbon dioxide sensors, the R&D level of various sensors: seedling nutrient element (nitrogen), hormone, amino acid, growth phenology, and other seedling life information are relatively low, which makes it difficult to provide valuable data support for breeding. In addition, R&D on intelligent breeding equipment, such as crop phenotype observation, intelligent germination, and automatic transplanting machinery and equipment, started late in China. Although we have a certain foundation at present, there is a big gap between China and developed countries in terms of phenotype high-throughput acquisition, robot arm development, etc., and there are problems such as the "black box" of key technologies and unstable equipment. Meanwhile, the integration of agricultural biotechnology, big data technology, and intelligent equipment is insufficient, which makes the practical application effect of intelligent equipment for breeding and breeding in daily work average and does not show obvious advantages in improving breeding and breeding efficiency. Therefore, we must focus on breaking through core key technologies (e.g., special sensing technology for seed industry information acquisition), building a relationship model between crop phenotype information and growth demand, preparing and improving the reliability of Internet Plus modern seed industry intelligent equipment, forming a set of industry standards for common key technologies, and improving the international competitiveness of China's modern seed industry.

3.4 Limited acceptance of commercial breeding, and urgent need to further promote the commercial breeding system

The acceptance of commercial breeding is limited. First, commercial breeding software has yet to mature. As the core tool of breeding work, commercial breeding software in China still has difficulty meeting the changing needs of breeding, and the applicability of technical products needs to be improved. For example, most of the major breeding software in the market is installed on a computer for use without adapting it to the mobile terminal, which reduces the efficiency and accuracy of breeding data collection and lowers verification. Due to the limitation of the calculation efficiency of the genetic evaluation program, many commercial breeding software tests cannot complete the selection and retention work on the same day, which negatively impacts breeding efficiency. Meanwhile, the mathematical operation model of breeding decision-making is not sufficiently mature, so the quantitative and intelligent decision-making effect of the software is not obvious. Second, because the breeder acceptance is limited and digital literacy needs to be improved, the application of commercial breeding software can weaken breeders' dependence on experience and enhance the breeding accuracy. However, at present, a considerable number of breeders still subjectively prefer traditional breeding methods and conduct breeding through simple data records. Meanwhile, it is difficult for most breeders to actively learn and apply commercial breeding software and cross the threshold of breeding software applications, which hinders the wide popularization and application of breeding software. Therefore, it is urgent to rely on existing commercial breeding technology platforms; integrate molecular markers, gene editing, biosynthesis, phenotype information acquisition, multi-omics big data, and other biological and information technologies; promote the R&D and application of intelligent breeding and analysis models; accelerate the R&D and manufacturing of intelligent equipment for the seed industry; strengthen the cultivation of breeding subjects (e.g., scientific research institutes and large breeding enterprises); and establish and improve the commercial breeding system.

4 China's Internet Plus modern seed industry development strategy and technical route

4.1 Development strategy

The period from the 14th Five Year Plan to 2035 is a critical period for China to move from an all-round well-off society to basic modernization and to achieve self-reliance in science and technology. Seeds are the chips of agriculture. Therefore, we should consider the seed industry as key to tackling agricultural science and technology and agricultural and rural modernization. With the theme of promoting high-quality agricultural development, we should thoroughly implement a national big data strategy, accelerate the construction of digital China, and resolve to promote the national seed industry. We must accelerate the cultivation of fine varieties with independent intellectual property rights, ensure national food security, take reform and innovation as the driving forces, consider the Internet Plus modern seed industry as powerful support for food security and rural revitalization as the main line of development, focus on improving the digital regulatory capacity of the modern seed industry, promote an intelligent transformation layout, and strengthen the joint research and independent innovation of core technologies. We must vigorously promote the construction of the Internet Plus modern seed industry application demonstration base, actively cultivate new types of Internet Plus modern seed industry and new subjects, accelerate the construction of the Internet Plus modern seed industry system with Chinese characteristics, comprehensively promote the informatization of seed industry management, ensure accurate decision-making and intelligent service, and promote the modernization of the seed industry governance system and governance capability to lay a solid foundation for China's agricultural and rural modern seed industry.

4.2 Technical route

By 2025, with the goal of strengthening scientific and technological innovation and realizing the digital transformation of leading enterprises led by the digital seed industry, we hope to cultivate sustainable digital seed industry and value chains and ecosystems and establish and improve the big data platform and working mechanism so that it covers the entire business chain of the crop seed industry. The focus will be on strengthening the deep integration of agricultural biotechnology with digital technologies, such as AI, big data, and intelligent equipment. Meanwhile, research will promote the technical upgrading of commercial breeding information systems and equipment for seed enterprises. Further, we aim to create a multi-dimensional big data-driven precision breeding program for genotype phenotype environments and tackle key technologies such as protection and utilization of germplasm resources, precise identification of germplasm resources, and gene mining based on AI. Extensive research on the methods of node security verification, asymmetric encryption, and data addition consensus models, etc. in the open environment of the blockchain will be conducted. R&D will encompass germplasm resource investigation and collection, resource registration, introduction and exchange, sorting and cataloging, inventory management, nursery stock management, monitoring and early warning, reproduction and renewal, evaluation and identification, distribution and sharing, and monitoring, command and scheduling platforms. Future research should also explore the data sharing methods and cooperation mechanisms of the seed trading market supervision and law enforcement systems and seed industry e-commerce platforms in terms of germplasm resource counterfeiting, early warning of risks, etc.

By 2035, we will accelerate the large-scale application of Internet Plus breeding technology, establish and improve the Internet plus modern seed industry ecosystem, and achieve precision and intelligent breeding as the main goals. Additionally, we will complete the orderly sharing of seed industry big data and the opening of the whole society, realize the precise identification and sharing of germplasm resources, and make breakthroughs in typical applications in key fields such as whole genome selective breeding, precision breeding and large-scale genome editing, and holographic query and verification of crop varieties. Key related technologies include whole genome association analysis and molecular design breeding models, crop molecular physiological and ecological perception mechanisms, high-throughput acquisition technology of plant phenotype information, multi-source heterogeneous phenotype information analysis technology, seed industry intelligent equipment, and commercial breeding software industry core technology. We will also continue to explore intelligent models based on big data and AI technology, such as variety evaluation, ecological region division, and optimal layout of test sites and promote technical upgrade solutions of commercial breeding information systems and equipment for seed enterprises. There will be a focus on the construction of a national Internet Plus modern seed industry data sharing platform, an engineering breeding software service cloud platform and commercial operation platforms based on breeding big data. We will promote the integration of commercial breeding software and the entire seed industry

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chain and promote the development of new agricultural sensor R&D and manufacturing, and the manufacturing of field crop high-throughput phenotype detection equipment and intelligent agricultural machinery equipment, as well as other industries. Finally, we will guide leading enterprises or industry alliances in the seed industry to build a big data platform for breeding and promote the entire industry chain, consolidate the digital upgrading effect of seed industry enterprises' breeding technology, and achieve data decision support for seed industry safety review, early warning, and emergency response.

5 Suggestions on demonstration project of Internet Plus modern seed industry in China

5.1 Suggestions on major projects for the Internet Plus modern seed industry

5.1.1 National germplasm resource big data platform construction project

It is suggested to build a database of crop germplasm resources and manage the information of wild, selected, and introduced germplasm resources and genetic materials of crops such as grain, cotton, oil, vegetable, fruit, sugar, tobacco, tea, mulberry, pasture, and green manure. It is necessary to accelerate the construction of the national germplasm resources big data platform and link it with the national seed industry big data platform to provide management departments with relevant decision-making information on crop resource protection and sustainable utilization, provide information on excellent variety resources for crop breeding and agricultural production, and inform the public of popular scientific information on crop varieties and biodiversity.

5.1.2 Demonstration project of new base infrastructure of national Internet Plus modern seed industry

With the goal of comprehensively improving the information infrastructure construction and service capacity of bases, such as germplasm resource protection, breeding, seed production, variety testing, seed quality supervision, inspection and testing center, with Hainan, Gansu, and Sichuan as the core and a modern seed industry park and Southern Silicon Valley as the focus, we should upgrade seed industry base network access, security monitoring, field automation testing machinery, and indoor phenotype high-throughput observation equipment. There will also be intelligent construction of infrastructure such as data center. We should build a breeding big data platform that integrates phenotype, genotype, and environmental data, assists in screening and selection of field breeding, and improves the informatization and intelligence level of breeding work. Aimed at managing and controlling key links in the production and breeding of major crops, we will continue to maintain a comprehensive monitoring technology based on high-resolution satellite remote sensing, agile micro UAV remote sensing, and ground patrol monitoring. Moreover, a number of digital production and breeding bases for crops should be built with high standards to achieve accurate and efficient management and intelligent decision-making for production and breeding.

5.1.3 National project for constructing an Internet Plus modern seed industry data-sharing platform

We will formulate basic common standards such as digital seed industry metadata and data dictionaries, data quality control, and information security and provide data exchange interfaces for cross-sectoral and cross-regional seed industry information resource sharing. In view of the insufficient openness and sharing of seed industry data and the lack of a seed industry information resource data integration platform and database management system, we will establish a “one network” platform for seed industry government affairs; improve the basic database of seed industry research, production, and operation; and deepen the information and command action linkage platform. We will realize the integration of seed industry data and the interconnection and intercommunication with variety approval and monitoring data. Additionally, we will gradually realize the effective sharing and opening of seed industry data and support the in-depth development of seed industry management and service reforms.

5.1.4 Seed industry big data intelligent service project

Relying on the national seed industry big data platforms and integrating modern information technologies such as IoT, big data, AI, and cloud computing, we will conduct R&D related to the seed industry big data intelligent service platform. For all levels of governments, agricultural enterprises, scientific research institutions, agricultural socialized service organizations, and other types of users, we will provide seed industry big data intelligent services (e.g., precision services, seed information express services, big data services for the healthy development of the seed industry, seed inspector service track nebula map service, seed industry expert community service, and seed industry technology promotion information service) to expand channels for promoting excellent crop varieties and technologies and boost the efficiency of seed industry services.

5.2 Suggestions on industrial development for the Internet Plus modern seed industry

5.2.1 Seed industry intelligent equipment R&D and manufacturing industry

We should increase investment in R&D of core technologies and key bottleneck technologies for plant life information sensors. We must focus on supporting research on the agricultural IoT, plant phenotype recognition, crop growth regulation mechanism models, and other application technologies. Further, we should explore new agricultural sensing mechanisms based on optical, electrochemical, electromagnetic, ultrasonic, and imaging methods. We will research and invent sensitive devices, photoelectric conversion, weak signal processing, and other core components. Additionally, we will study a number of high-precision high-end agricultural environmental sensors, including soil nitrogen, and other nutrient sensors, soil heavy metal sensors, and special sensors for plant physiological and ecological signs. At the same time, we will explore new sensors, such as plant wearable life information sensors, grasp the initiative of international competition, and achieve comprehensive and independent innovation of new sensors for crop breeding. We will accelerate the development of independently controllable indoor and greenhouse high-throughput phenotype acquisition platforms and high-throughput phenotype acquisition systems carried by field UAVs, field phenotype platforms, and agricultural machinery. Moreover, there is an urgent need to speed up the integration and innovation of seed industry equipment digital design, manufacturing process planning, manufacturing process control, and other technologies. We will accelerate the development of intelligent equipment manufacturing industries, such as precision seeders, intelligent harvesting and production measuring machines, phenotype observation equipment, seed selection, and processing lines, and promote the intelligent manufacturing level of key parts and complete machine production lines.

5.2.2 Commercial breeding software industry

Efforts have been made to complement the weaknesses of basic and high-end commercial breeding software. In the future, we will focus on strengthening the deep integration of agricultural biotechnology with digital technologies such as AI, big data, and intelligent equipment. We will research and promote technical upgrades solution for commercial breeding information systems and equipment for seed enterprises. We will create a precision breeding program driven by genotype, phenotype, and environment multi-dimensional big data and build a basic and cutting-edge commercial breeding software industry system at an advanced international level. We will support the integrated enterprise of breeding and promotion to carry out whole genome selection and intelligent breeding and provide science, technology, and service support for targeted and efficient improvement and breeding of new varieties. We will focus on supporting breeding promotion enterprises to use commercial breeding software based on seed industry big data to conduct breeding innovation, test evaluation, and other related R&D and promotion activities. We will promote the commercial operation of the seed industry big data value chain and lead the digital transformation and upgrading of the entire seed industry. We will create a number of domestic commercial breeding software industry R&D and promotion bases and accelerate the construction of the seed industry open source software ecology of crowd research, crowd use, and crowd innovation. Finally, we will guide domestic and foreign breeding units and information enterprises to carry out collaborative innovation cooperation in technology, standards, talents, intellectual property rights, etc. in the field of modern seed industry special software and information services, actively build a high-quality talent team, and support high-quality development of domestic commercial breeding software.

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