



Reorienting Public Agri-Food R&D for Achieving Sustainable, Nutritious, and Climate-Resilient Food Systems in China

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Abstract

The global agri-food system faces huge challenges such as resource and environmental degradation, climate change, and malnutrition and must be transformed to achieve the goals of healthy nutrition, sustainable development, and climate adaptation. Innovation is critical in this regard, and public research and development (R&D) in agri-food systems remains a major force for innovation in the agriculture and food sectors, especially in developing countries. China has made remarkable progress in feeding its growing population and eradicating hunger and poverty. However, its traditional agri-food system is unsustainable because of high inputs use, the exploitation of natural resources, and high pollution. China is also facing a rapid transition from hunger to obesity as well as micronutrient deficiencies. Meanwhile, the adverse effects of climate change on food security, nutrition and health, and sustainable agricultural development are increasing in China.

This project analyzes public R&D programs in the agriculture and food industries in China to identify and address the major gaps in how public agricultural research can be repurposed to transform food systems and thus achieve the country's nutrition and sustainability goals. The objectives of the project includes (a) review major official policy documents on R&D in agriculture, food and nutrition security, the food industry, natural resource management, and climate change; (b) collect data on public and private R&D investment in agri-food systems, including R&D expenditure by local agri-food companies and multinational corporations in China; (c) analyze the patterns and priorities of public and private R&D investment in agri-food systems; (d) review the R&D management system, funding sources, and allocation mechanisms in agri-food systems; (e) identify gaps and explore how to reorient current public and private research funding to address the challenges of the environment, health, and climate change; and (f) communicate the results with decision-makers in government and the private sector as well as other stakeholders.

To accomplish the above research objectives, we first use the data from open-access sources including the National Bureau of Statistics, Ministry of Agriculture and Rural Affairs, Ministry of Science and Technology, National Science Foundation of China, and other relevant national government agencies. We also visit research institutes such as China Agricultural University, the Chinese Academy of Agricultural Sciences, and Jiangsu Academy of Agricultural Sciences to collect the data about R&D inputs and outputs. To explore the role of R&D by the private sector, we collect and analyze data from the food processing industry and

agricultural enterprises. To seek perspectives on future innovation and R&D, we also discuss with government officials and the administrators of R&D institutes and enterprises.

There are three main findings of the study. First, China's public agricultural research system is large, with the highest number of R&D personnel and largest amount of funding in the world. However, the intensity of agricultural R&D investment is low. R&D in China's agri-food system is mainly dominated by public R&D institutes, especially agricultural research institutes and agricultural universities, with a low proportion of private sector enterprises. Hence, innovation capacity is insufficient overall. Second, the main goal of public R&D in China's agri-food system is to increase food production. Less attention has been paid to the problems of resources, the environment, and nutrition and health arising from yield growth, while inputs and outputs related to these have recently grown rapidly. Third, R&D investment in China's agri-food system focuses on the three major staple grains (rice, corn, and wheat) and meat products, with relatively insufficient investment in agricultural products with more nutritional value, such as non-staple grains, fruit, and vegetables.

Based on the above main findings, we make the following three suggestions. First, the goal of R&D in agri-food systems should shift from the previous focus on production to the four development goals of high yield and efficiency, nutrition, environmental sustainability, and climate adaptation. This shift calls for the development of mutually beneficial technologies for both the human and the earth. Second, the agri-food R&D inputs (investment and personnel) should be increased for non-staple grains, fruits, and vegetables, while ensuring adequate investment for major staple grains and meat. Third, while ensuring governmental investment in agri-food R&D, China should introduce a more diversified agri-food R&D program and encourage more private investment in agri-food R&D. The country should create a more enabling environment for the private sector and increase its support for private R&D investment through public-private partnerships, subsidies, financial support, and tax incentives, especially for agri-tech startups.

1 Research background and design

This section first focuses on the background of reorienting public research and development (R&D) in agri-food systems in terms of food system transformation and then presents the research framework and objectives as well as the outline of the report.

1.1 Food system and its transformation

The concept of food systems has recently received increasing attention among scholars and policymakers because of the multiple challenges embedded in global agriculture and food sectors, such as climate change, malnutrition and resource degradation (Béné, et al., 2019; Fan, et al., 2021b). The food system encompasses all the actors involved in food production, harvesting, processing, distribution, consumption, and disposal in the agricultural (including livestock), forestry, fisheries, and food industries; the value-added activities associated with the actors; and the embedded economic, social, and natural environment (HLPE, 2017; FAO, 2018; von Braun, et al., 2021). On the one hand, food system transformation is essential to achieve food security, improve nutrition, and ensure access to healthy diets for all (FAO, et al., 2020). For example, the number and proportion of people in hunger globally increased in 2020 owing to the COVID-19 outbreak, and three billion adults and children now cannot obtain healthy diets due to the excessive economic burden (FAO, et al., 2021). The “perfect storm” of various risks such as climate change, natural resource degradation, biodiversity reduction, and frequent epidemics (Fan, et al., 2021a) is making the failure of the international food market even more prominent (Chen, et al., 2021). On the other hand, the food system is the main driver of climate change, depletion of freshwater resources, and nitrogen and phosphorus pollution. If no measures are taken, the impact of the food system on the environment will exceed a safe limit (Springmann, et al., 2018).

Internationally, the concepts of the food system and its transformation are widely accepted. Global reports include the EAT-Lancet Commission’s “Food, planet and health” in 2019, the Food and Land Use Coalition’s “Growing better: Ten critical transitions to transform food and land use” in the same year, and the Global Panel on Agriculture and Food Systems for Nutrition’s “Future food systems: For people, our planet, and prosperity.” All three reports highlight the need to advance food system transformation and suggest key strategies for doing so. Many international agricultural organizations have also made food system transformation

a priority. For example, the 2020 and 2021 annual reports of the International Food Policy Research Institute (IFPRI) focused on food system transformation (IFPRI, 2020; IFPRI, 2021). The FAO Strategic Framework 2022–31 seeks to support the 2030 Agenda through the transformation to more efficient, inclusive, resilient, and sustainable agri-food systems that can provide everyone with better nutrition, a better environment, and a better life (FAO, 2021). In 2020, Germany announced a sustainable food policy that includes the four dimensions of health, society, the environment, and animal welfare (Yu, et al., 2021a).

In China, academia is also paying increasing attention to food system transformation, especially during the COVID-19 period. The China Agricultural Sector Development Report 2019 by the Chinese Academy of Agricultural Sciences re-estimates the contribution of China's agricultural industry to the national economy from the value chain perspective. The report finds that the value added of the agri-food system accounts for 23.3% of GDP, which is 15.4 percentage points higher than the value added of agriculture alone. Moreover, the employment proportion of the agri-food system amounts to 36.1%, which is 9.2 percentage points higher than the proportion of employment in agriculture alone (Chinese Academy of Agricultural Sciences, 2019). A growing number of scholars have also proposed nutrition-oriented food security strategies (Chen, et al., 2019; Fan, et al., 2020), nutrition-oriented agriculture (Lu, et al., 2019; Sun, et al., 2019), and the transformational development of agri-food nutrition (Chen, 2019). Others have emphasized the shift from the “staple food security” concept to “food security” (Huang, et al., 2021) and the multifunctionality of agriculture (Yu, et al., 2021b). Many research institutes have also established dedicated bodies for food economics and policy, including the Academy of Global Food Economics and Policy at China Agricultural University and Food Economics Research Unit at the Institute of Rural Development, Chinese Academy of Social Sciences. In addition, research institutes have released a number of important reports. For example, in April 2021, five institutes, namely, China Agricultural University, Zhejiang University, Nanjing Agricultural University, the Chinese Academy of Agricultural Sciences, and the International Food Policy Research Institute, jointly released China's first food policy report entitled “Rethinking agrifood systems for the post-COVID world.”

Similarly, policymakers in China are becoming aware of the need to develop a broader perspective of food (Liu, 2021) and food supply security (Chen, 2021). However, the Chinese government's understanding of food systems is mostly from the perspective of the whole agricultural supply chain. For example, in 2020, the National Bureau of Statistics defined

agricultural and related industries as all economic activities formed by the production, processing, manufacturing, distribution, and services of agriculture, forestry, animal husbandry, and fisheries. Although considering the perspective of the whole agricultural supply chain shows some progress, we must continue to think about it in conjunction with nutrition and health, natural resources and the environment and climate change.

1.2 Reorienting public R&D in agri-food systems to promote food system transformation

1.2.1 Transformation of agri-food R&D programs

Scientific and technological (S&T) progress is the primary way to increase the volume of agricultural products. Scientific research is thus crucial for agricultural development, with 15% of global agricultural growth driven by developments in agricultural science and technology (Gong, 2020). With the gradual increase in corn and soybean imports, the main problem of China's food security is the shortage of feed to ensure the safe supply of livestock products. Further, the reduction of corn and soybean imports depends on improving total factor productivity, while innovation in the seed industry is an important way to enhance total factor productivity (Huang, 2021).

While increasing the volume of agricultural products, agricultural R&D has begun to shift from a production orientation to research into areas such as food quality and nutrition, food safety, natural resource and environmental protection, bioenergy, and animal systems and animal health in addition to the two important input areas of cropping systems and crop protection (Wu, 2019; Zhang and Li, 2017). For example, the proportion of agricultural production-oriented investments in US public institutes' agricultural research expenditure declined from 66% in 1975 to 57% in 2007 (Wu and Yan, 2019). Public agricultural research funding in the United Kingdom has similarly shifted from productivity-oriented research to ecological and environmental protection-oriented research, including a focus on the decline in water quality and ecological damage; likewise, the focus of UK agricultural science and technology policy has shifted to environmental protection, food nutrition, and greenhouse gas emissions in the agricultural industry (Gong, et al., 2018). In China, studies have found that agricultural research can mitigate the effects of temperature and precipitation intensity on agricultural total factor productivity, but not those of annual precipitation (Yi, et al., 2021).

1.2.2 Research framework

Agri-food systems must be transformed toward healthier, more equitable, more resilient, and more sustainable systems (Barrett, et al., 2020) to improve both human and planetary health (Fan and Otsuka, 2021). China's future food system transformation should thus achieve the following five development goals: high yield and efficiency (production goal), healthy nutrition (nutrition goal), environmental sustainability and climate adaptation (sustainability goal), greater resilience (resilience goal), and greater inclusivity (inclusivity goal; Fan, et al., 2021b). However, doing so will inevitably involve trade-offs among these development goals, as shown in Figure 1-1. Further, R&D in agri-food systems must also meet the abovementioned five development goals. However, such R&D has its limitations, and some of these five goals may not be able to be accomplished without improving R&D in agri-food systems.

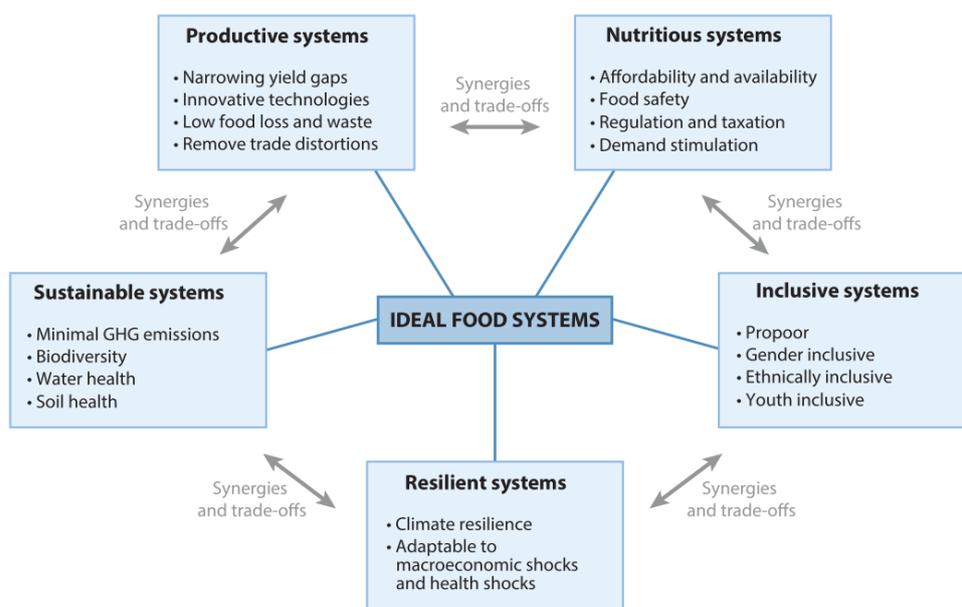


Figure 1-1 Framework for evaluating trade-offs and synergies of food systems for human and planetary health

Source: Fan, et al. (2021b)

Within the framework of the five development goals of agri-food system transformation shown in Figure 1-1, R&D in agri-food systems is more directly related to the production, nutrition, and sustainability goals. Therefore, the ideal R&D program in agri-food systems

should aim to achieve the goals of high yield and efficiency, healthy nutrition, and sustainable development and climate adaptation. Figure 1-2 divides these three goals into four main domains. For high yield and efficiency, R&D in agri-food systems should aim to increase the volume of agricultural products, optimize the structure of agricultural products, and reduce food loss. For healthy nutrition, R&D in agri-food systems should aim to ensure food safety and food quality and promote a healthy diet. For sustainable development, R&D in agri-food systems should aim to reduce resource consumption, maintain soil and water health, and preserve biological diversity. Finally, for climate adaptation, R&D in agri-food systems should aim to reduce greenhouse gas emissions, adapt to climate change, and be resilient to natural disasters.

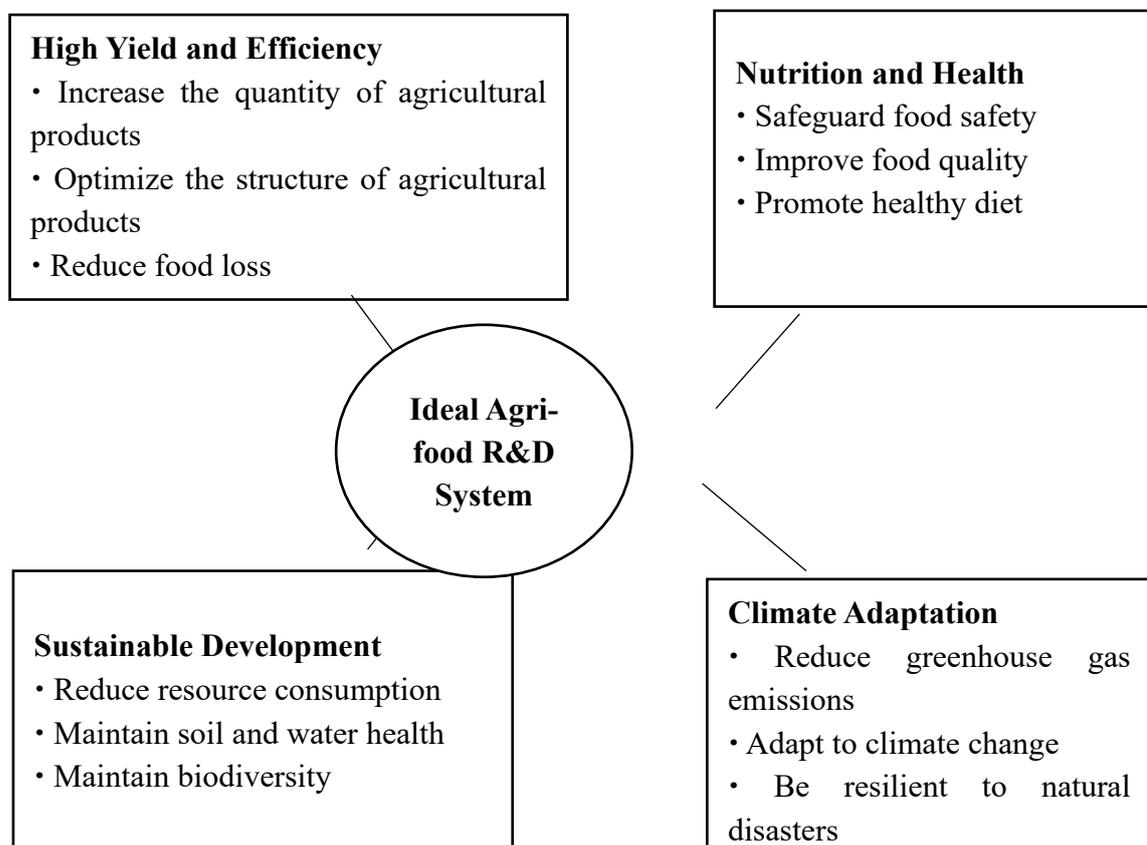


Figure 1-2 Ideal agri-food R&D system

1.2.3 Research objectives

The objectives of this project are sixfold:

(a) To review major official policy documents on R&D in agriculture, food and nutrition security, the food industry, natural resource management, and climate change

(b) To collect data on public and private R&D investment in agri-food systems, including R&D expenditure by local agri-food companies and multinational corporations in China

(c) To analyze the patterns and priorities of public and private R&D investment in agri-food systems

(d) To review the R&D management system, funding sources, and allocation mechanisms in agri-food systems;

(e) To identify gaps and explore how to reorient current public and private research funding to address the challenges of the environment, health, and climate change, and

(f) To communicate the results to decision-makers in government and the private sector as well as other stakeholders.

1.2.4 Report outline

As shown in Figure 1-3, the report has five major sections. Section 1 introduces the concept of food systems and importance of their transformation. Based on the aim to transform the food system, we then develop the research framework of the project.

Section 2 introduces R&D in agri-food systems in China, including China's agricultural research system, which comprises public agricultural research institutes and universities, funding sources, and the allocation of funding.

Section 3 explores the characteristics and trends of public R&D of China's agri-food system using case studies, including the funding of agri-food-related disciplines and various agricultural products in the Life Sciences Division (LSD) of the National Natural Science Foundation of China (NSFC) and the establishment process and input characteristics of China's modern agricultural industrial technology system. It also assesses the research inputs and outputs of three institutions, namely, Chinese Agricultural University, the Chinese Academy of Agricultural Sciences, and the Jiangsu Academy of Agricultural Sciences as well as the input

characteristics of China’s National Special Programs.

Section 4 analyzes the characteristics and trends of private sector R&D in China’s agri-food system. Owing to data limitations, this section focuses on the two aspects of R&D inputs and outputs of the food processing industry and R&D by agricultural enterprises.

Section 5 summarizes the main findings of the project and provides policy recommendations for reorienting public R&D in agri-food systems to achieve sustainable, nutritious, and climate-resilient food systems in China.

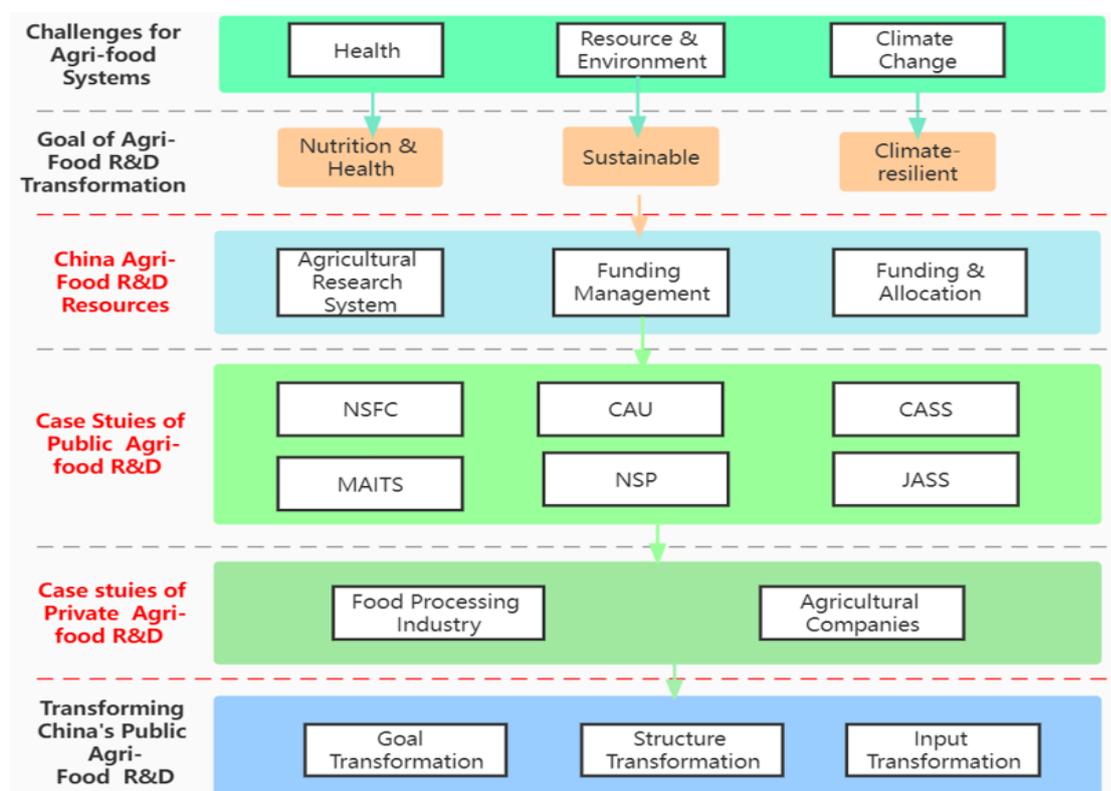


Figure 1-3 Report outline

2 R&D in agri-food systems in China

This section introduces R&D in China's agri-food system from the perspective of China's agricultural research system, funding sources, and allocation of funding.

2.1 China's agricultural research system

China's agricultural research system is an important but complex part of the national research system. Many organizations conduct agricultural research, not only agricultural research institutes and universities, but also general research institutes and enterprises. The central and local governments are responsible for formulating, implementing, and managing policies; building institutes and improving infrastructure; and allocating funding for agricultural research. China's agricultural research system is largely dominated by the public sector, with the government playing an important role. In 2019, 88.4% of R&D funding for public agricultural research institutes came from the government. By contrast, non-governmental stakeholders such as enterprises invest less in R&D. Their interest lies in protecting intellectual property and investing in R&D activities with a high return on investment, such as food processing, agrochemical inputs, agricultural machinery, hybrid seeds, and genetically modified crop breeding (Zhao, et al., 2015).

2.1.1 Management of China's agricultural research system

China's agricultural research system is managed by the national innovation system. The National Science and Technology Leading Group is responsible for formulating national strategies, plans, and major policies for S&T development; discussing and carrying out major national scientific tasks and projects; and coordinating major S&T affairs among ministries, departments, and local authorities. The major responsibilities of the Ministry of Science and Technology include formulating S&T development policies; promoting the building of China's innovation system and S&T decision-making advisory system; coordinating and supervising central government-funded S&T programs (projects and funding); promoting the optimal allocation of S&T resources for building a diversified S&T investment system; drawing up plans, policies, and measures for raising external communication and encouraging projects that promote innovation and cooperation; and organizing and carrying out international exchanges. It has also pioneered a nationally unified S&T information system and developed a mechanism

for allocating, evaluating, and monitoring research funding.

Other institutions are also involved. For example, the National Natural Science Foundation plays an important role in the allocation of R&D funding. In addition, the Development Center of Science and Technology of the Ministry of Agriculture and Rural Affairs, which is part of the Ministry of Science and Technology, is responsible for managing and supervising agricultural and rural S&T projects. The Ministry of Finance is responsible for setting the annual national budget and allocating public funding for agricultural research. The Ministry of Agriculture and Rural Affairs is responsible for implementing agricultural research policies and overseeing agricultural research institutes nationally. Finally, the Ministry of Education is responsible for planning and guiding scientific innovation in universities.

2.1.2 Public agricultural research institutes and universities

China's agricultural research system contains several agricultural research institutes and universities at the national and the local levels, with a large number of researchers. The system is a research institutes-led model that separates their research and education activities (Chen and Zhang, 2010; Chen, et al., 2012).

China has the largest number of agricultural researchers in the world and most work in research institutes. In 2019, there were 1014 agricultural research institutes, accounting for 31.5% of all research institutes in China (MST, 2020). These employed 58,282 R&D personnel, including 50,135 full-time equivalent personnel. Of these, 10,859 held PhDs, 19,011 held master's degrees, and 18,827 held bachelor's degrees, accounting for 18.6%, 32.6%, and 32.3% of the personnel, respectively. In addition, there were 96 agricultural and forestry universities with 57,205 teaching and research staff, including 24,039 researchers engaged in R&D and 14,131 full-time equivalent personnel (Ministry of Education, 2019). In 2018, the number of full-time equivalent personnel in R&D at agricultural research institutes and agricultural and forestry universities reached 63,184, of which 78% worked in research institutes.

China's public agricultural research system is highly decentralized and can be divided into the national, provincial, and prefectural levels according to administrative affiliation (Fan and Qian, 2006). Public agricultural R&D institutes at the national, provincial, and prefectural levels have different responsibilities. National institutes, as part of the Ministry of Agriculture and Rural Affairs, focus on high-tech and general R&D. Provincial institutes mainly conduct

applied research in the context of the local agroecological conditions, while prefectural institutes mainly conduct extension work, including experimental demonstrations and technology dissemination and processing. In 2018, national, provincial, and prefectural agricultural research institutes accounted for 6.9%, 40.4%, and 52.7%, respectively (MARA, 2019).

Finally, China's public agricultural research system is dominated by crop research. In 2019, 487 research institutes were engaged in crop research, followed by 166 research institutes in forestry research, 68 research institutes in animal husbandry research, 46 research institutes in fishery research, and 247 institutes engaging in research across the agriculture, forestry, animal husbandry, and fishery sectors, which accounted for 48%, 16%, 7%, 5%, and 24%, respectively (MST, 2020).

2.2 China's agricultural research funding sources

China's agricultural research institutes receive core funding and program-specific funding. As shown in Figure 2-1, the allocation of core funding, which is mainly used to pay the salaries of the staff at agricultural research institutes, is determined by the Ministry of Finance and local financial departments. This funding supports continuous capacity building and innovative development of public research institutes and their research topics, and the budgets are allocated according to the progress and characteristics of the research institute in question (Zhang and Chen, 2021).

Program-specific funding mainly supports the projects undertaken by research actors. It is divided into stable funding (central/local) and competitive funding. Among the stable funding category, the three largest categories are basic research expenses, program-specific funding for S&T innovation, and program-specific funding for China's modern agricultural industrial technology system. These three categories receive funding directly from the Ministry of Finance. The Department of Science & Technology and Education of the Ministry of Agriculture and Rural Affairs and Ministry of Finance are jointly responsible for managing these three stable funding categories as well as the program-specific funding for the maintenance and purchase of bases (key laboratories, platforms) and central-level scientific institutes. The Ministry of Education and Ministry of Finance jointly manage the basic research

expenses of central universities.

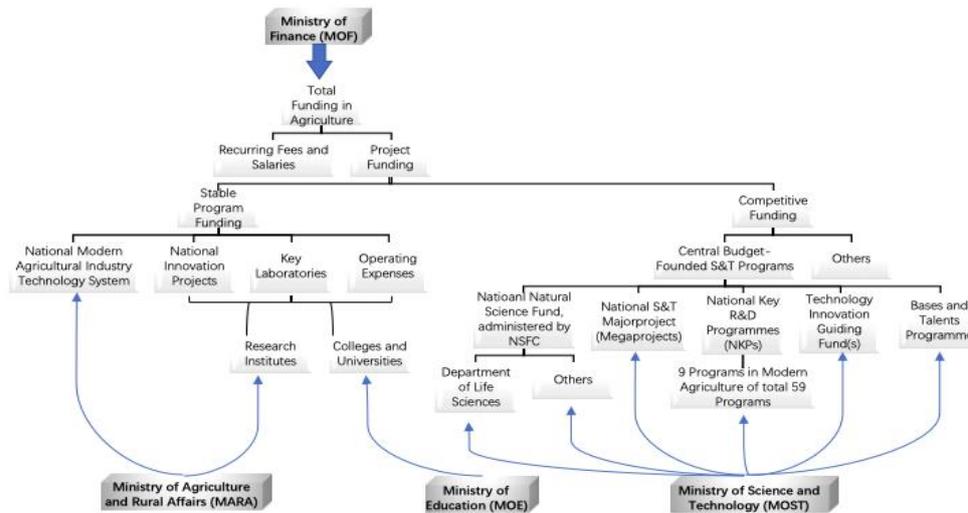


Figure 2-1 Main actors in China's agricultural S&T system, 2019

Source: Zhang and Chen (2021)

Competitive funding, which finances various national S&T projects, is an important tool for the government to support innovation activities. It includes central government-funded S&T research projects as well as other projects. Before 2014, the various S&T projects were fragmented, with more than 40 ministries managing nearly 100 types. However, central government-funded S&T research projects have recently undergone a comprehensive reform. Since 2017, to optimize the funding management system, they have been merged into five plans, namely, the NSFC, the National Major S&T Project (Major Projects), the National Key R&D Program, the Technical Innovation Leading Project (Funds), and the S&T Bases and Talents Plan. These plans are described in more detail below.

The NSFC supports basic research that pushes the boundaries of scientific exploration, promotes skill development and team building, and enhances resource mobilization and innovation capabilities. The National Major S&T Project focuses on providing major strategic products nationally. It also carries out social and public research on China's economy and people's livelihood to address major S&T problems vital to the core competitiveness of industries, ensure independent innovation and national security, and break through technological bottlenecks in major areas of national economic and social development. The

Technical Innovation Leading Project (Funds) mainly provides dedicated funding to support enterprises' technical innovation. The S&T Bases and Talents Plan supports the construction of research bases and cultivation of innovative talent with skills and innovation capabilities to engage in R&D activities (Figure 2-1).

2.3 China's agricultural R&D allocation of funding

2.3.1 Agricultural R&D funding

Owing to the lack of data on China's complex agricultural S&T system, agricultural S&T expenditure in this report only includes the S&T expenditure of agricultural research institutes and agricultural universities and not that of general institutes or enterprises. The scope and concept of agricultural S&T funding in China has constantly been redefined over the past four decades.

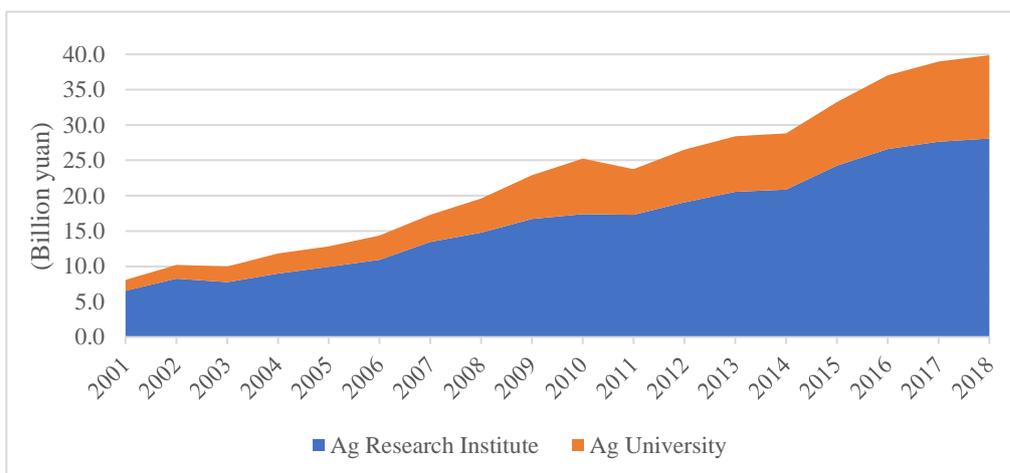


Figure 2-2 China's agricultural S&T revenue

Source: National Statistics of Agricultural Science and Technology, Ministry of Agriculture and Rural Affairs; University of Science and Technology Statistics, Ministry of Education

Note: Data only refer to agricultural research institutes and universities under the jurisdiction of the Ministry of Agriculture and Rural Affairs

Before 2009, agricultural research institutes and universities used total expenditure or revenue from agricultural S&T activities as an indicator of agricultural S&T funding. However,

since then, the Ministry of Science and Technology has only released expenditure on S&T funding for R&D activities, indicating a significantly narrowed definition. In inflation-adjusted terms of 2015, the total agricultural S&T revenue of agricultural research institutes increased from CNY 8.09 billion in 2001 to CNY 39.87 billion in 2018, an average annual growth rate of 13.9%. The S&T revenue of agricultural research institutes increased from CNY 6.52 billion in 2001 to CNY 28.09 billion in 2018, an average annual growth rate of 12%. In addition, the S&T revenue of agricultural universities grew from CNY 1.57 billion in 2001 to CNY 11.78 billion in 2018, an average annual growth rate of 16.7%. The proportion of the S&T revenue of agricultural research institutes decreased from 81% in 2001 to 70% in 2018, compared with an increase from 19% to nearly 30% for agricultural universities (Figure 2-2).

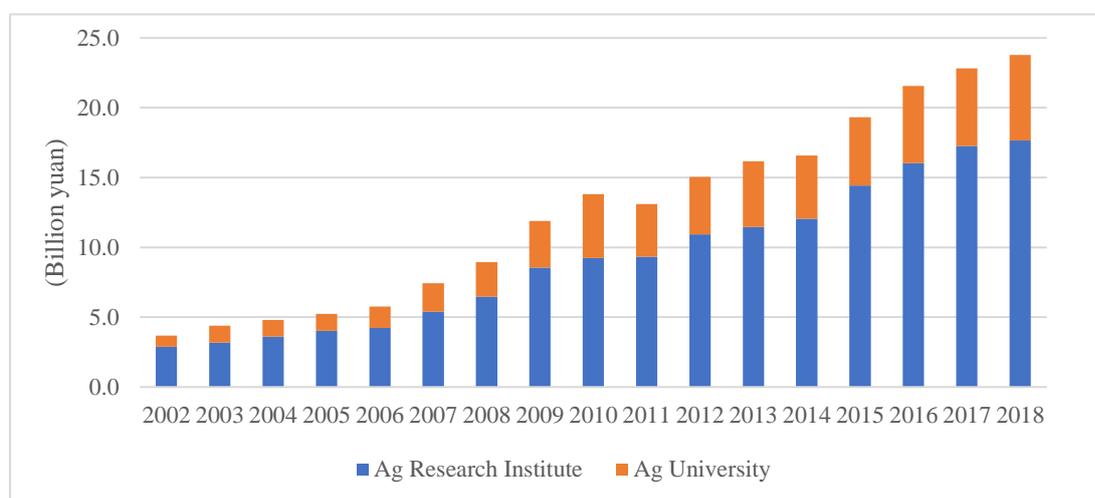


Figure 2-3 Agricultural R&D expenditure in China

Source: National Statistics of Agricultural Science and Technology, Ministry of Agriculture and Rural Affairs; University of Science and Technology Statistics, Ministry of Education

Note: Data refer only to agricultural research institutes and universities under the direct supervision of the Ministry of Agriculture and Rural Affairs

China's agricultural R&D expenditure has snowballed during the past two decades. In 2015 prices, as shown in Figure 2-3, China's agricultural R&D expenditure continuously expanded from \$3.69 billion in 2002 to \$23.79 billion in 2018. Specifically, the R&D expenditure of agricultural research institutes was \$17.65 billion in 2018, accounting for 74% of all agricultural R&D expenditure, whereas that of agricultural universities was \$6.14 billion, accounting for 26%. The growth in the R&D expenditure of agricultural universities

outweighed that of agricultural research institutes over the same period, with annual growth rates of 18% and 16.3%, respectively.

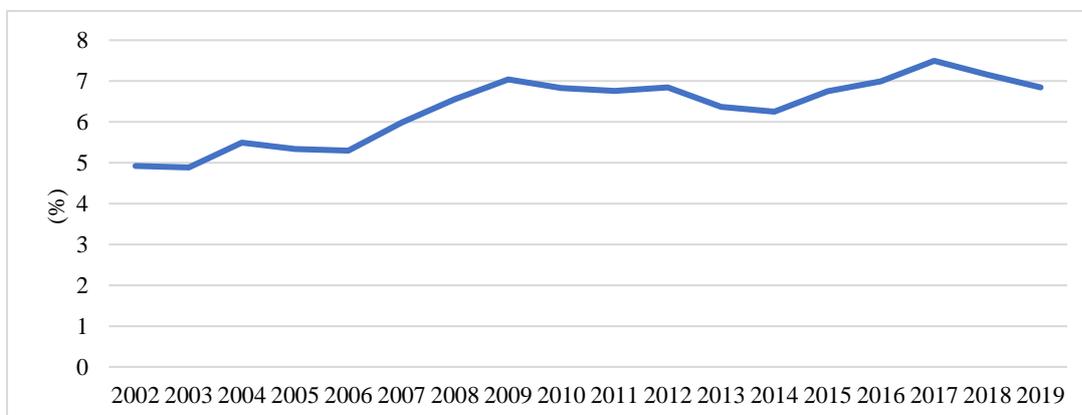


Figure 2-4 The proportion of China’s agricultural R&D expenditures in all public research institutions in China

Source: China Statistical Yearbook on Science and Technology, Ministry of Science and Technology

The proportion of agricultural S&T funding in the total S&T funding of all sectors is relatively low. Although it is difficult to obtain accurate figures on the proportion of agricultural S&T funding due to differences in statistical definitions and scope, data on R&D expenditure from the research institutes of the Ministry of Science and Technology show that the proportion of agricultural R&D expenditure in all public research institutions kept increasing, rising from 4.9% in 2002 to 7.5% in 2017 before decreasing to 6.8% in 2019 (Figure 2-4).

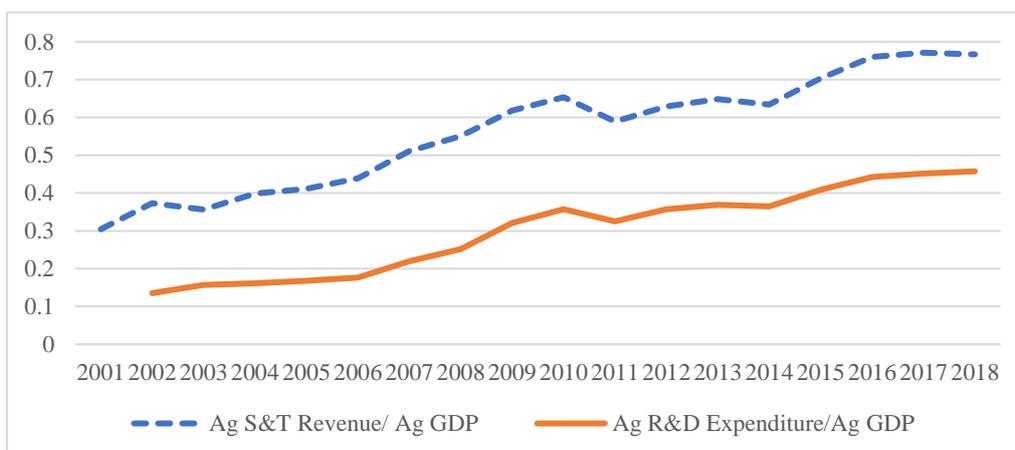


Figure 2-5 China's agricultural research investment intensity (%)

Source: National Statistics of Agricultural Science and Technology, Ministry of Agriculture and Rural Affairs; University of Science and Technology Statistics, Ministry of Education; China Statistical Yearbook on Science and Technology

Agricultural research intensity in China is also rising. However, compared with that of developed economies and other sectors, it is still low and must be strengthened. The ratio of agricultural S&T revenue to overall agricultural GDP increased from 0.30% in 2001 to 0.77% in 2018. The ratio of agricultural R&D expenditure to agricultural GDP increased from 0.14% in 2002 to 0.46% in 2018. Agricultural research intensity again lagged far behind the global average intensity of 1% and the 2% average in developed countries (OECD, 2018). Furthermore, agricultural research intensity in China is markedly lower than its average intensity of all industries nationally, which is around 2% (Figure 2-5).

2.3.2 Sources of agricultural R&D funding

China's agricultural R&D funding is mostly provided by the government. Figure 2-6 compares the sources of R&D funding for agricultural research institutes in China in 2002 and 2019. The government's proportional provision of all agricultural R&D expenditure expanded from 80.9% in 2002 to 88.4% in 2019. In addition, enterprise funding increased from 1.1% in 2002 to 2.9% in 2019. By contrast, foreign funding only accounted for 0.2% in 2019 and other funding accounted for 8.5% (Figure 2-6).

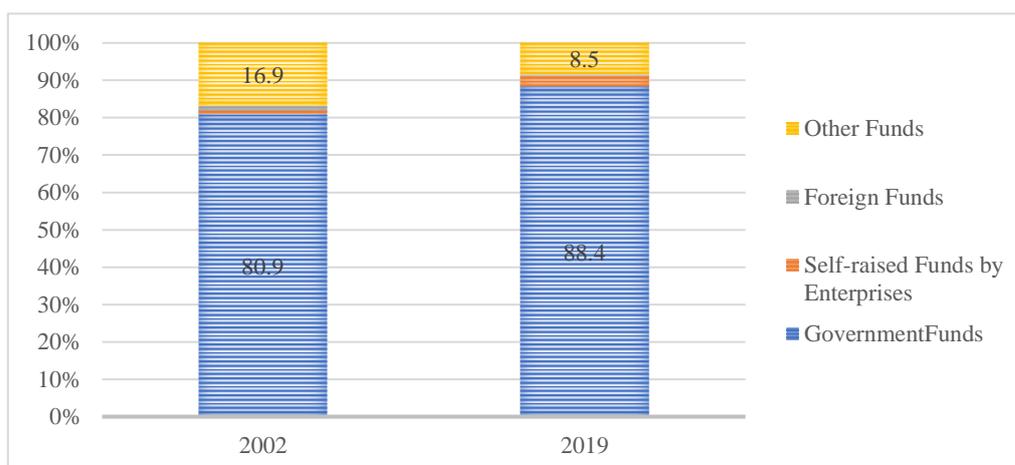


Figure 2-6 China's agricultural R&D expenditure by funding source

Source: *China Statistical Yearbook on Science and Technology, Ministry of Science and Technology*

However, investment in basic agricultural research has risen considerably. As shown in Figure 2-7, the proportions of agricultural R&D funding for basic research, applied research, and experimental development in 2002 were 10%, 34%, and 56%, respectively. By 2018, the proportions of these three types of research had grown to 19.7%, 33.6%, and 46.7%, respectively. The proportion of funding for basic research had therefore increased by nearly 10 percentage points in those 16 years. Agricultural universities attach great importance to basic research, which accounted for one-third (33.6%) of their R&D expenditure in 2018, compared with 58.9% and 7.5% for applied research and experiments, respectively. By contrast, in agricultural research institutes, basic research accounted for 14.9% of R&D expenditure, applied research accounted for 24.8%, and experiments accounted for 60.3%.

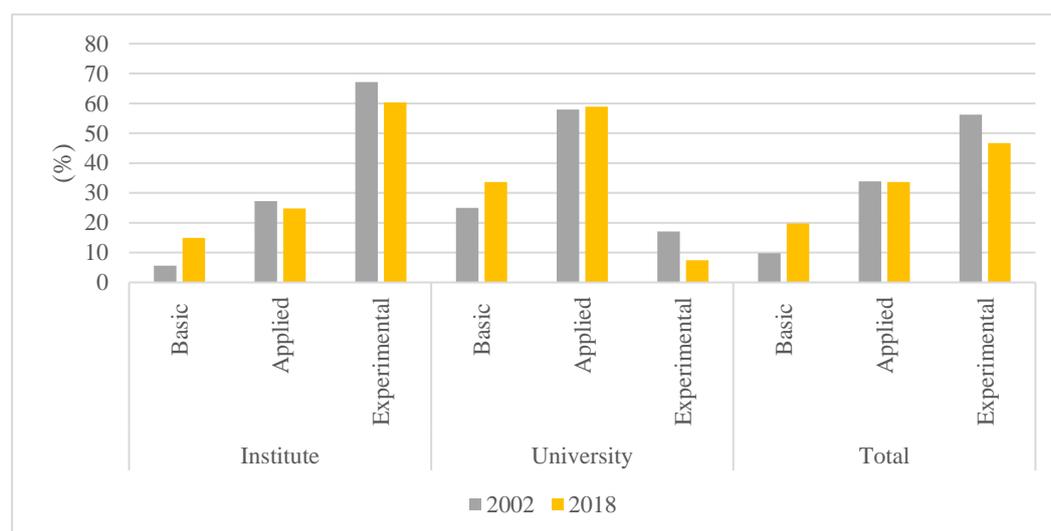


Figure 2-7 China's agricultural R&D expenditure by research type

Source: *China Statistical Yearbook on Science and Technology, Ministry of Science and Technology; University of Science and Technology Statistics, Ministry of Education*

Although the allocation of research funds to agricultural research institutions in China is still dominated by the crop sector, the research funds' structure has changed significantly in recent years, with a decrease in the share for the crop and forestry sectors, and a significant increase in the shares of livestock, fisheries and agricultural services. In 2015 prices, R&D expenditure on crop farming has grown relatively slowly, increasing from CNY 1.79 billion in

2002 to CNY 10.13 billion in 2018, with real annual growth rates of 11.5%, with its share in total agricultural R&D expenditure decreasing from 61.8% in 2002 to 57.4% in 2018. Similarly, R&D expenditure on forestry was CNY 1.48 billion in 2018, decreasing from 9.4% of total agricultural R&D expenditure to 8.4%. Conversely, R&D expenditure on animal husbandry, fishery, and agricultural services rose rapidly over 2002 to 2018, reaching CNY 1.22, 1.05, and 3.78 billion in 2018, accounting for 6.9%, 5.9%, and 21.4% of total agricultural R&D expenditure, respectively (Figure 2-8).

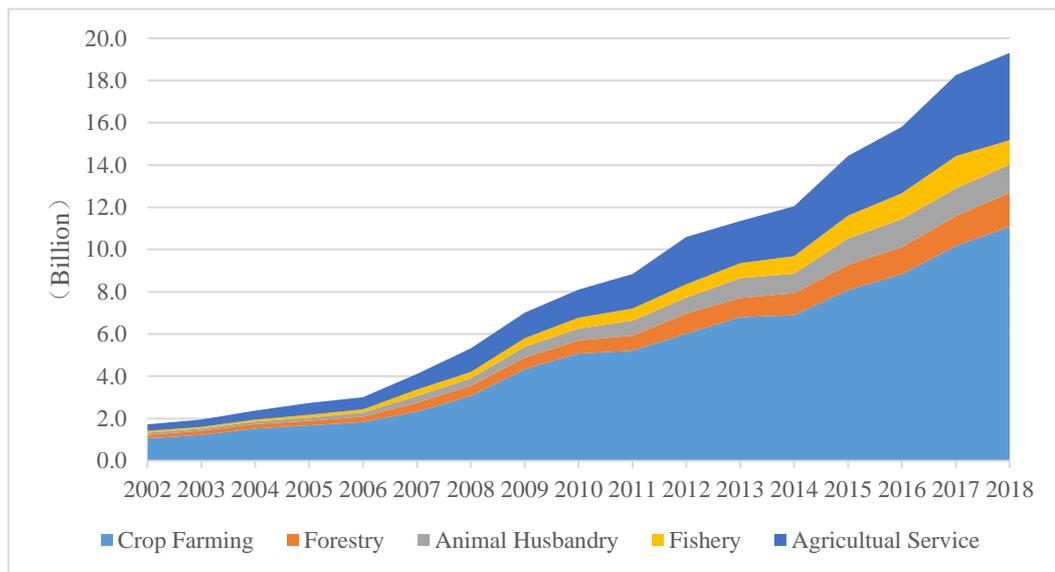


Figure 2-8 R&D expenditure of China's agricultural research institutes by subsector (Billion CNY)

Source: China Statistical Yearbook on Science and Technology, Ministry of Science and Technology

3 Characteristics and trends of public R&D in China’s agri-food system

This section focuses on public R&D in China’s agri-food system and highlights its characteristics and trends using case studies of the Life Sciences Department (LSD) of the National Natural Science Foundation of China (NSFC), the Modern Agricultural Industrial Technology System (MAITS), National Special Programs, China Agricultural University, the Chinese Academy of Agricultural Sciences, and the Jiangsu Academy of Agricultural Sciences.

3.1 The Life Sciences Division (LSD) of the NSFC

3.1.1 Overview

The NSFC has nine divisions, of which the most relevant to agri-food systems is the LSD. The LSD covers biology, agricultural sciences, and basic medicine. The related areas of the LSD include resources, the environment and ecology, population, and health (Table 3-1).

Table 3-1 Departments and areas of the LSD of the NSFC

Department	Areas
Biology-1	Microbiology, botany, zoology
Biology-2	Genetics and bioinformatics, cell biology, developmental biology, reproductive biology
Biomedical sciences	Immunology, neuroscience, and psychology, physiology and integrative biology
Cross sciences	Biophysics and biochemistry, biomaterials, imaging and tissue engineering, molecular biology and biotechnology
Environmental and ecological sciences	Ecology, forestry, and herbology
Agronomy and food science	Basic agronomy and crop science, food science
Agri-environmental and horticultural sciences	Plant protection, horticulture and plant nutrition
Agricultural animal science	Animal husbandry, veterinary medicine, aquaculture

In 2020, the LSD ranked third in the amount of funding among eight divisions of the NSFC (excluding the Crosscutting Division), after the Medical Sciences Division and the Engineering and Materials Sciences Division, demonstrating the importance the NSFC attaches

to the disciplines related to the LSD.

3.1.2 Funding by discipline

Within the funding for the general projects, youth projects, regional projects of the LSD of the NSFC in 2020, basic agronomy and crop science, and plant science received the most funding (Figure 3-1). Ecology, forestry and grassland science, and plant protection also received considerable funding, whereas animal husbandry, veterinary medicine, and aquaculture received less funding. Hence, the funding of the LSD still focuses on cultivation, and relatively less on animal husbandry and aquaculture.

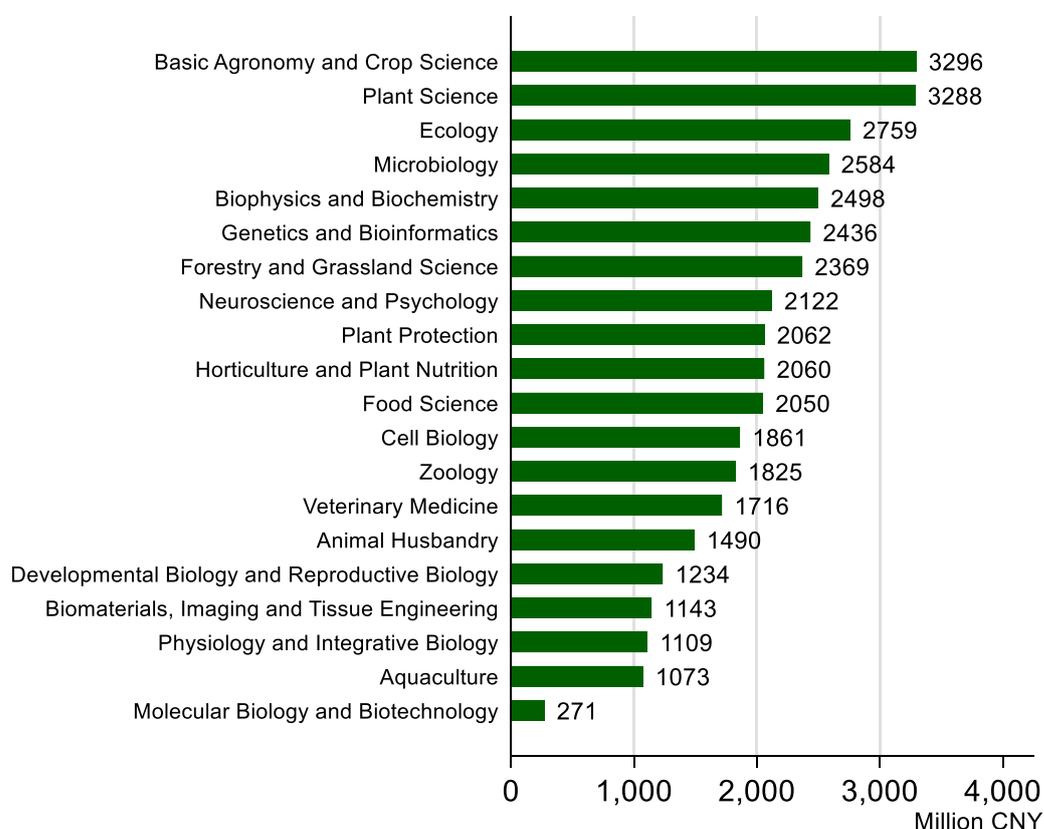


Figure 3-1 Number of projects funded by discipline, 1986–2019

Of the projects funded in 1986–2019, disciplines that received more than CNY 3 billion in funding included basic agronomy and crop science and plant science. Disciplines that received funding of CNY 2–3 billion included ecology, microbiology, biophysics and

biochemistry, genetics and bioinformatics, forestry and grassland science, neuroscience and psychology, plant protection, horticulture and plant nutrition, and food science. Disciplines that received funding of CNY 1–2 billion included cell biology; zoology; veterinary medicine; animal husbandry; developmental biology and reproductive biology; biomaterials, imaging, and tissue engineering; physiology and integrative biology, immunology, and aquaculture. Molecular biology and biotechnology only received funding of CNY 271 million.

3.1.3 Funding by product

3.1.3.1 Overview of funding by product

First, the three traditional staple grains of rice, wheat, and corn occupy a dominant position in terms of funding. Among them, there are 2956 funded projects for rice and the amount of funding is CNY 1.42 billion, 1668 funded projects for wheat (CNY 764 million), and 1260 funded projects for corn (CNY 622 million). Various types of non-staple grains, other oil crops, soybeans, sugar crops, and potatoes are relatively less funded. For these, the numbers of funded projects are 1154, 915, 905, 338, and 334, respectively and the amounts are CNY 430, 386, 369, 114, and 123 million, respectively (Figures 3-2 and 3-3).

Second, the number of projects funded for livestock and poultry is relatively high (up to 6099), as is the funding amount (up to CNY 2.52 billion). However, fewer projects are funded for fruit, vegetables, and aquatic products (3243, 2814, and 2658, respectively), with funding amounts of CNY 1.26, 1.16, and 1.13 billion, respectively. The number of projects for fruit is slightly higher than that for rice, whereas the numbers of projects for vegetables and aquacultures are lower than that for rice. The funding amounts for fruit, vegetables, and aquaculture are all lower than that for rice.

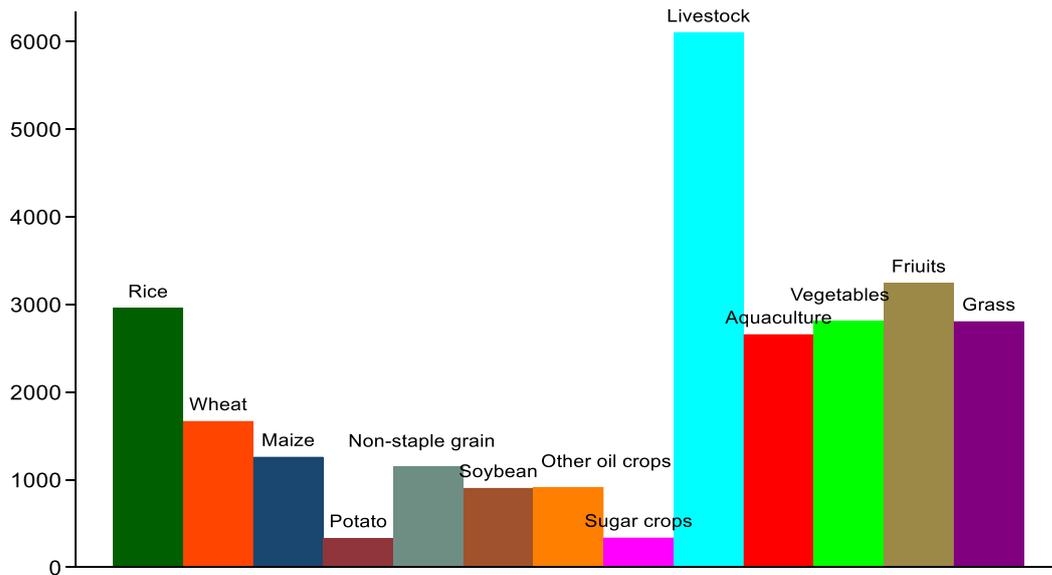


Figure 3-2 Number of projects funded by product, 1986–2019

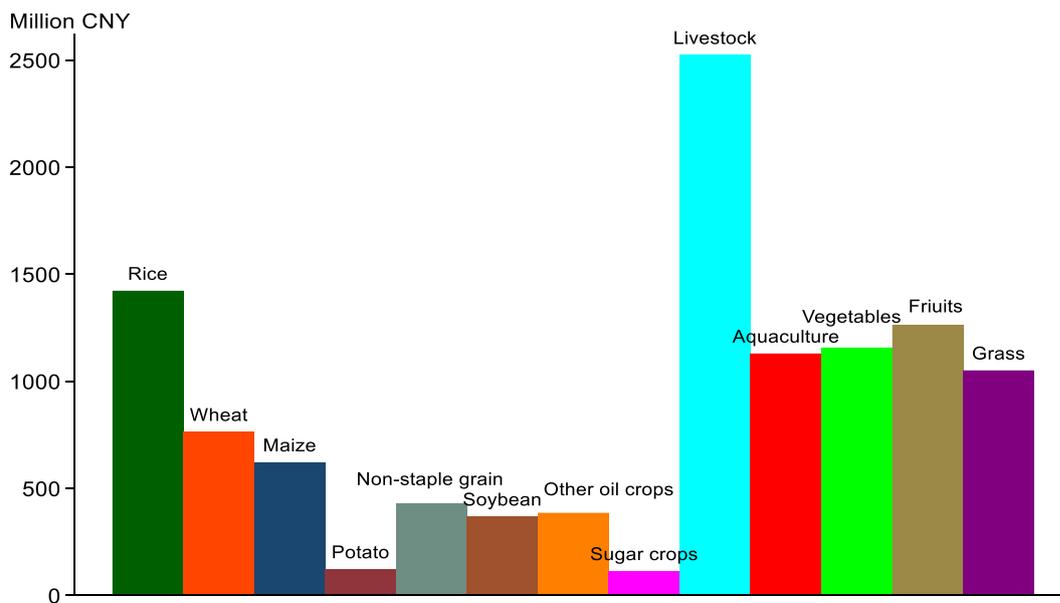


Figure 3-3 Amount of funding by product, 1986–2019

3.1.3.2 Funding in different years by product

The number of funded projects and amount of funding for the products in Figures 3.4 and 3.5 show the following patterns:

- (a) The number of funded projects and amount of funding for all the types of agricultural

products have gradually been increasing over time. In particular, the number of funded projects and amount of funding for all the products have increased significantly since 2010.

(b) Among the types of agricultural products, the number of funded projects and amount of funding for livestock and poultry have grown the fastest, with 481 funded projects in 2019 and CNY 252 million in funding, much higher than the other types of agricultural products.

(c) Fruit, vegetables, aquaculture, and grass have seen rapid growth in funding amounts (CNY 135, 161, and 107 million, respectively), with the number of funded projects in 2019 being 305, 261, and 205, respectively.

(d) Although the funding amounts of the three traditional crops (rice, wheat, and corn) have also increased, the growth rate has been relatively sluggish after 2012.

(e) The slowest growth in the amount of funding is for potatoes, soybeans, other oilseeds, and sugar crops.

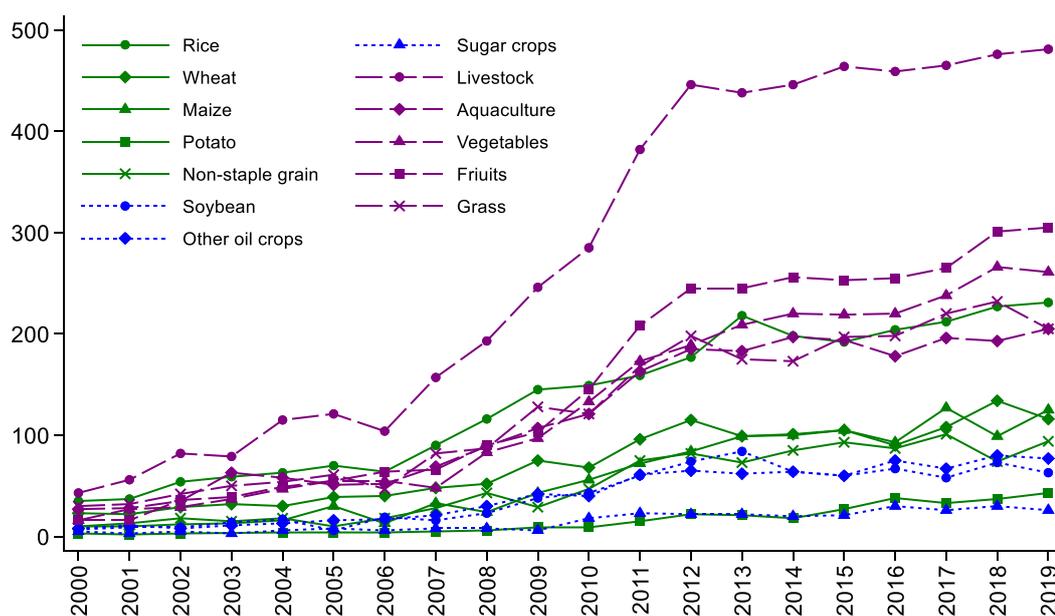


Figure 3-4 Number of funded projects by product over time, 1986–2019

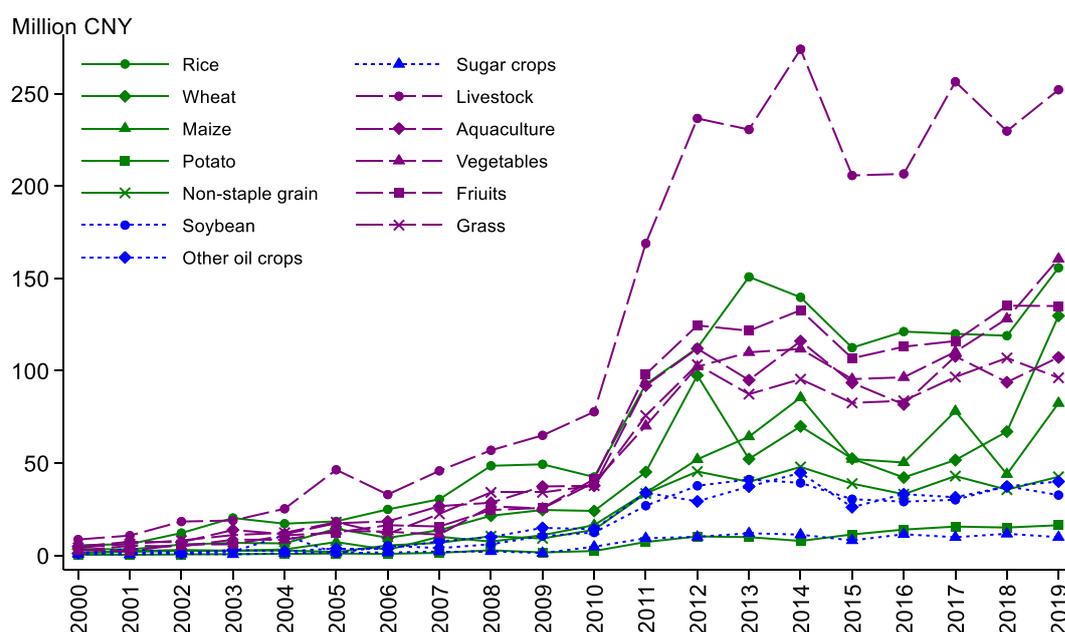


Figure 3-5 Amount of funding by product over time, 1986–2019

3.2 Modern agricultural industrial technology system (MAITS)

We first analyze the construction of the MAITS and R&D investment in three categories: grain and oil crops, cash crops, and livestock and aquatic products. Then, we carry out a comparative analysis.

3.2.1 Construction of the MAITS

From 2007 to 2008, the Ministry of Agriculture and Ministry of Finance constructed the MAITS for 50 major agricultural products. Under the MAITS, the main agricultural products are the unit and the industrial chain is the mainline. This system covers all aspects from production to consumption and from R&D to the market.

In the MAITS, the main agricultural products include three categories, namely, grain and oil crops, cash crops, and livestock and aquatic products, as detailed in Table 3-2. Usually, with each agricultural product, a National Industrial Technology R&D Center and a chief scientist are mapped. The National Industrial Technology R&D Center is composed of several laboratories, each with an office manager and several scientists. Depending on the

characteristics of the main production area of each product, several comprehensive testing stations are also set up, each with a station manager.

Table 3-2 Main agricultural products of the MAITS

Classification	Varieties
Grain and oil crops	Rice, corn, wheat, soybeans, barley, millet sorghum, oat buckwheat, edible beans, potatoes, sweet potatoes, cassava, rape, peanuts, specialty oilseeds
Cash crops	Cotton, hemp, sugar, silkworm mulberry, tea, edible mushrooms, Chinese herbal medicines, green manure, bulk vegetables, specialty vegetables, watermelon, citrus, apples, pears, grapes, peaches, bananas, lychee & longan, natural rubber
Livestock and aquatic products	Pigs, dairy cows, beef yaks, meat sheep, fluffy sheep, pastures, layer chickens, broilers, waterfowl, rabbits, bees, bulk freshwater fish, shrimp and crabs, shellfish, specialty freshwater fish, marine fish, algae

3.2.2 Input characteristics of the MAITS

This subsection analyzes the input characteristics of the MAITS for the three major categories of agricultural products: the numbers of scientists and testing stations as well as the number of laboratories.

3.2.2.1 Input characteristics of grain and oil crops

For grain and oil crops, the numbers of scientists and testing stations for staple grains such as rice, corn, and wheat are much higher than those for the other crops. Grain and oil crops mainly include cereals, pulses, potatoes, and oil crops, of which the numbers of scientists and testing stations for cereals are much higher than those for the other crops (Figure 3-6).

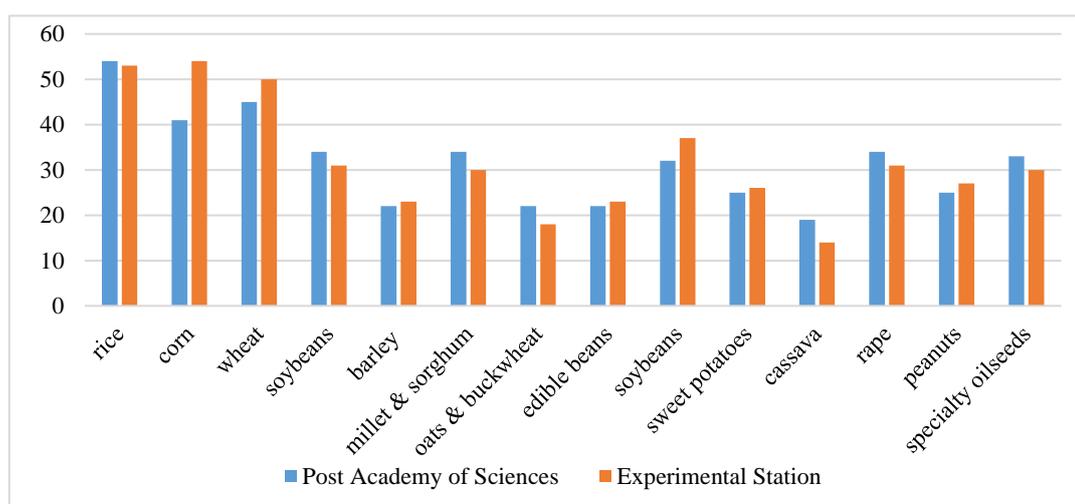


Figure 3-6 Numbers of scientists and testing stations for grain and oil crops

The laboratories of grain and oil crops are mainly concentrated on genetic modification research and cultivation and soil fertilizer research, with more staple grain laboratories than those for the other crops. As shown in Figure 3-7, the laboratories for grain and oil crops mainly include those for the prevention and control of pests and diseases, industrial economics, mechanization, processing, genetic modification, and cultivation and soil fertility.

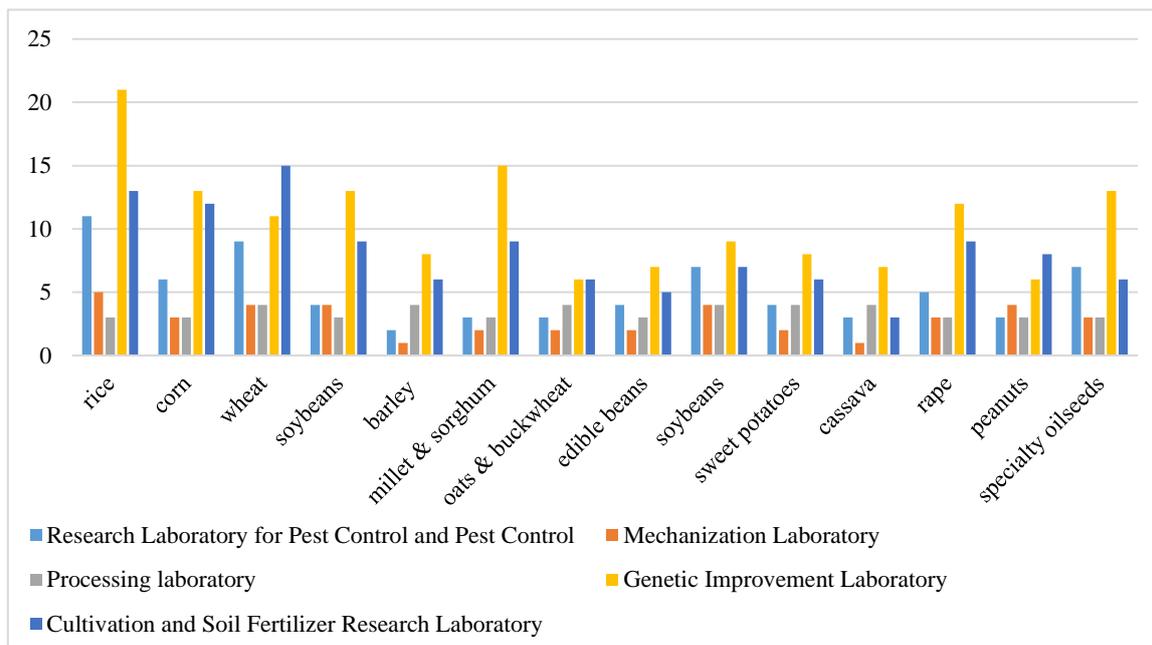


Figure 3-7 Number of laboratories for grain and oil crops

3.2.2. Input characteristics of cash crops

As the fruits and melons category covers the largest number of crop varieties, its numbers of scientists and testing stations are higher than those of vegetables, sugar, and other crops, while the numbers of scientists and testing stations of bulk vegetables are the highest for a single variety, as shown in Figure 3-8.

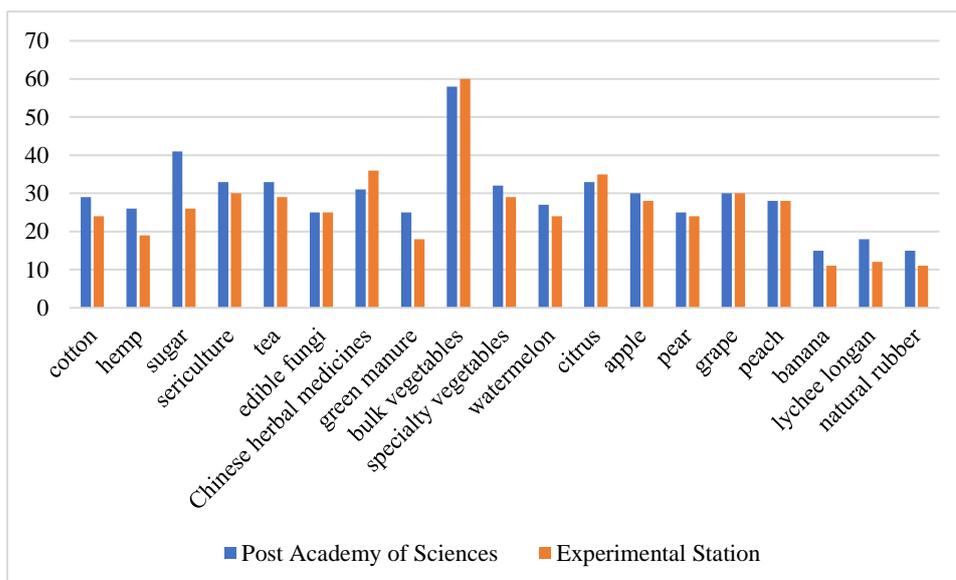


Figure 3-8 Numbers of scientists and testing stations for cash crops

The laboratories of cash crops focus on genetic modification and cultivation and soil fertilizer research, and the number of bulk vegetables is much larger than that of other individual crops, as shown in Figure 3-9.

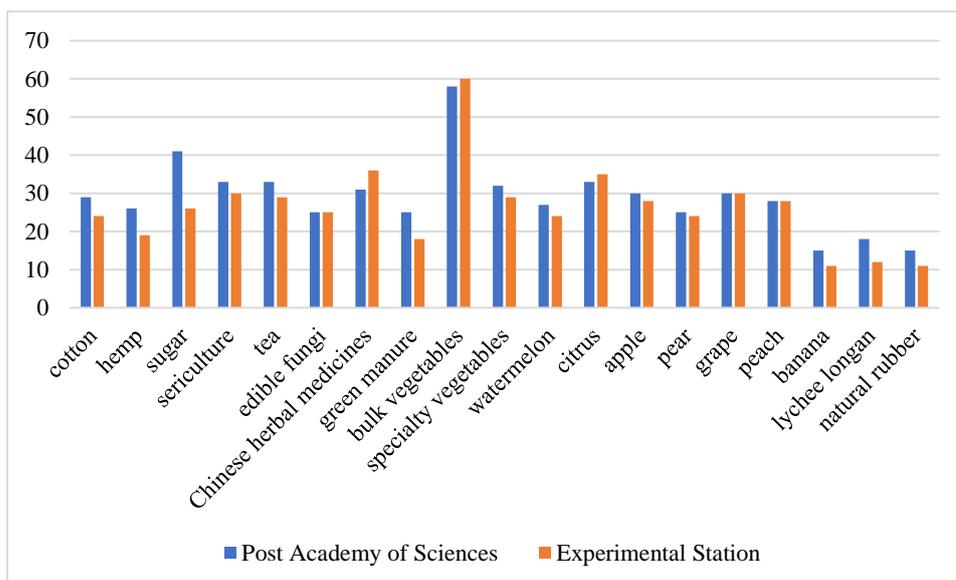


Figure 3-9 Number of laboratories for cash crops

3.2.2.3 Input characteristics of livestock and aquatic products

The numbers of scientists and testing stations for aquatic products are higher than those of livestock products. The numbers of scientists and testing stations of pigs are the

largest. Livestock and aquatic products mainly include livestock products (including pasture), poultry products, and aquatic products. Among them, there are 191 and 158 scientists and testing stations for livestock products, which are higher than those for poultry products and aquatic products, as shown in Figure 3-10.

The laboratories of livestock and aquatic products focus on genetic modification, nutrition and feed, and production and environmental control. The number of the pig laboratories is much larger than that of other livestock and aquatic products. The laboratories of livestock and fishery mainly include disease prevention and control research, industrial economic research, production and environmental control research, processing research, genetic modification research, and nutrition and feed research, as shown in Figure 3-11. Except for industrial economics, the other laboratories are mainly used for research into genetic modification, nutrition and feed, and production and environmental control.

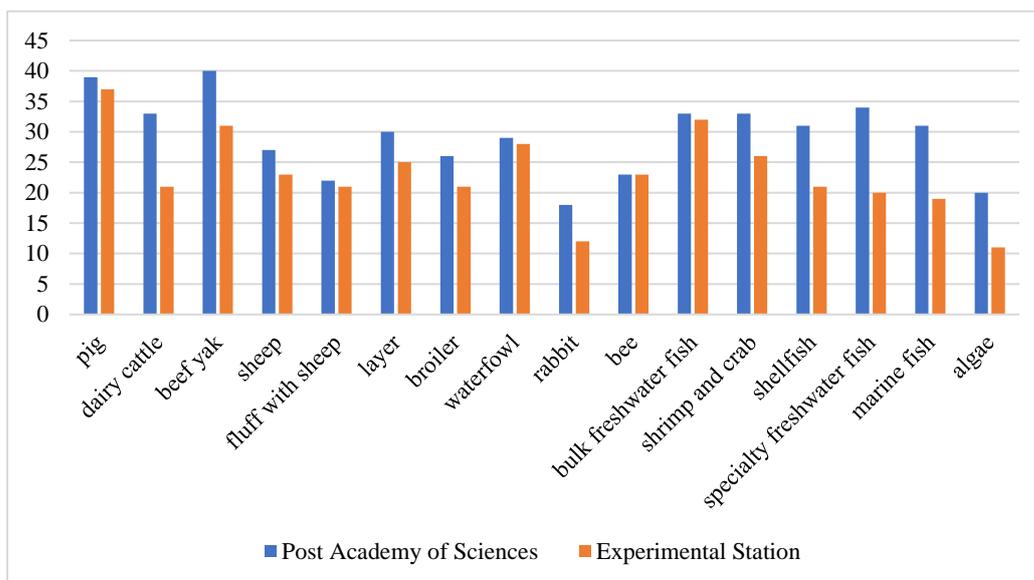


Figure 3-10 Numbers of scientists and testing stations for livestock and aquatic products

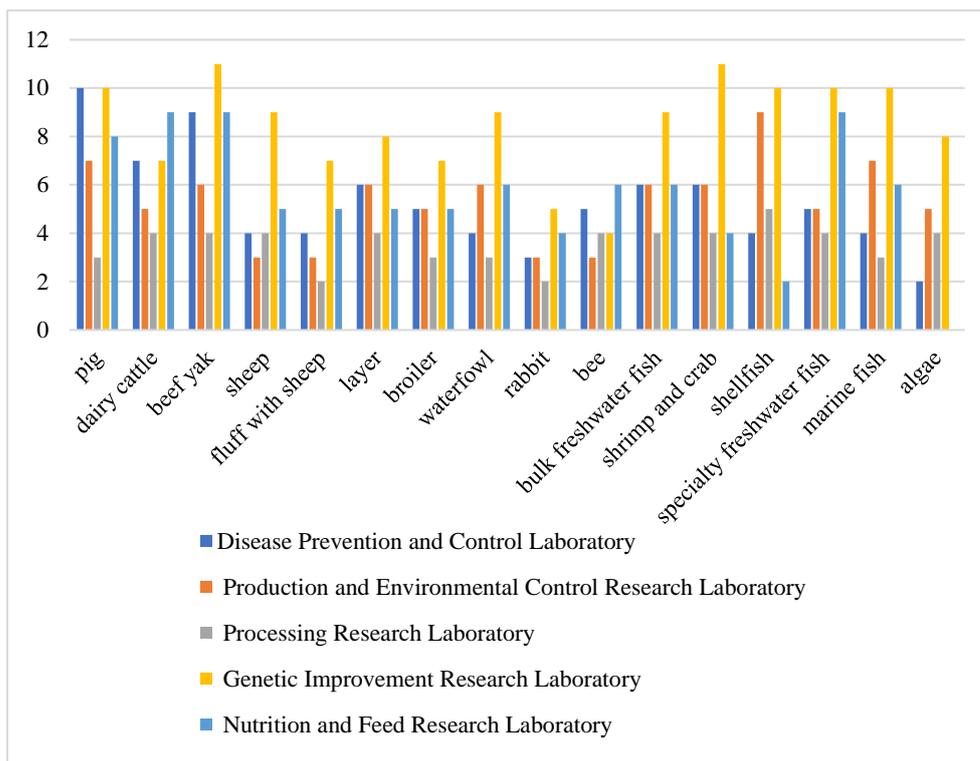


Figure 3-11 Number of laboratories for livestock and aquatic products

3.2.2.4 Comparative analysis

Grain crops have the highest proportion of team members, followed by proportions for fruit and livestock products; by contrast, the proportion for vegetables is relatively low. Specifically, as shown in Table 3-3, the proportion of team members for grain crops is 27.7%, while the proportion for cereals (17.4%) is much higher than that for pulses (4.4%) and potatoes (5.9%). The proportions of team members for fruit, livestock products, aquatic products, and poultry products are 15.2%, 14.7%, 12.5%, and 9.9%, respectively. The proportions of team members for oil crops and vegetables are 6.9% and 6.5%.

The R&D of the MAITS focuses on research into genetic breeding, cultivation and soil fertilizer, nutrition and feed, and disease prevention and control, while R&D investment in processing and machinery is relatively insufficient. Specifically, the R&D of grain crops and cash crops focuses on genetic modification research, cultivation and soil fertilizer, disease and pest control, and other research, while investment in R&D into processing and mechanization is relatively low (Figure 3-12). There are many R&D priorities for livestock

and aquatic products, including research in genetic modification, nutrition and feed, production and environmental control, and disease prevention and control; however, there is again less investment in R&D into processing for these products (Figure 3-13).

Table 3-3 Team members in the MAITS by type

Type	Number of team members	Proportion of team members (%)
Grain	2912	27.7
Cereals	1830	17.4
Legume	459	4.4
Potato	623	5.9
Oil	726	6.9
Cotton hemp	406	3.9
Sugar	284	2.7
Vegetables	679	6.5
Fruit	1600	15.2
Livestock products (including forage)	1542	14.7
Poultry products	1036	9.9
Aquatic products	1311	12.5
Total	10496	100

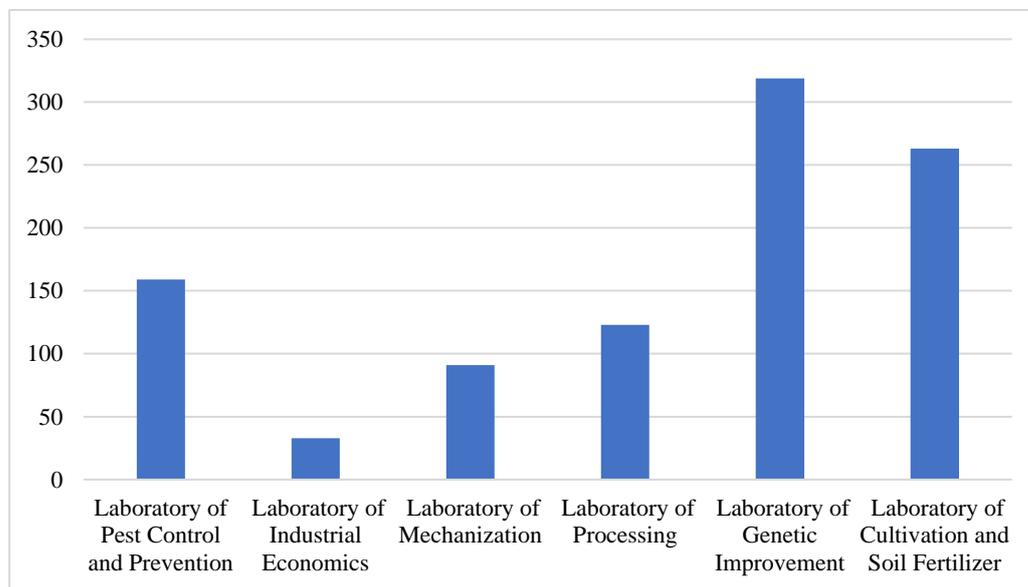


Figure 3-12 Number of laboratories for grain and cash crops

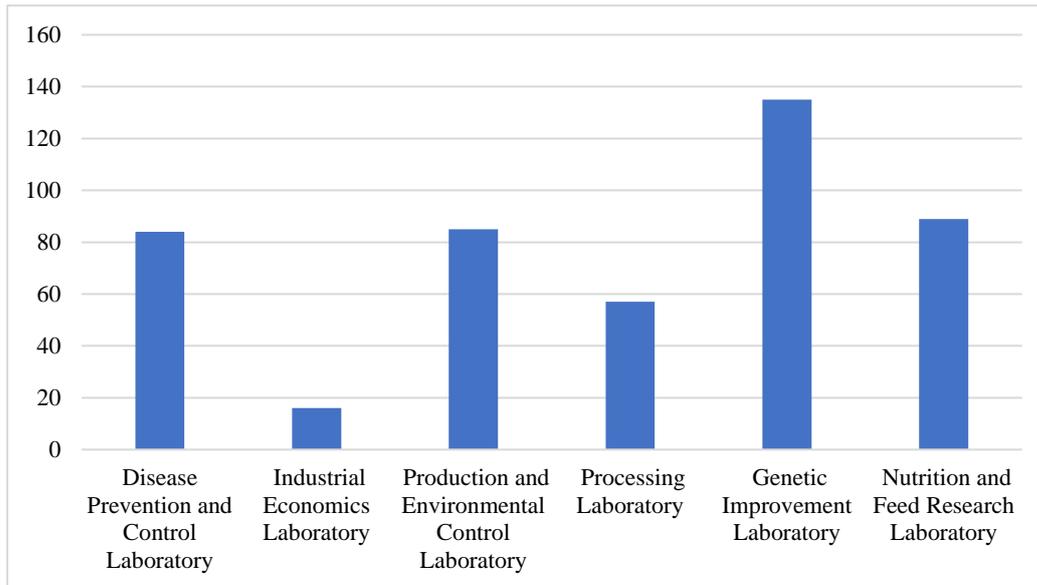


Figure 3-13 Number of laboratories for livestock and aquatic products

3.3 National special programs

3.3.1 National Key R&D Program

China's National Key R&D Program integrates the original National Basic R&D Program (973 Program) and National High-technology R&D Program (863 Program) with other programs such as the National Science and Technology Support Program, special projects for international S&T cooperation and exchange, the industrial technology R&D fund, and public welfare industry S&T projects. It comprises public welfare research on China's economy and people's livelihoods as well as the core competitiveness of China's industries. The project provides continuous support and guidance for the main fields of national economic and social development. During the 13th Five-Year Plan period, the National Key R&D Program carried out four key projects (two reduction, abundant grain, non-point source, and economic operation), which improved national food security, raised the supply of major agricultural products, thus promoting green agricultural development and high-quality cultivated land construction, helping the fight against poverty, and improving the competitiveness of agricultural S&T projects regionally.

In May 2017, 140 key agricultural projects were included in the National Key R&D

Program, with funding of more than CNY 3.8 billion. During the 14th Five-Year Plan period, the following 12 R&D projects in the field of agriculture were running: (1) basic research on the formation of important agricultural biological traits and environmental adaptability, (2) excavation and innovative utilization of agricultural biological germplasm resources, (3) improvement of the capacity of medium and low yield fields such as arid and semi-arid regions in the north and red and yellow soils in the south, (4) S&T innovation in black land protection and utilization, (5) agricultural non-point source heavy metal pollution prevention and control and R&D in green inputs, (6) R&D and demonstration of comprehensive technology for the prevention and control of major diseases and insect pests, (7) breeding of new livestock and poultry varieties and S&T innovation of modern pastures, (8) R&D and application of key technologies for the prevention and control of animal diseases, (9) cultivation and quality improvement of forestry germplasm resources, (10) development of key technologies of industrialized agriculture and intelligent agricultural machinery and equipment, (11) S&T support for food manufacturing and agricultural product logistics, and (12) R&D and integrated application of key common technologies to the rural industry.

3.3.2 National Science and Technology Support Program

The National Science and Technology Support Program aims to achieve China's major S&T strategic development goals, develop key core technologies, integrate national resources, and promote major strategic products, key common technologies, and major projects. Major projects with a deadline of 2020 (2006–2020) included those related to transgenic breeding technology and water pollution control. Three major projects with a deadline of 2030 (2016–2030) are noteworthy. First, independent innovation projects in the seed industry focus on agricultural plants, animals, trees, and microorganisms. Their aim is to develop key technologies such as heterosis utilization and molecular design breeding to support China's food security strategy. The second project aims to improve health in China. In particular, it aims to strengthen R&D in technologies such as precision medicine; prevent and control chronic non-contiguous diseases, frequently occurring diseases, and reproductive health and birth defects; accelerate the transfer and transformation of technological achievements; and promote demonstration services to benefit Chinese people. Finally, a project relates to comprehensive environmental management in Beijing, Tianjin, and Hebei.

3.3.3 Special plan for agricultural and rural S&T innovation

In 2017, the Ministry of Science and Technology and another 16 departments jointly formulated the special plan for agricultural and rural S&T innovation in the 13th Five-Year Plan period (hereafter referred to as the special plan). The basic principles of the special plan are to provide strategic guidance, focus on achieving China's agricultural S&T objectives, deepen the reform of the agricultural S&T system, expand the global vision of agricultural S&T development, and enhance the value of the whole agricultural supply chain to make China's agricultural S&T innovation at the forefront in the world. In particular, it aims to significantly improve agricultural S&T innovation and industrial competitiveness, construct an innovation platform and talent team, raise the efficiency of the agricultural S&T innovation system, and optimize the innovation and entrepreneurship of rural villages in five main ways: (i) improve the agricultural S&T innovation system, build China's first-mover advantage, and consolidate the foundation of agricultural S&T innovation; (ii) expand high-tech agricultural industries; (iii) improve international cooperation in agricultural S&T; (iv) strengthen regional S&T innovation; and (v) eradicate poverty through science and technology.

3.4 China Agricultural University (CAU)

3.4.1 Funding for China Agricultural University

Between 2011 and 2018, funding for China Agricultural University increased from CNY 870 million to CNY 1.52 billion, a rise of 75%. As shown in Figure 3-14, from 2012 to 2014, the amount of funding flattened, falling slightly from CNY 1.02 billion to 940 million, but the amount was still higher in 2014 than in 2011. From 2014 to 2016, funding rose rapidly, with an increase of CNY 520 million and a growth rate of 55%. After 2016, funding stabilized and then showed a steady increase.

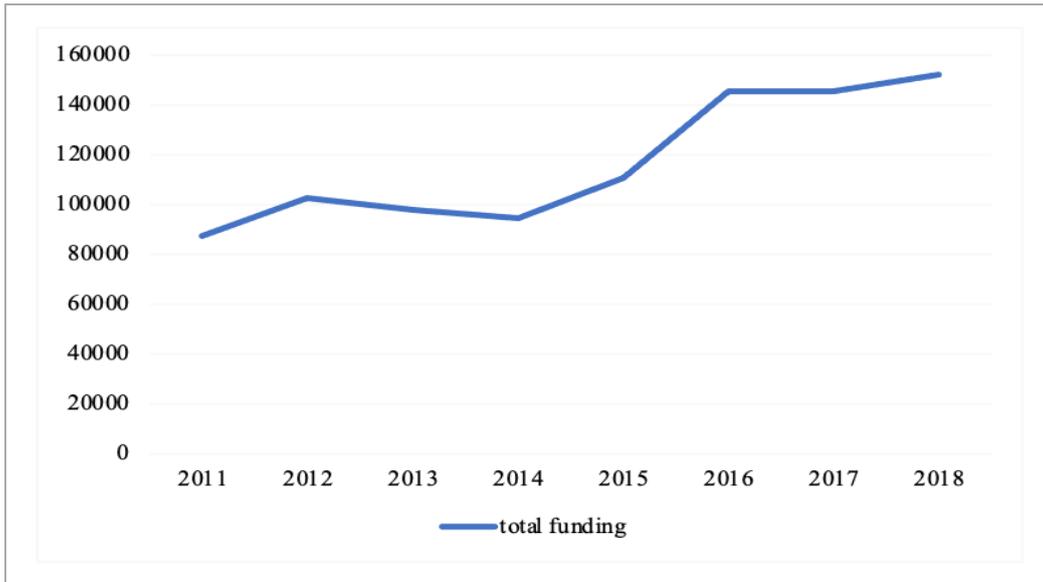


Figure 3-14 Total funding (million CNY) of CAU, 2011–2018

Note: The following institutes were not aggregated in this figure due to incomplete data: College of Marxism, College of Biological Sciences – Laboratory, College of Animal Science and Technology – Laboratory, Department of P.E. & Art, International College Beijing, College of Plant Protection, State Key Laboratory Special Funds, College of Horticulture, Beijing Advanced Innovation Center for Food Nutrition and Human Health, and Advanced Innovation Center for Food

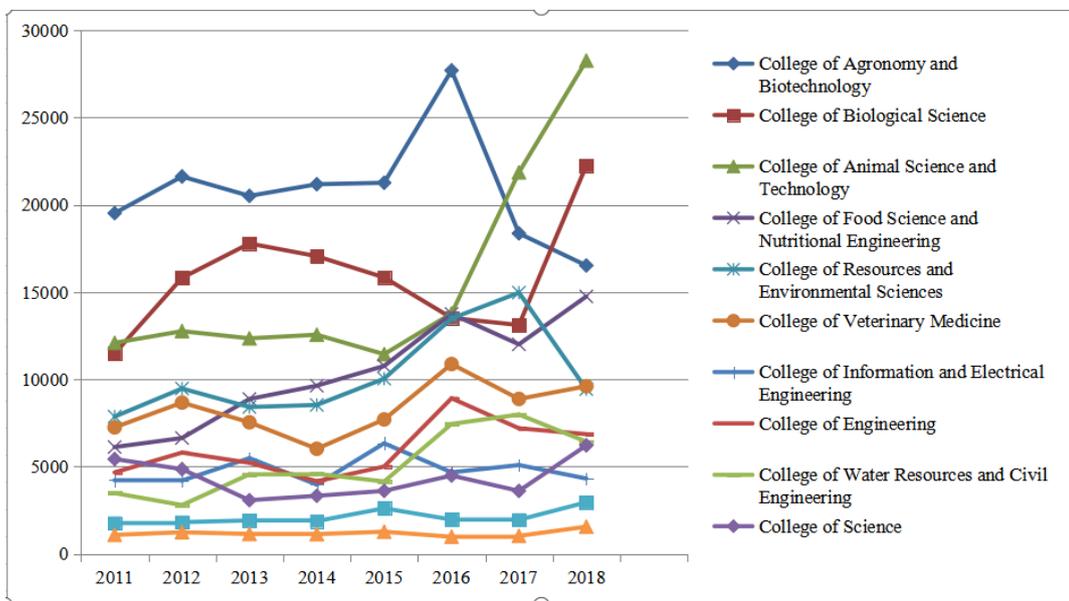


Figure 3-15 Funding by college (million CNY) of CAU, 2011–2018

Note: see Figure 3-14.

Figure 3-15 shows the trend in the amount of funding at the college level. Annual funding varied widely across colleges. The funding of most colleges rose over this eight-year period, with funding for the College of Food Science & Nutritional Engineering and College of Animal Science and Technology increasing by more than 100%. Funding for the College of Biological Sciences, College of Water Resources & Civil Engineering, and College of Economics and Management increased by more than 50%. Growth rates of less than 50% can be seen for the College of Resources and Environment Sciences, College of Veterinary Medicine, College of Engineering, the College of Information and Electrical Engineering, College of Science, and College of Humanities and Development Studies. The fastest growth rate was for the College of Food Science & Nutritional Engineering, with an eight-year funding growth rate of 141%. This college's funding has continued to grow rapidly except for a brief decline between 2016 and 2017. Funding for the College of Animal Science and Technology also grew at a high rate, increasing by 147% from 2015 to 2018 and becoming the highest funded of all the colleges in 2018.

In summary, the following conclusions are drawn. First, funding for all the colleges of China Agricultural University has typically grown, with funding for the College of Animal Science and Technology, College of Food Science & Nutritional Engineering, College of Biological Sciences, and College of Water Resources & Civil Engineering showing strong growth, driving the overall rise in funding of the university. Second, there were significant differences in funding among colleges, with higher funding and higher growth rates for colleges in which top disciplines are located, such as the College of Animal Science and Technology and College of Food Science & Nutritional Engineering. Further, funding for natural science colleges was higher than that for social science colleges. Third, there might be a correlation in funding changes between the colleges, such as a decrease in funding for six colleges from 2016 to 2017, but an increase in funding for seven colleges from 2017 to 2018.

3.4.2 Projects by research category

3.4.2.1 Vertical projects by research category

Vertical projects are divided into four categories based on the keyword filtering of project names: staple food, fruit, livestock and poultry, and vegetables. As shown in Figure 3-16, the

vertical projects from 2016 to 2020 in descending order were livestock and poultry (615), staple food (370), vegetables (251), and fruit (144). The numbers of projects in the fruit, vegetables, and livestock and poultry categories all showed a fluctuating downward trend over time and continued to decline after rebounding in 2018. The number of projects in the staple food category decreased over time, with a greater magnitude in 2016–2017, and then a gradual slowdown.

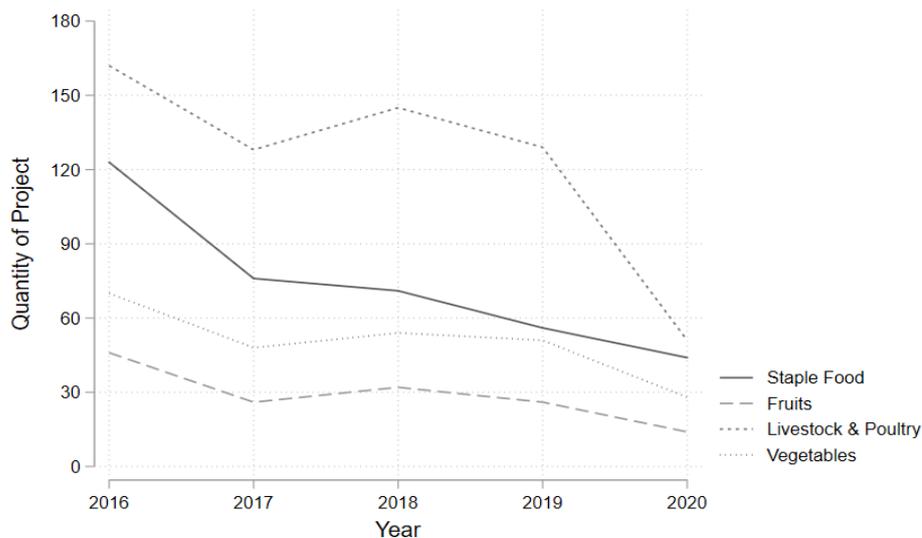


Figure 3-16 Number of vertical projects for staple food, fruit, livestock and poultry, and vegetables

As shown in Figure 3-17, funding for vertical projects in the fruit and livestock and poultry categories followed the same trend, peaking in 2017 and then decreasing in each year thereafter. Funding for vertical projects in the livestock and poultry category was much higher than that in the fruit category, while funding for the staple food category decreased from 2016 (RMB 651.93 million) to 2019 (RMB 34.54 million), with a slight increase in 2020 to RMB 70.75 million. Funding for vertical projects in the vegetables category gradually decreased and was the lowest among the four categories.

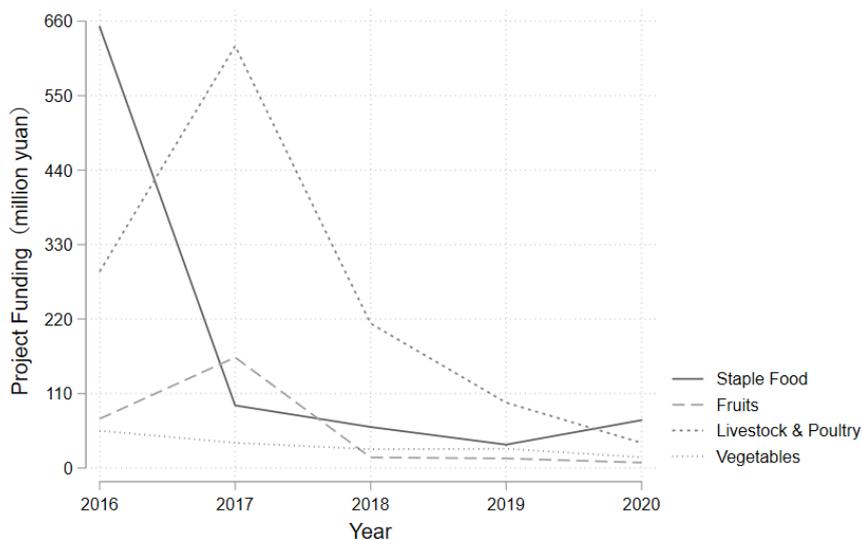


Figure 3-17 Vertical projects' funding for staple food, fruit, livestock and poultry, and vegetables

3.4.2.2 Horizontal projects by research category

Figure 3-18 shows the number of horizontal projects for the four categories from 2016 to 2020. The horizontal projects in increasing order were fruit (155), staple food (212), vegetables (231), and livestock and poultry (462). The numbers of projects in all four categories tended to rise and then fall, with livestock and poultry bottoming out in 2019 (141) and the remaining three categories all peaking in 2018 and then declining. In addition, the numbers of horizontal projects in 2020 were similar for the staple food (18), fruit (15), and vegetables (14) categories.

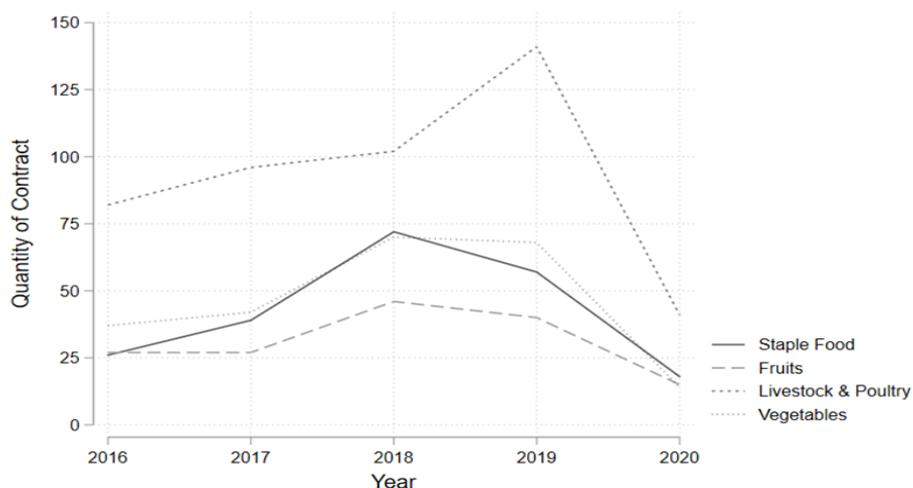


Figure 3-18 Number of horizontal projects for staple food, fruit, livestock and poultry, and vegetables

Figure 3-19 shows the funding for horizontal projects. The funding for horizontal projects in the vegetables and staple food categories both showed an upward and then a downward trend. Meanwhile, the funding for the fruit category showed a fluctuating trend that fell over the study period from RMB 20.45 million in 2017 to RMB 8.02 million in 2020. The funding for the livestock and poultry category was the highest of the four categories, but it too fluctuated. After peaking in 2019 (RMB 50.83 million), it dropped sharply. In addition, funding for the staple food (RMB 4.66 million) and vegetables (RMB 2.61 million) categories were similar in 2020.

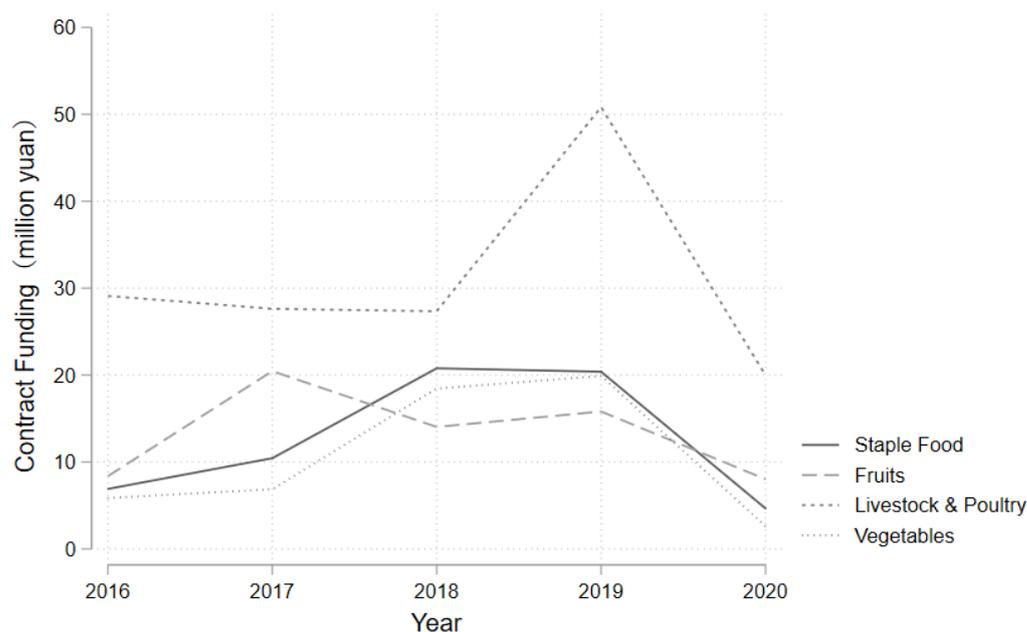


Figure 3-19 Horizontal projects' funding for staple food, fruit, livestock and poultry, and vegetables

3.5 Chinese Academy of Agricultural Sciences

The Chinese Academy of Agricultural Sciences is the largest agricultural research institute in China, with 7026 employees, including 5911 scientific researchers. It had 34 directly subordinate research institutes and 9 collaborating research institutes in 2017. In this subsection,

we use data from Compilation of Statistical Data on the Science and Technology of the Chinese Academy of Agricultural Sciences, 2004–2016.

3.5.1 R&D investment

3.5.1.1 Expenditure on R&D activities

As shown in Table 3-4, expenditure on the R&D activities of the institutes at the Chinese Academy of Agricultural Sciences increased from CNY 1.58 billion in 2005 to CNY 4.17 billion in 2016, an average annual growth rate of 9.25%. Expenditure on the R&D activities of the Institute of Crop Sciences was the largest of all the institutes and the highest proportion of total expenditure. Its expenditure on S&T activities in 2010 accounted for 20.10% of the total expenditure of the Chinese Academy of Agricultural Sciences, indicating that R&D in crops such as wheat, corn, soybeans, rice, and grains was the primary target of support. The proportion of expenditure on the R&D activities of the Harbin Veterinary Institute, Institute of Plant Protection, Animal Husbandry Institute, Rice Institute, Information Institute, Lanzhou Veterinary Institute, Cotton Institute, and Agricultural Resources and Regional Planning Institute gradually stabilized at 3–6%. This indicates that plant diseases, plant insect pests, weeds and rodents, chemical control, biological control, biosecurity, and plant protection biotechnology have increasingly become the focus of R&D investment.

Table 3-4 shows some of the characteristics of agricultural R&D investment by the Chinese Academy of Agricultural Sciences. **First, since the 12th Five-Year Plan period, R&D funding in nutrition and health related areas such as agricultural product processing industry, animal husbandry, and fruit and vegetable industry has been rapid, whereas the growth rate of investment in traditional crop fields has slowed.**

Table 3-4 Expenditure on R&D activities at the Chinese Academy of Agricultural Sciences (2015 prices)

	2005		2010		2015		2016		Average annual growth rate (%)
	Amount (10000 CNY)	Proportion (%)							
Shanghai Veterinary Institute	980	0.62	5973	1.73	10734	2.41	12869	3.09	26.38
Institute of Processing	1155	0.73	6222	1.80	14051	3.15	11897	2.86	23.62

Institute of Biogas Science	656	0.42	3159	0.91	3548	0.80	5764	1.38	21.85
Lanzhou Animal Husbandry and Medicine Institute	979	0.62	3015	0.87	8319	1.86	8322	2.00	21.47
Feed Institute	1461	0.93	7559	2.19	11666	2.61	11505	2.76	20.63
Environmental Protection Institute	1634	1.04	5416	1.57	9213	2.07	11796	2.83	19.69
Lanzhou Veterinary Institute	2603	1.65	8788	2.54	19751	4.43	17676	4.24	19.02
Fruit Tree Institute	846	0.54	3177	0.92	5240	1.17	4976	1.19	17.48
Hemp Institute	1290	0.82	4240	1.23	8636	1.94	7560	1.81	17.44
Institute of Agricultural Mechanization	2044	1.30	6342	1.84	11599	2.60	11531	2.77	17.04
Nutrition Institute					1834	0.41	2123	0.51	15.76
Tobacco Institute	2717	1.73	11151	3.23	14108	3.16	13427	3.22	15.63
Institute of Special Agricultural Products	2263	1.44	9325	2.70	11775	2.64	10963	2.63	15.42
Oil Institute	3154	2.00	9095	2.63	16249	3.64	15161	3.64	15.34
Bee Institute	1246	0.79	4105	1.19	4975	1.12	5930	1.42	15.24
Institute of Biology	2983	1.89	12098	3.50	9983	2.24	13162	3.16	14.45
Vegetable Institute	3686	2.34	9938	2.88	15894	3.56	15673	3.76	14.06
Institute of Plant Protection	6210	3.94	17926	5.19	26756	6.00	22369	5.37	12.36
Zhengzhou Pomology Research Institute	2304	1.46	5537	1.60	8629	1.93	8160	1.96	12.18
Irrigation Institute	1676	1.06	3560	1.03	6920	1.55	5214	1.25	10.87
Rice Institute	6716	4.27	17576	5.09	19959	4.47	20294	4.87	10.58
Agricultural Heritage Room	110	0.07	326	0.09	385	0.09	320	0.08	10.21
Institute of Animal Husbandry	7478	4.75	17690	5.12	23775	5.33	21773	5.23	10.20
Information Institute	6647	4.22	8978	2.60	14712	3.30	17981	4.32	9.47
Agricultural Economic Institute	2094	1.33	4078	1.18	4542	1.02	5546	1.33	9.26
Prairie Institute	2154	1.37	4441	1.29	6898	1.55	5464	1.31	8.83
Quality Standard Institute	2973	1.89	4795	1.39	7244	1.62	7128	1.71	8.27
Institute of Crop Sciences	13876	8.81	69406	20.10	40358	9.05	30232	7.26	7.34
Citrus Institute	3227	2.05	5531	1.60	6270	1.41	6358	1.53	6.36
Tea Institute	5041	3.20	6823	1.98	8909	2.00	9430	2.26	5.86

Cotton Institute	9304	5.91	33812	9.79	18907	4.24	17260	4.14	5.78
Institute of Agro-Environment and Sustainable Development	6621	4.20	8508	2.46	11517	2.58	12262	2.94	5.76
Harbin Veterinary Institute	15954	10.13	3475	1.01	43214	9.69	26234	6.30	4.63
Agricultural Resources and Regional Planning Institute	11025	7.00	19371	5.61	16721	3.75	16866	4.05	3.94
Sugar Beet Institute	1805	1.15	1283	0.37	1057	0.24	1049	0.25	-4.82
Sericulture Institute	20959	13.31	2652	0.77	1806	0.40	2366	0.57	-17.99
Total	157450	100.00	345370	100.00	446152	100.00	416645	100.00	9.25

As shown in Figure 3-20, before 2010, expenditure on the R&D activities of traditional crops (except fruit and vegetables) and veterinary and animal husbandry institutes fluctuated greatly, and the growth rate was slow after 2010. Expenditure on the S&T activities of fruit and vegetables institutes, processing institutes, and nutrition institutes has grown rapidly.

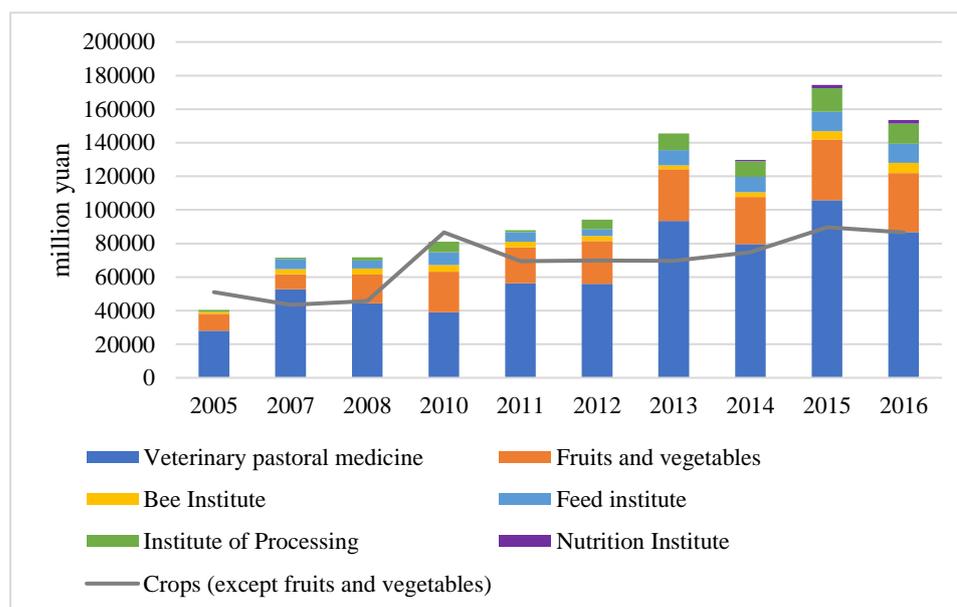


Figure 3-20 Expenditure on the R&D activities of nutrition and health institutes, 2005–2016 (2015 prices)

Second, since the 15th Five-Year Plan period, investment in R&D on environmental protection and resource conservation has increased significantly. Figure 3-21 shows that from the 10th Five-Year Plan period to the 13th Five-Year Plan period, the actual expenditure

of the Institute of Biogas Science, Institute of Environmental Protection, Institute of Biotechnology, Institute of Plant Protection, Agricultural Resources and Regional Planning Institute, and Institute of Biotechnology rose, with an average annual growth rate of 14.46%. Among them, the Institute of Biogas Science's expenditure increased the most.

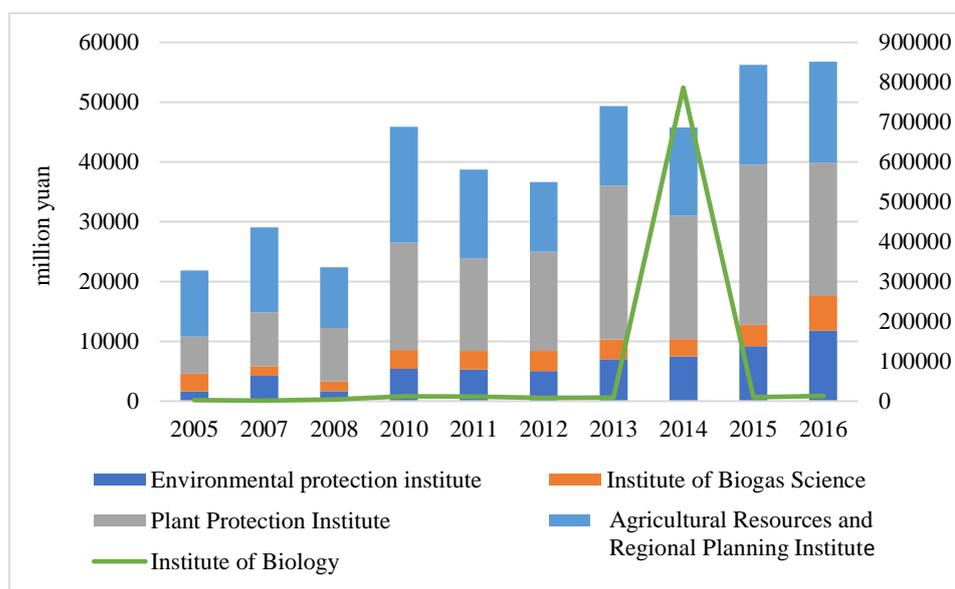


Figure 3-21 Expenditure on the R&D activities of resources and environment institutes, 2004–2016 (2015 prices)

Third, since 2005, R&D investment in the fields of climate change and mitigation of meteorological disasters has shown a significant upward trend. As shown in Figure 3-22, expenditure on the R&D activities of the Irrigation Institute increased from CNY 16.76 million in 2005 to CNY 52.14 million in 2016, an average annual growth rate of 10.87%. The expenditure of the Institute of Agro-Environment and Sustainable Development also increased from CNY 66.21 million in 2005 to CNY 122.62 million in 2016, an average annual growth rate of 5.76%.

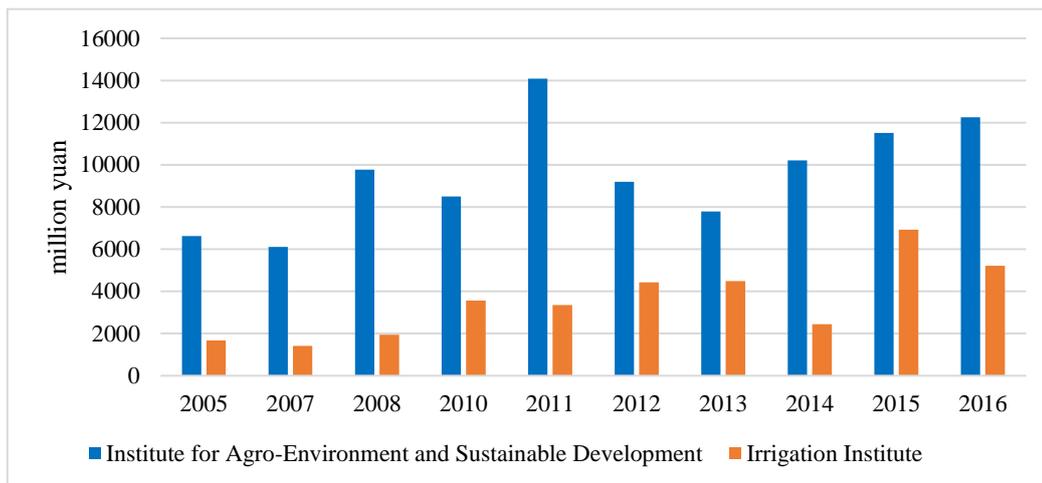


Figure 3-22 Expenditure on the R&D activities of climate adaptation institutes, 2004–2016 (2015 prices)

3.5.1.2 R&D personnel

Table 3-5 shows that from the 10th Five-Year Plan period to 13th Five-Year Plan period, the number of R&D personnel engaged in R&D activities at the Chinese Academy of Agricultural Sciences increased from 4477 in 2005 to 6955 in 2016, an average annual growth rate of 9.25%. Overall, investment in R&D personnel has thus increased.

From 2005 to 2016, the investment in personnel of the Institute of Special Agricultural Products was the largest and the proportion of R&D activities was the highest, with an average investment of 6.11%, indicating that R&D in special animals and plants consumed the most human capital. The average investment in R&D personnel in Agricultural Resources and Regional Planning Institute, Cotton Institute, and Institute of Crop Sciences was 5.64%, 5.49%, and 5.46%, respectively. Agricultural Heritage Room and Institute of Nutrition was less than 1%; and other institutes was between 1% and 5%.

Table 3-5 shows the characteristics of investment in R&D personnel at the Chinese Academy of Agricultural Sciences. **First, investment in the fields related to agricultural product nutrition, processing, fruit, and vegetables has increased significantly, while investment in crop science and technology personnel has been stable and rising.**

Table 3-5 Personnel engaged in R&D activities at the Chinese Academy of Agricultural Sciences

	2005		2010		2015		2016		Average annual growth rate (%)
	Number	Proportion (%)							
Nutrition Institute					25	0.36	31	0.45	24.00
Institute of Processing	38	0.85	76	1.27	158	2.31	160	2.30	13.96
Institute of Plant Protection	114	2.55	180	3.01	325	4.74	366	5.26	11.19
Institute of Animal Husbandry	106	2.37	239	4.00	308	4.49	340	4.89	11.18
Institute of Special Agricultural Products	152	3.40	538	9.00	410	5.98	421	6.05	9.70
Agricultural Resources and Regional Planning Institute	194	4.33	350	5.85	435	6.35	419	6.02	7.25
Tobacco Institute	117	2.61	143	2.39	265	3.87	247	3.55	7.03
Cotton Institute	220	4.91	259	4.33	447	6.52	432	6.21	6.33
Zhengzhou Pomology Research Institute	141	3.15	159	2.66	269	3.92	274	3.94	6.23
Hemp Institute	82	1.83	147	2.46	141	2.06	154	2.21	5.90
Quality Standard Institute	60	1.34	70	1.17	111	1.62	106	1.52	5.31
Lanzhou Veterinary Institute	114	2.55	249	4.16	191	2.79	197	2.83	5.10
Institute of Biology	89	1.99	148	2.47	125	1.82	152	2.19	4.99
Feed Institute	88	1.97	112	1.87	154	2.25	148	2.13	4.84
Tea Research Institute	106	2.37	178	2.98	190	2.77	178	2.56	4.83
Bee Institute	73	1.63	82	1.37	102	1.49	115	1.65	4.22
Oil Institute	143	3.19	186	3.11	223	3.25	217	3.12	3.86
Irrigation Institute	97	2.17	108	1.81	127	1.85	142	2.04	3.53
Institute of Biogas Science	73	1.63	87	1.45	105	1.53	103	1.48	3.18

Environmental Protection Institute	92	2.05	127	2.12	123	1.79	126	1.81	2.90
Fruit Tree Institute	90	2.01	91	1.52	122	1.78	121	1.74	2.73
Vegetable Institute	114	2.55	135	2.26	166	2.42	151	2.17	2.59
Institute of Agricultural Mechanization	181	4.04	197	3.29	245	3.57	237	3.41	2.48
Information Institute	217	4.85	232	3.88	273	3.98	273	3.93	2.11
Prairie Institute	103	2.30	119	1.99	125	1.82	127	1.83	1.92
Agricultural Economic Institute	84	1.88	103	1.72	96	1.40	103	1.48	1.87
Sericulture Institute	84	1.88	76	1.27	101	1.47	102	1.47	1.78
Institute of Agro-Environment and Sustainable Development	135	3.02	158	2.64	153	2.23	160	2.30	1.56
Rice Institute	229	5.12	246	4.11	265	3.87	268	3.85	1.44
Shanghai Veterinary Institute	88	1.97	106	1.77	101	1.47	96	1.38	0.79
Institute of Crop Sciences	309	6.90	339	5.67	318	4.64	321	4.62	0.35
Agricultural Heritage Room	69	1.54	68	1.14	70	1.02	69	0.99	0.00
Sugar Beet Institute	16	0.36	14	0.23	16	0.23	16	0.23	0.00
Lanzhou Animal Husbandry and Medicine Institute	174	3.89	166	2.78	158	2.31	156	2.24	-0.99
Harbin Veterinary Institute	278	6.21	315	5.27	239	3.49	248	3.57	-1.03
Citrus Institute	207	4.62	178	2.98	172	2.51	179	2.57	-1.31
Total	4477	100.00	5981	100.00	6854	100.00	6955	100.00	4.49

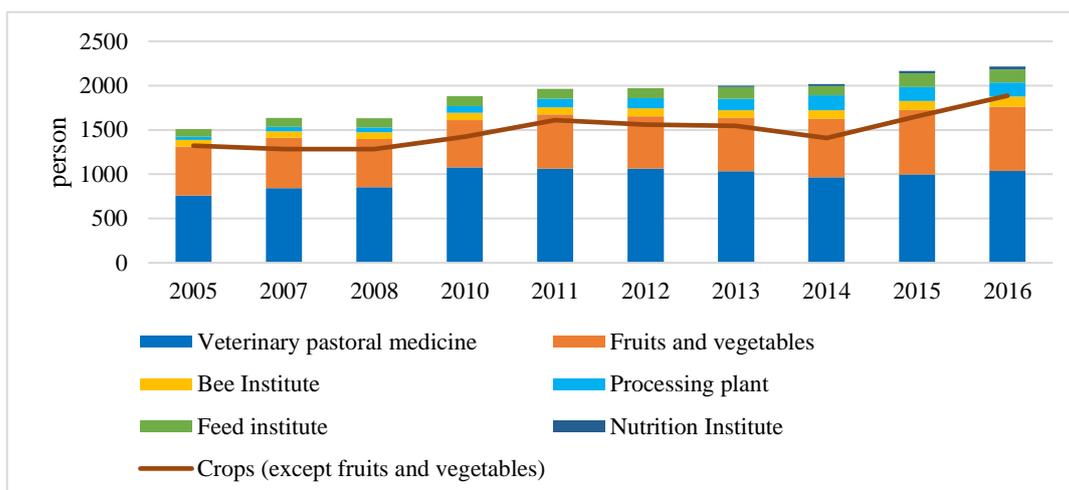


Figure 3-23 Investment in R&D personnel in veterinary and animal husbandry, 2004–2016

Second, investment in agricultural environmental protection and resource conservation personnel has increased. From 2005 to 2016, the numbers of employees engaged in R&D activities at the Environmental Protection Institute, Institute of Biogas Science, Institute of Plant Protection, Agricultural Resources and Regional Planning Institute, and Institute of Biology increased from 562 in 2005 to 1166 in 2016, an average annual growth rate of 7.34%.

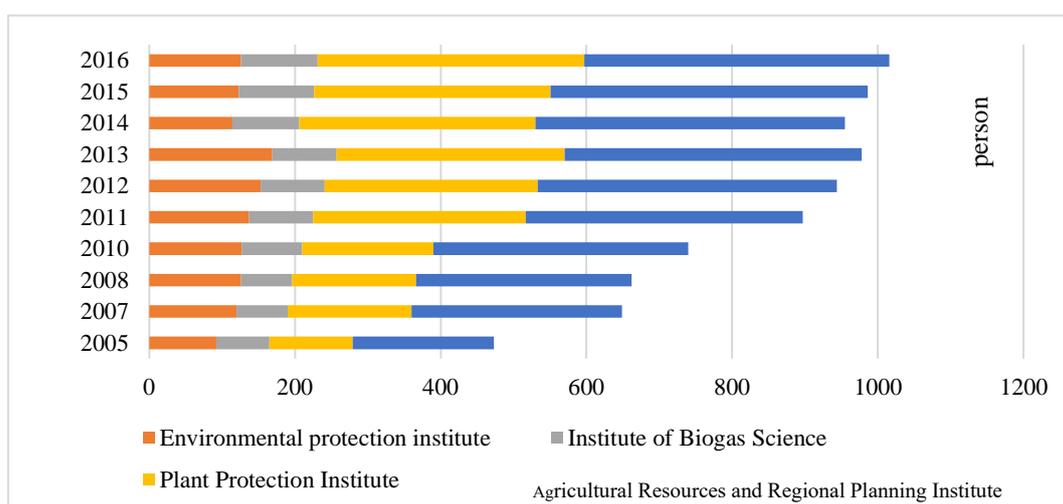


Figure 3-24 Investment in R&D personnel at selected institutes, 2005–2016

Third, the number of R&D personnel in the fields related to climate change and

mitigating meteorological disasters is rising. As shown in Figure 3-25, since 2004, the numbers of employees engaged in R&D activities at the Irrigation Institute and Institute of Agro-Environment and Sustainable Development have increased.

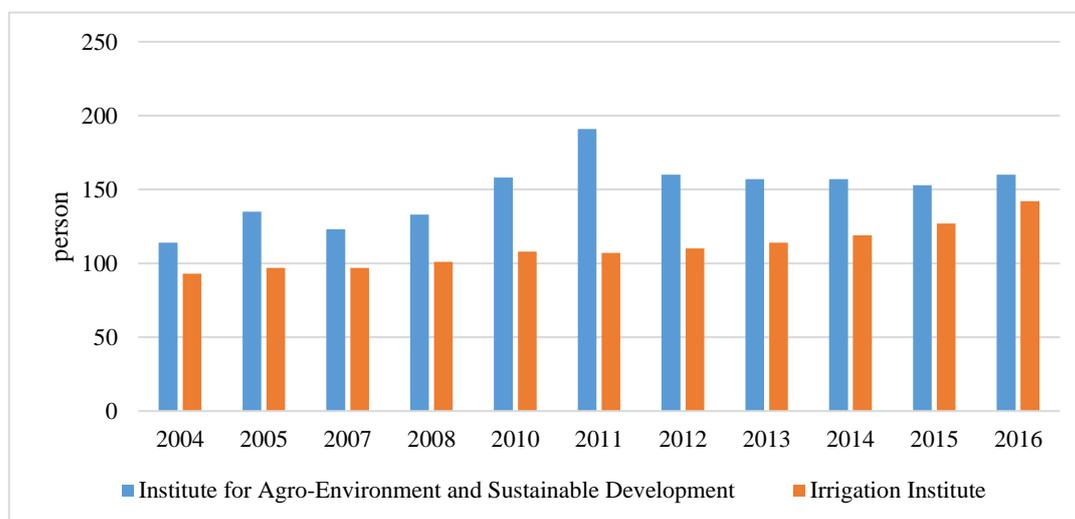


Figure 3-25 Investment in R&D personnel at selected institutes, 2004–2016

3.5.1.3 Summary of R&D investment

At the Chinese Academy of Agricultural Sciences, since the 12th Five-Year Plan period, investment in R&D funding has been increasing in nutrition and health related areas such as agricultural product processing industry, animal husbandry, fruit and vegetables industry, while the growth rate of investment in traditional crop fields has slowed. Since 2001, investment in R&D in environmental protection and resource conservation as well as in fields related to climate change and mitigating meteorological disasters has increased significantly. Similarly, investment in R&D personnel in agricultural nutrition, processing, fruit, and vegetables has increased significantly, while investment in crop science and technology personnel has been stable and rising. The focus of R&D by traditional crop institutes has also shifted from increasing production to improving nutrition and health. Investment in personnel working on environmental protection and resource conservation as well as in fields related to climate change and mitigating meteorological disasters has risen.

In summary, agricultural R&D has shifted from focusing on traditional crops to health-related fields such as fruit and vegetables and food processing. At the same time, investment in R&D into environmental protection, resource conservation, and climate adaptation has gradually increased.

3.5.2 R&D output

3.5.2.1 Research output: S&T papers

Table 3-6 shows the number of S&T papers published by each institute in descending order according to the 2016 data. From the 15th Five-Year Plan period to the 13th Five-Year Plan period, the number of S&T papers published by the Institute of Crop Sciences increased, peaking at 411 in 2016, accounting for 6.81% of all papers. This shows that since the beginning of the 21st century, China's key support policies for crops such as wheat, corn, soybeans, rice, and miscellaneous grains have achieved remarkable results. Publications by the Institute of Plant Protection declined slightly in 2016, second only to the Institute of Crop Sciences, accounting for 5.83%. The number of S&T papers by the Harbin Veterinary Institute also declined slightly.

Table 3-6 shows three characteristics. First, the numbers of papers published by the Veterinary Animal Husbandry and Institute of Crop Sciences are relatively high, while the numbers of papers of the Institute of Processing, Institute of Special Agricultural Products, and Institute of Fruit and Vegetables have increased significantly. Second, the numbers of S&T papers on agricultural environmental protection and resource conservation have been increasing, but have declined slightly in the past three years. Third, the number of S&T papers published by the Irrigation Institute began to increase steadily in 2013, whereas that of the Institute of Biology declined slightly.

Table 3-6 S&T papers by institute, 2004–2016

Institute	2004		2008		2013		2016	
	Number of publications	Proportion (%)						
Institute of Crop Sciences	107	3.72	289	7.21	359	7.55	411	6.81
Institute of Plant Protection	223	7.75	351	8.75	412	8.66	352	5.83
Agricultural Resources and Regional Planning Institute	138	4.79	165	4.11	271	5.70	307	5.09
Harbin Veterinary Institute	219	7.61	295	7.35	234	4.92	288	4.77
Cotton Institute	145	5.04	98	2.44	153	3.22	282	4.67
Institute of Special Agricultural Products	113	3.92	85	2.12	170	3.57	280	4.64
Institute of Processing	33	1.15	55	1.37	160	3.36	272	4.51
Institute of Animal Husbandry	143	4.97	283	7.06	150	3.15	271	4.49
Information Institute	186	6.46	195	4.86	237	4.98	270	4.47

Rice Institute	117	4.06	177	4.41	138	2.90	205	3.40
Shanghai Veterinary Institute	48	1.67	90	2.24	176	3.70	196	3.25
Institute of Agro-Environment and Sustainable Development	98	3.40	114	2.84	187	3.93	192	3.18
Vegetable Institute	50	1.74	125	3.12	171	3.60	192	3.18
Lanzhou Veterinary Institute	83	2.88	0	0.00	172	3.62	183	3.03
Agricultural Economic Institute	120	4.17	110	2.74	116	2.44	175	2.90
Feed Institute	78	2.71	149	3.71	110	2.31	166	2.75
Zhengzhou Pomology Research Institute	45	1.56	60	1.50	77	1.62	158	2.62
Lanzhou Animal Husbandry and Medicine Institute	153	5.31	191	4.76	115	2.42	156	2.58
Oil Institute	62	2.15	113	2.82	177	3.72	156	2.58
Institute of Biology	57	1.98	121	3.02	107	2.25	143	2.37
Quality Standard Institute	7	0.24	55	1.37	69	1.45	134	2.22
Institute of Agricultural Mechanization	45	1.56	64	1.60	74	1.56	131	2.17
Tea Research Institute	87	3.02	95	2.37	75	1.58	123	2.04
Environmental Protection Institute	16	0.56	86	2.14	102	2.14	121	2.00
Fruit Tree Institute	40	1.39	46	1.15	69	1.45	105	1.74
Tobacco Institute	84	2.92	49	1.22	122	2.57	105	1.74
Bee Institute	51	1.77	140	3.49	125	2.63	94	1.56
Prairie Institute	52	1.81	115	2.87	113	2.38	89	1.47
Sericulture Institute	80	2.78	68	1.70	64	1.35	85	1.41
Irrigation Institute	53	1.84	61	1.52	48	1.01	74	1.23
Hemp Institute	25	0.87	30	0.75	53	1.11	73	1.21
Citrus Institute	38	1.32	42	1.05	79	1.66	69	1.14
Institute of Biogas Science	20	0.69	26	0.65	33	0.69	65	1.08
Agricultural Heritage Room	31	1.08	28	0.70	16	0.34	40	0.66
Nutrition Institute		0.00		0.00	0	0.00	38	0.63
Sugar Beet Institute	32	1.11	40	1.00	22	0.46	35	0.58

3.5.2.2 Research output: Number of patents granted

Table 3-7 shows that the research institutes with a large number of patents granted after 2011 were the Lanzhou Institute of Animal Husbandry and Medicine, Institute of Agricultural Mechanization, Institute of Agro-Environment and Sustainable Development, Institute of Processing, Institute of Agricultural Resources and Regional Planning, and Institute of Plant Protection.

Table 3-7 Number of patents granted by institute, 2004–2016

Institute	2004		2008		2013		2016	
	Number	Proportion (%)						
Lanzhou Animal Husbandry and Medicine Institute	0	0.00	4	2.67	44	5.94	211	13.65
Institute of Agricultural Mechanization	13	19.40	21	14.00	72	9.72	168	10.87
Institute of Agro-Environment and Sustainable Development	11	16.42	4	2.67	54	7.29	113	7.31
Institute of Processing	0	0.00	0	0.00	47	6.34	110	7.12
Agricultural Resources and Regional Planning Institute	2	2.99	7	4.67	38	5.13	61	3.95
Institute of Plant Protection	4	5.97	10	6.67	61	8.23	58	3.75
Institute of Animal Husbandry	0	0.00	19	12.67	26	3.51	55	3.56
Institute of Crop Sciences	2	2.99	14	9.33	27	3.64	54	3.49
Rice Institute	0	0.00	3	2.00	33	4.45	51	3.30
Institute of Biogas Science	1	1.49	8	5.33	6	0.81	51	3.30
Lanzhou Veterinary Institute	0	0.00	2	1.33	15	2.02	50	3.23
Cotton Institute	0	0.00	8	5.33	28	3.78	50	3.23
Prairie Institute	1	1.49	1	0.67	5	0.67	46	2.98
Information Institute	0	0.00	0	0.00	14	1.89	43	2.78
Institute of Special Agricultural Products	0	0.00	6	4.00	7	0.94	41	2.65
Tea Research Institute	0	0.00	6	4.00	21	2.83	38	2.46
Irrigation Institute	4	5.97	1	0.67	21	2.83	36	2.33
Oil Institute	2	2.99	1	0.67	28	3.78	34	2.20
Hemp Institute	1	1.49	3	2.00	4	0.54	33	2.13
Environmental Protection Institute	1	1.49	2	1.33	9	1.21	30	1.94
Sericulture Institute	1	1.49	3	2.00	7	0.94	27	1.75
Feed Institute	2	2.99	5	3.33	10	1.35	25	1.62
Harbin Veterinary Institute	2	2.99	2	1.33	47	6.34	23	1.49
Institute of Biology	11	16.42	11	7.33	31	4.18	23	1.49
Tobacco Institute	1	1.49	0	0.00	32	4.32	23	1.49
Vegetable Institute	3	4.48	2	1.33	10	1.35	18	1.16
Shanghai Veterinary Institute	3	4.48	1	0.67	18	2.43	17	1.10
Quality Standard Institute	0	0.00	0	0.00	2	0.27	16	1.03
Citrus Institute	0	0.00	1	0.67	5	0.67	14	0.91
Zhengzhou Pomology Research Institute	1	1.49	0	0.00	5	0.67	11	0.71
Fruit Tree Institute	0	0.00	1	0.67	6	0.81	9	0.58
Agricultural Economic Institute	0	0.00	0	0.00	0	0.00	5	0.32
Nutrition Institute		0.00		0.00	0	0.00	2	0.13
Bee Institute	1	1.49	4	2.67	7	0.94	0	0.00
Agricultural Heritage Room	0	0.00	0	0.00	0	0.00	0	0.00

Sugar Beet Institute	0	0.00	0	0.00	1	0.13	0	0.00
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Table 3-8 shows that the top four institutes that were granted invention patents in 2016 were the Animal Husbandry Institute, Oil Institute, Institute of Agricultural Mechanization, and Lanzhou Animal Husbandry and Medicine Institute. Overall, the number of patents granted for the Institute of Nutrition and Health increased significantly until 2016, while it decreased slightly in the following years. The numbers of patents granted for the Institute of Agricultural Environmental Protection and Resource Conservation fluctuated greatly, while those for the Institute of Environmental Protection, Institute of Biogas Science, and Institute of Agricultural Resources and Regional Planning all increased significantly compared with before 2012. The numbers of patents granted for the Institute of Biology and Irrigation Institute fluctuated greatly and the number of patents granted for the Irrigation Institute showed an increasing trend over time.

Table 3-8 Number of invention patents granted by institute, 2004–2016

Institute	2004		2008		2013		2016	
	Number	Proportion (%)						
Institute of Animal Husbandry	0	0.00	11	11	22	4.51	94	14.33
Oil Institute	1	2.94	1	1	26	5.33	50	7.62
Institute of Agricultural Mechanization	0	0.00	1	1	23	4.71	48	7.32
Lanzhou Animal Husbandry and Medicine Institute	0	0.00	3	3	9	1.84	46	7.01
Agricultural Resources and Regional Planning Institute	2	5.88	7	7	28	5.74	39	5.95
Institute of Agro-Environment and Sustainable Development	2	5.88	1	1	14	2.87	35	5.34
Hemp Institute	1	2.94	0	0	0	0.00	30	4.57
Information Institute	1	2.94	1	1	1	0.20	29	4.42
Institute of Biogas Science	0	0.00	0	0	2	0.41	29	4.42
Citrus Institute	0	0.00	1	1	5	1.02	27	4.12
Environmental Protection Institute	1	2.94	2	2	5	1.02	23	3.51
Vegetable Institute	1	2.94	2	2	8	1.64	22	3.35
Institute of Crop Sciences	2	5.88	14	14	27	5.53	21	3.20

Institute of Plant Protection	4	11.76	10	10	43	8.81	18	2.74
Harbin Veterinary Institute	1	2.94	2	2	47	9.63	17	2.59
Cotton Institute	0	0.00	2	2	13	2.66	16	2.44
Sericulture Institute	0	0.00	7	7	24	4.92	13	1.98
Prairie Institute	0	0.00	0	0	4	0.82	13	1.98
Tea Research Institute	0	0.00	4	4	13	2.66	13	1.98
Lanzhou Veterinary Institute	1	2.94	2	2	6	1.23	13	1.98
Zhengzhou Pomology Research Institute	1	2.94	0	0	3	0.61	10	1.52
Fruit Tree Institute	2	5.88	5	5	33	6.76	9	1.37
Feed Institute	0	0.00	0	0	1	0.20	9	1.37
Agricultural Economic Institute	0	0.00	0	0	0	0.00	8	1.22
Nutrition Institute		0.00		0	0	0.00	7	1.07
Institute of Biology	11	32.35	11	11	28	5.74	6	0.91
Quality Standard Institute	0	0.00	0	0	2	0.41	5	0.76
Institute of Processing	0	0.00	0	0	16	3.28	3	0.46
Rice Institute	0	0.00	3	3	36	7.38	1	0.15
Institute of Special Agricultural Products	0	0.00	6	6	6	1.23	1	0.15
Tobacco Institute	1	2.94	0	0	14	2.87	1	0.15
Irrigation Institute	0	0.00	0	0	8	1.64	0	0.00
Bee Institute	1	2.94	1	1	16	3.28	0	0.00
Agricultural Heritage Room	1	2.94	3	3	4	0.82	0	0.00
Shanghai Veterinary Institute	0	0.00	0	0	0	0.00	0	0.00
Sugar Beet Institute	0	0.00	0	0	1	0.20	0	0.00

3.5.2.3 Summary of R&D output

Based on the above analysis, we can see that the outcomes of the agricultural research by the Chinese Academy of Agricultural Sciences have increased significantly. For both the number of S&T papers published and the number of patents granted, there is a clear trend toward a transition to improved nutrition and health, climate adaptation, and sustainable development.

3.6 Jiangsu Academy of Agricultural Sciences

The Jiangsu Academy of Agricultural Sciences is a leading agricultural public welfare

institute managed directly by the Jiangsu Provincial Government. It has 28 research institutes, including 16 professional research institutes and 12 agricultural district institutes, as well as nearly 4000 R&D personnel.

3.6.1 Research funding

The number of R&D projects at the Jiangsu Academy of Agricultural Sciences increased from 1020 in 2007 to 1694 in 2018, while project funding increased from CNY 178 million to 825 million in that time; the intensity of project funding was CNY 174,100/piece and CNY 180,900/person in 2007, respectively, after deducting price influencing factors, which increased to CNY 344,500/piece and CNY 321,200/person in 2018. A total of 6263 new S&T projects were started from 2013 to 2018, an annual average of 1044. Among these, 1100 new scientific research projects were started in 2018, an increase of 106 compared with that in 2013. Total funding from 2013 to 2018 was CNY 1.541 billion, with an average annual funding amount of CNY 257 million.

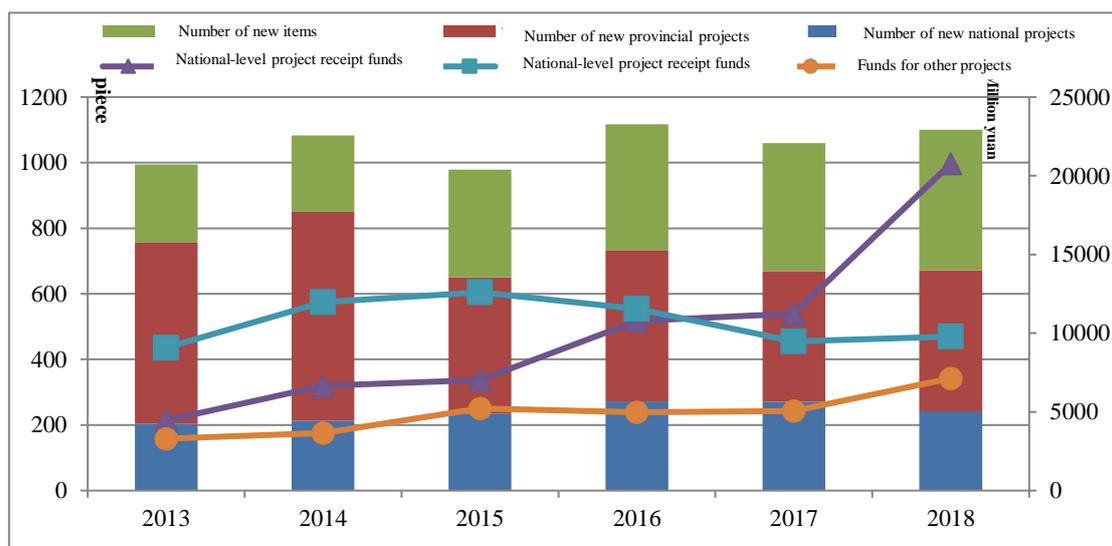


Figure 3-26 New R&D projects by year, 2013–2018

Source: Editorial Board of the Yearbook of the Jiangsu Academy of Agricultural Sciences, Yearbook of the Jiangsu Academy of Agricultural Sciences (2016–2018), Scientific Research Office of the Jiangsu Academy of Agricultural Sciences, Annual Report on the Scientific Research Work of the Jiangsu Academy of Agricultural Sciences (2013–2015)

During the 13th Five-Year Plan period, the Jiangsu Academy of Agricultural Sciences

added 5256 new projects, with CNY 2.25 billion in funding. Among these, there were 1068 national projects, with contract funding of CNY 890 million and actual funding of CNY 971 million. By contrast, there were 2016 provincial projects (CNY 684 million and 759 million, respectively). The number of new projects added by the Institute of Professional Research was 2916, with contract funding of CNY 1.45 billion. The numbers of national, provincial, and other projects were about equal.

Moreover, during the 13th Five-Year Plan period, the Jiangsu Academy of Agricultural Sciences had 21 experts in agricultural industrial technology system, including 5 chief (integrated innovation center) experts, 14 experts (innovation team), and 2 base managers. In 2021, it added another seven experts, including six experts (innovation team) and one base manager. Total expenditure in 2021 was CNY 9.7 million, covering 15 of the 25 systems. The five integrated innovation centers of the Jiangsu Academy of Agricultural Sciences are the special grain/special economy, watermelon, strawberry, peach, and vegetables centers. Since 2018, the Jiangsu Academy of Agricultural Sciences has undertaken 10 major provincial projects to create new varieties (wheat, corn, pepper, watermelon, peach, strawberry, pear, grape, tomato, and pig). The total cost has been CNY 20 million and the implementation cycle is 4–5 years.

3.6.2 Investment in R&D personnel

As shown in Table 3-9, the number of agricultural R&D personnel was the highest at the Institute of Agricultural Resources and the Environment, followed by the Institute of Plant Protection, indicating a high focus on changes in resources and the environment. From the perspective of the highest academic qualifications of researchers, doctoral personnel accounted for the highest proportion at these two institutes, indicating that the key scientific research focuses are mainly distributed in the field of resources and the environment. Further, the proportion of researchers at the Institute of Cash Crops is very high, indicating that food diversity and food nutrition issues are valued. Investment in agricultural research is related to the transformation of agricultural systems.

Table 3-9 Investment in R&D personnel, 2021

Institute	Number	Category			Highest academic qualification				Job title			
		Innovation team member	Manager	Other	Doctor	Master	Undergraduate	Other	Researcher	Associate Researcher	Research Assistant	Other
Institute of Food Crops	76	70	6	0	46	23	5	2	21	31	19	5
Institute of Cash Crops	64	61	3	0	44	14	6	0	19	29	15	1
Institute of Vegetable Research	62	57	4	1	34	20	7	1	19	24	14	5
Institute of Fruit Trees	50	47	3	0	27	12	9	2	15	17	11	7
Institute of Germplasm Resources and Biotechnology	46	42	4	0	25	12	7	2	11	15	16	4
Institute of Plant Protection	85	74	10	1	62	13	7	3	19	44	20	2
Institute of Animal Husbandry	72	68	4	0	44	13	13	2	14	30	23	5
Institute of Veterinary Research	78	66	12	0	48	16	10	4	18	27	27	6
Institute of Animal Immunoengineering	48	44	4	0	26	16	5	1	5	17	21	5
Institute of Agricultural Resources and the Environment	120	110	10	0	80	25	11	4	19	47	46	8
Institute of Quality Safety and Nutrition of Agricultural Products	59	53	6	0	44	8	4	3	8	28	17	6
Institute of Agro-Processing	61	55	6	0	39	18	3	1	13	23	17	8
Institute of Agricultural Facilities and Equipment	56	48	7	1	25	17	6	8	6	14	22	14
Agricultural Information Institute	44	27	7	10	18	10	12	4	10	17	12	5
Institute of Recreational Agriculture	60	46	4	10	26	24	7	3	10	13	20	17
Institute of Agricultural Economics and Development	33	28	4	1	16	11	6	0	4	16	9	4

3.6.3 R&D output

As shown in Table 3-10, during the 13th Five-Year Plan period, the Jiangsu Academy of Agricultural Sciences published 3912 articles. Of these, the numbers of papers published by

the Institute of Plant Protection, Institute of Veterinary Research, Institute of Agricultural Resources and the Environment, and Institute of Quality Safety and Nutrition of Agricultural Products were relatively high. Among the 888 granted patents, the performance of the Institute of Agricultural Facilities and Equipment and Institute of Agricultural Resources and the Environment was outstanding. In total, 200 varieties were examined and appraised, mainly concentrated on grain crops, economic works, and vegetable institutes. Further, 88 main technologies were promoted at or above the provincial level of professional institutes, and the performance of the Institutes of Agricultural Resources and the Environment, Animal Husbandry, Fruit Trees, and Vegetable Research was outstanding. Few regions had outstanding performance in terms of granted patents, variety rights and appraisal of varieties, and other outputs. The gap between the regions is clear, with the R&D output of the Xuzhou Institute, Huaiyin Institute, Lianyungang Institute, and Lixiahe Institute higher.

Table 3-10 Published papers by institute, 2016–2020

Institute	2016	2017	2018	2019	2020	Total
Institute of Food Crops	55	53	49	37	66	260
Institute of Cash Crops	54	44	47	46	52	243
Institute of Vegetable Research	63	53	53	27	37	233
Institute of Fruit Trees	49	42	31	23	20	165
Institute of Germplasm Resources and Biotechnology	44	28	11	21	24	128
Institute of Plant Protection	65	67	66	69	72	339
Institute of Animal Husbandry	46	45	42	58	60	251
Institute of Veterinary Research	89	57	68	81	64	359
Institute of Animal Immunoengineering	—	22	24	23	29	98
Institute of Agricultural Resources and the Environment	111	95	88	81	119	494
Institute of Agro-Processing	79	71	44	62	71	327
Institute of Quality Safety and Nutrition of Agricultural	41	56	89	81	90	357
Institute of Agricultural Facilities and Equipment	30	35	28	37	38	168
Institute of Agricultural Information	75	33	29	21	24	182
Institute of Recreational Agriculture	—	10	23	27	18	78
Institute of Agricultural Economics and Development	—	55	24	30	19	128
Circular Agriculture Center	—	41	30	31	—	102
Total	801	807	746	755	803	3912

Altogether, 3912 papers were published by all the institutes from 2016 to 2020. Specifically, the Institute of Agricultural Resources and the Environment, Institute of Veterinary Research, and Institute of Quality Safety and Nutrition of Agricultural Products

were the three highest publishers, with 494, 359, and 357 papers published in 2016–2020, respectively. The highest growth of the Institute of Agricultural Facilities and Equipment indicates the increase in concern for resources and the environment, while the large increases for the Institute of Veterinary Research and Institute of Quality Safety and Nutrition of Agricultural Products indicate rising concern for food safety and quality and nutritional standards over time.

As shown in Table 3-11, from 2016 to 2020, the Institute of Agricultural Facilities and Equipment had the largest number of granted patents (162), followed by the Institute of Agricultural Resources and the Environment (127) and Institute of Agro-Processing (104). The Institute of Agricultural Facilities and Equipment showed the greatest fluctuation and the Institute of Quality Safety and Nutrition of Agricultural Products and Institute of Agricultural Resources and the Environment showed upward trends.

Table 3-11 Patents granted by institute, 2016–2020

Institute	2016	2017	2018	2019	2020	Total
Institute of Food Crops	10	7	7	1	8	33
Institute of Cash Crops	7	7	3	14	8	39
Institute of Vegetable Research	6	6	13	8	10	43
Institute of Fruit Trees	6	11	3	8	6	34
Institute of Germplasm Resources and Biotechnology	9	5	7	11	4	36
Institute of Plant Protection	12	8	5	13	19	57
Institute of Animal Husbandry	9	8	12	12	10	51
Institute of Veterinary Research	15	4	5	9	12	45
Institute of Animal Immunoengineering	—	6	5	11	12	34
Institute of Agricultural Resources and the Environment	31	20	26	21	29	127
Institute of Agro-Processing	7	14	23	10	15	69
Institute of Quality Safety and Nutrition of Agricultural	16	18	25	23	22	104
Institute of Agricultural Facilities and Equipment	20	35	64	26	17	162
Institute of Agricultural Information	1	1		2	4	8
Institute of Recreational Agriculture	—	2	5	1	2	10
Institute of Agricultural Economics and Development	—	—	—	—	—	0
Circular Agriculture Center		18	6	12	—	36
Total	149	170	209	182	178	888

As shown in Table 3-12, granted variety rights varied greatly by institute. The Institute of Food Crops had the highest number but showed a slight decline in 2019 and 2020. The Institute of Cash Crops gradually increased over time, suggesting that consumers’ demand for food

diversification has increased, which has also led to structural changes in the food supply system. The Institutes of Fruit Trees and Vegetable Research both fell then rose, reflecting increased demand for fruit and vegetables over time. Overall, the number of granted variety rights increased significantly over time, inferring that the attention paid to resources and the environment has gradually increased.

Table 3-12 Granted variety rights by institute, 2016–2020

Institute	2016	2017	2018	2019	2020	Total
Institute of Food Crops	21	21	20	14	18	94
Institute of Cash Crops	2	3	3	4	4	16
Institute of Vegetable Research	6	5	4	2	3	20
Institute of Fruit Trees	5	2	2		5	14
Institute of Germplasm Resources and Biotechnology	1	2	0	4	3	10
Institute of Plant Protection	0	0	0	0	0	0
Institute of Animal Husbandry	0	0	0	0	0	0
Institute of Veterinary Research	0	0	0	0	0	0
Institute of Animal Immunoengineering	0	0	0	0	0	0
Institute of Agricultural Resources and the Environment	0	0	0	0	0	0
Institute of Agro-Processing	0	0	0	0	0	0
Institute of Quality Safety and Nutrition of Agricultural	0	0	0	0	0	0
Institute of Agricultural Facilities and Equipment	0	0	0	0	0	0
Institute of Agricultural Information	0	0	0	0	0	0
Institute of Recreational Agriculture	0	3	3	3	0	9
Institute of Agricultural Economics and Development	0	0	0	0	0	0
Circular Agriculture Center	0	0	0	0	—	0
Total	35	36	32	27	33	163

As shown in Figure 3-27, the Institute of Food Crops and Institute of Vegetable Research had the highest number of identified varieties, with some fluctuations, followed by the Institute of Cash Crops. The growth of the Institute of Agricultural Resources and the Environment was the most pronounced over time, while the identified varieties of the Institute for Food Crops and Institute of Cash Crops declined slightly. The identified varieties of the Institute of Animal Husbandry and Institute of Agricultural Resources and the Environment were the lowest.

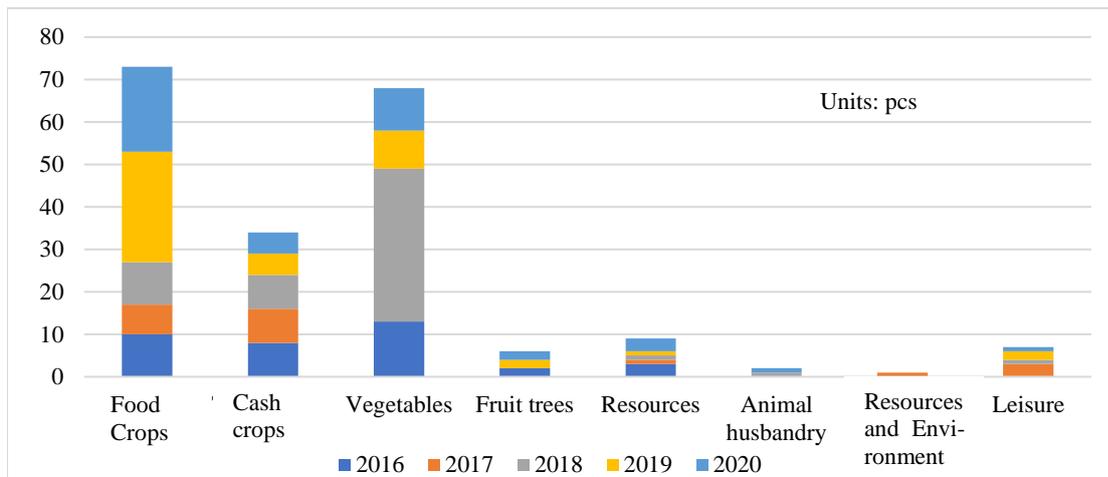


Figure 3-27 Identified varieties, 2016–2020

As shown in Figure 3-28, the Institute of Agricultural Resources and the Environment had the highest number of technologies promoted at or above the provincial level, followed by the Institute of Animal Husbandry, Institute of Fruit Trees, Institute of Vegetable Research, and Institute of Cash Crops. The institutes of cash crops, vegetable research, and fruit trees all showed steady growth over time, highlighting that demand for food nutrition and health has increased. Overall, investment in agricultural research has risen, showing that such investment has promoted the transformation of China’s agri-food system.

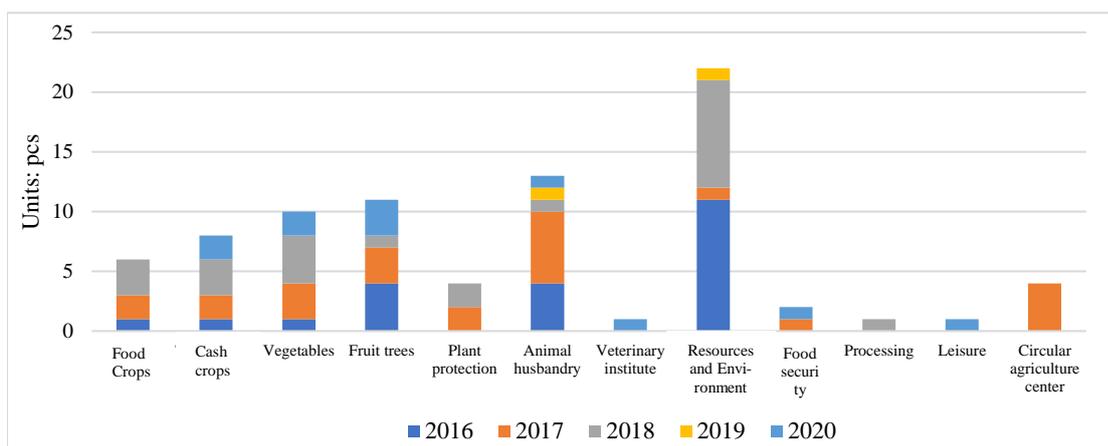


Figure 3-28 Technologies promoted at or above the provincial level in 2016–2020

3.6.4 Key areas and trends of R&D

Since 2021, the Jiangsu Academy of Agricultural Sciences has focused on several key areas, including biological breeding, cultivated land quality, non-point source pollution, resources and the environment, and green control. It has also created 8–10 key disciplines, including gene editing and molecular design and breeding, as well as 5–8 emerging interdisciplinary disciplines such as smart agriculture, nutrition and health, and leisure agriculture, for which it continues to increase support. Focus has been placed on meeting the basic S&T needs of agricultural production and increasing support for germplasm innovation, agricultural biological products, green and efficient cultivation, and other fields.

4 Characteristics and trends of private R&D in China's agri-food system

This section discusses the characteristics and trends of private R&D in China's agri-food system based on the R&D inputs and outputs of the food processing industry as well as the R&D expenses of private agricultural enterprises.

4.1 R&D investment and production in the food processing industry

The agricultural and sideline food processing industry refers to the processing activities of agricultural, forestry, animal husbandry, and fishery products as raw materials for cultivation; feed processing; vegetable oil and sugar processing; slaughtering and meat processing; aquatic product processing; and vegetables, fruit, and nuts processing. The data on the agricultural and sideline food processing industry come from the Statistical Yearbook of Industrial Science and Technology Activities.

4.1.1. R&D inputs in the agricultural and sideline food processing industry

The indicators used to assess performance are R&D personnel, R&D personnel full-time equivalent, and R&D funding.

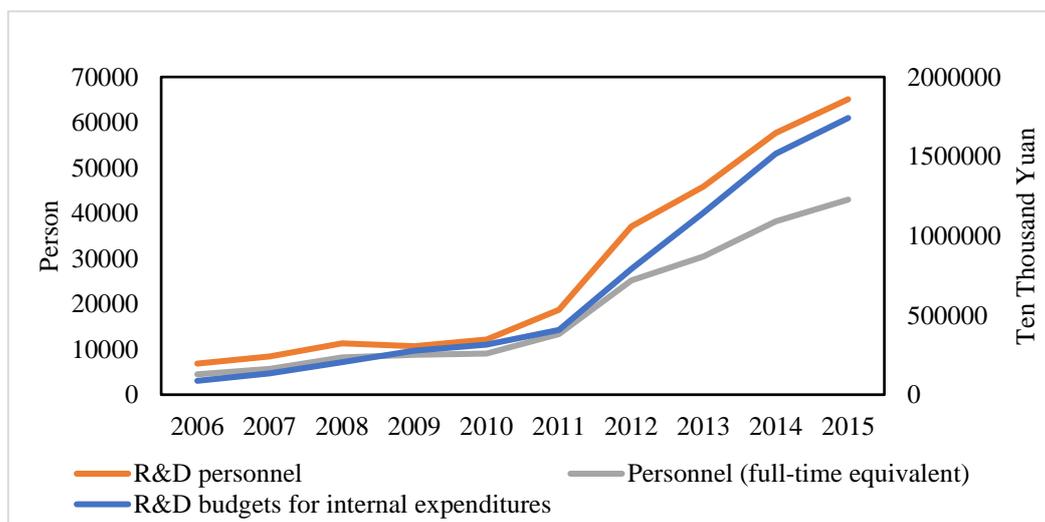


Figure 4-1 R&D inputs in the agricultural and sideline food processing industry, 2006–2015

Figure 4-1 shows that the three indicators of R&D inputs in the agricultural and sideline food processing industry were relatively consistent between 2006 and 2015, in line with the trend in R&D outputs over time. After 2011, R&D inputs and outputs in this industry grew

rapidly. R&D investment in the agricultural and sideline food processing industry reached CNY 17.42 billion in 2015. The slow growth in R&D personnel full-time equivalent after 2012 may indicate that the working hours of R&D workers have decreased.

4.1.2 R&D outputs in the agricultural and sideline food processing industry

In this report, to measure R&D outputs, we use the number of patent applications, number of invention patents, and number of favorable national or industry standards for patent formation, among which the latter only has data since 2010. Figure 4-2 shows that the numbers of patent applications and invention patents increased slowly from 2006 to 2011, with the latter rising from 51 to 558. After 2011, the numbers of patent applications and invention patents grew rapidly, with the latter rising rapidly from 558 to 3632 in five years. The number of favorable national or industry standards for patent formation in this industry also increased in 2012 and showed a steady rise thereafter.

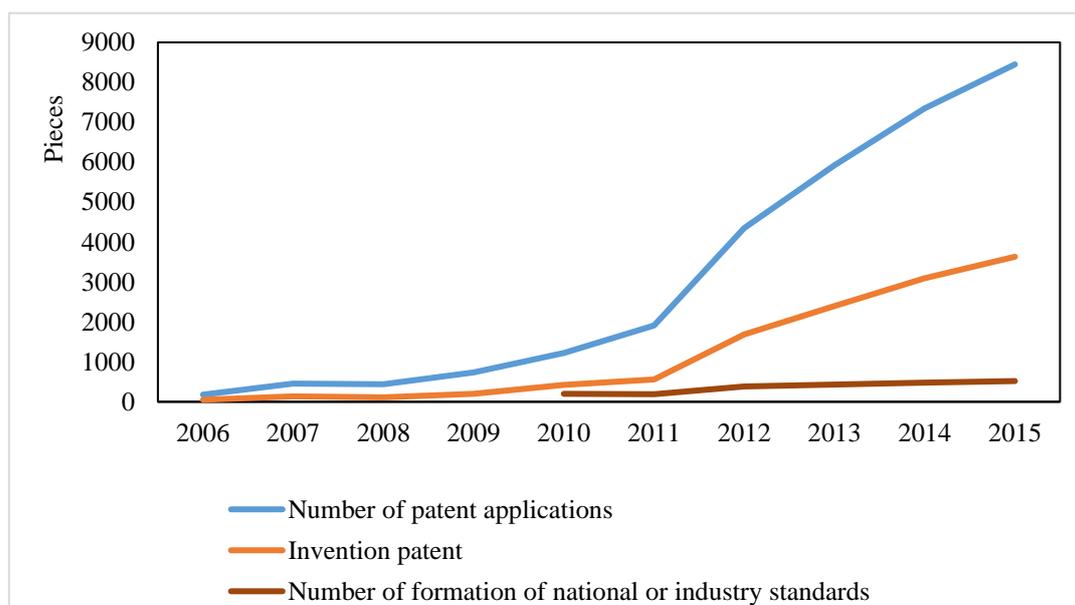


Figure 4-2 R&D outputs in the agricultural and sideline food processing industry, 2006–2015

4.2 R&D investment by agricultural enterprises

4.2.1 Current situation

A large gap remains between R&D investment by agricultural enterprises in China and the innovation of multinational agricultural companies. The report on innovation by China's agricultural enterprises published in November 2021 uses information from the annual reports of listed companies and data from the patent database of the State Intellectual Property Office to construct an evaluation index of the innovation capability of Chinese agricultural enterprises. This index includes 3 first-level indicators, 8 second-level indicators, and 18 third-level indicators of innovation input capability, innovation output capability, and innovation environment.

4.2.2 General trends and characteristics of agricultural enterprises

Agricultural enterprises in China are few in number and their proportion of listed enterprises is declining. Similarly, their proportion of the output of listed enterprises and the proportion of agricultural enterprises in the industry have both decreased.

4.2.2.1 R&D investment by agricultural companies

Using information from the annual reports of listed companies, Figure 4-3 shows the R&D investment by one multinational enterprise (Syngenta) and two Chinese agricultural enterprises from 2011 to 2020.

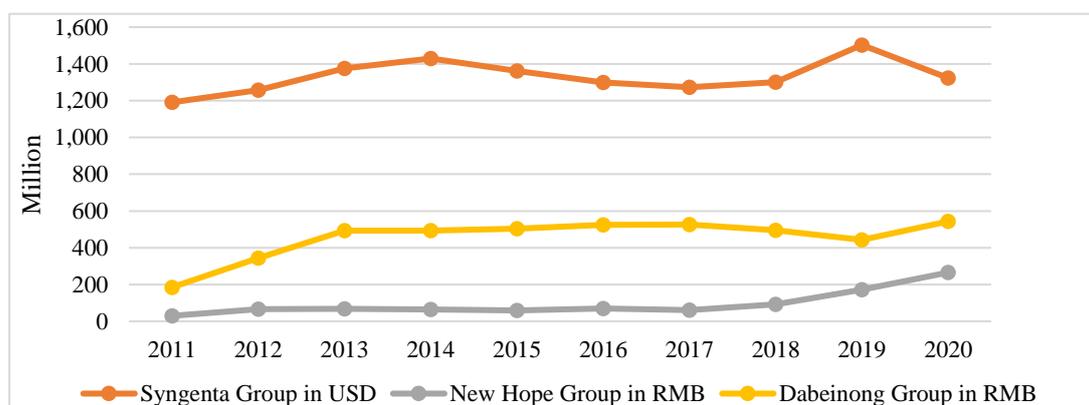


Figure 3-3 R&D investment by Syngenta, New Hope, and Dabeinong, 2011–2020

The figure shows that Syngenta’s R&D expenses globally decreased from \$1.50 billion in 2019 to \$1.32 billion in 2020, a decrease of 12%. By contrast, in this period, New Hope and Dabeinong increased their R&D investment. From 2019 to 2020, R&D investment by New Hope increased from CNY 173 million to CNY 265 million, a rise of 53%, while that by Dabeinong increased from CNY 443 million to CNY 543 million, a rise of 23%.

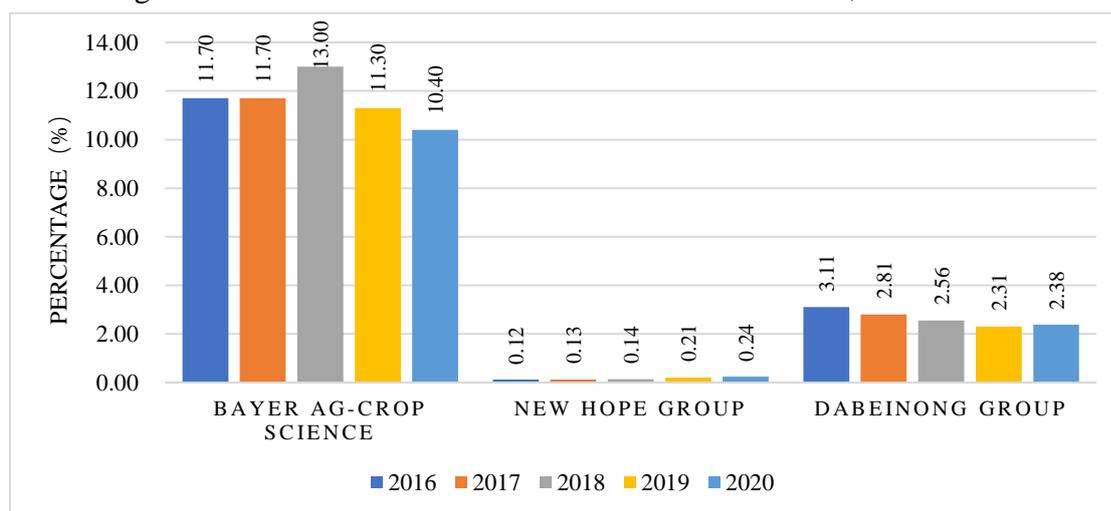


Figure 4-4 R&D investment by private enterprises as a percentage of operating income, 2016–2020

Figure 4-4 shows R&D investment as a proportion of the operating income of private enterprises over 2016–2020. Bayer’s R&D investment in crop science accounted for more than 10% of its operating income in these years. Owing to the large number of and product differences among agricultural enterprises, R&D investment as a proportion of operating income by agricultural enterprises in China is lower than that of multinational companies. From 2016 to 2020, R&D investment as a proportion of operating income by Dabeinong remained above 2.3%, while that of New Hope increased from 0.12% in 2016 to 0.24% in 2020.

4.2.3. R&D investment intensity of agricultural enterprises

Based on the 2021 report mentioned earlier, overall, the innovation ability of agricultural enterprises has improved. In 2020, the innovation index of agricultural enterprises was 47.25, which was 0.4 points higher than that in 2019 (46.85). In 2020, the investment intensity of

R&D funding was 2.6%, again higher than that in 2019 (2.55%). However, the innovation index of the top 20 agricultural enterprises was at a medium level, with a small gap between them (the highest score was 75.34 and the lowest score was 65.33), and there was still a lack of leading enterprises in R&D.

In contrast to R&D investment by agricultural universities and research institutes, enterprises' R&D investment has focused on applied research and new product development, which tend to earn higher profits. For example, Dabeinong's main business includes pig breeding, seed industry technology, and service chain management. According to its 2020 financial report, its R&D expenses increased by 41.8%, compared with 2019, mainly due to increased R&D investment in the feed, seed, and vaccine industries. New Hope has successively undertaken more than 100 national, provincial, and municipal R&D projects, such as the Application and Demonstration of Efficient and Safe Breeding Technology of Green Waterfowl and Regulation and Mechanism Project of Dietary Composition and Feeding System on the Formation of Healthy and High-quality Meat of Livestock and Poultry, which is the key R&D plan of Shandong Province. Further, it has managed the Research and Industrialization Promotion of Key Technologies of Environmentally Friendly and Non-resistant Feed for Pigs and Poultry project. The company has recently applied for 2006 patents, with 1371 being granted. It also applied for 295 patents in 2020, including 93 invention patents.

Nevertheless, it is necessary to strengthen innovation by enterprises and support collaboration among enterprises, universities, and research institutes to enhance their innovation ability and transform agricultural technology in China. At the same time, it is urgent to build leading agricultural S&T enterprises, develop mechanisms and systems, cultivate leading talent in agricultural fields, and transform the innovation environment.

5 Conclusions and policy suggestions

5.1. Main results and conclusions

First, China's public agricultural research system is large, with the highest number of R&D personnel and largest amount of funding in the world; however, the intensity of agricultural R&D investment is low. R&D in China's agri-food system is mainly dominated by public R&D institutes, especially agricultural research institutes and agricultural universities, with a low proportion of private sector enterprises. Hence, investment and innovation capacity are insufficient overall. In 2018, the number of R&D personnel at agricultural research institutes and agricultural universities reached 63,184, of which 78% worked in research institutes. In the same year, government funding accounted for 89% of all funding for agricultural research institutes and 82.5% of all funding for agricultural universities. The breakdown of national, provincial, and municipal agricultural research institutes is 6.9%, 40.4%, and 52.7%, respectively. China's agricultural R&D expenditure increased from CNY 3.69 billion in 2002 to CNY 23.79 billion in 2018 (2015 prices). The investment intensity of agricultural research (the ratio of agricultural R&D funding to agricultural GDP) increased, but was only 0.77% in 2018, which was far below the level of about 2% in developed countries and the global average of about 1%.

Second, the main goal of public R&D in China's agri-food system is to increase food production. Less attention has been paid to the problems of resources, the environment, and nutrition and health arising from yield growth. However, inputs and outputs related to resources, the environment, and nutrition and health have recently grown rapidly. Data from China Agricultural University and the Chinese Academy of Agricultural Sciences show that colleges or institutes focusing on traditional crops and livestock and poultry products receive the most research funding and have the most personnel, while colleges or institutes focusing on resources and the environment have relatively less research funding and fewer researchers, but the growth rate has increased significantly. Data from the Jiangsu Academy of Agricultural Sciences show that institutes related to resources and the environment, food quality, and nutrition have relatively high inputs (investment and personnel). The numbers of papers published, and patents of those institutes are also higher, reflecting the importance and transformation of agricultural research institutes in more developed regions in terms of

resources, the environment, nutrition, and health and climate adaptation.

Third, R&D investment in China's agri-food system focuses on the three major staple grains (rice, corn, and wheat) and meat products, with relatively insufficient investment in agricultural products with more nutritional value such as non-staple grains, fruit, and vegetables. In 1986–2019, funding provided by the NSFC for rice, corn, wheat, and non-staple grains was CNY 1.42, 0.76, 0.62, and 0.43 billion, respectively; by contrast, funding for livestock and poultry, fruit, vegetables, and aquaculture was CNY 2.52, 1.26, 1.16, and 1.13 billion, respectively. Although China's MAITS has 100 scientists and 94 testing stations for the four major non-staple grains (barley and highland barley, millet and sorghum, oats and buckwheat, and edible pulses), this number is still far below those for the three major staple grains (140 scientists and 157 testing stations). The ratio of research funding for staple grains, livestock and poultry, fruit, and vegetables at China Agricultural University was 65:12:14:9 in 2016–2020.

5.2. Policy recommendations for reorienting China's R&D in agri-food systems

First, R&D in agri-food systems should shift its focus from production to the four development goals of high yield and efficiency, nutrition and health, environmental sustainability, and climate adaptation. This shift calls for the development of mutually beneficial technologies for both the human and the earth. China should pay more attention to new trends in international agri-food science and technology, strengthen research on the cutting-edge technologies for transforming modern agriculture and food, and gradually increase investment in agri-food S&T projects related to emerging trends such as the environment, agricultural sustainability, food safety and nutrition, and climate change.

Second, agri-food R&D inputs should be increased for non-staple grains, fruit, and vegetables, while emphasizing the major staple grains and meat. Stable supply of major staple crops and meat is the core objective of China's food security policy. However, as people have recently begun to over-consume staple grains and meat, attention should also be paid to the R&D of more nutritious non-staple grains, fruit, and vegetables to improve their production and reduce their prices.

Third, while ensuring governmental investment in agri-food R&D, China should introduce a more diversified agri-food R&D program and encourage more private

investment in agri-food R&D. It should substantially increase its investment in addressing the major scientific and common technical issues related to national security and long-term development as well as the infrastructure of major research facilities and platforms. Meanwhile, it should increase its support for R&D investment in agricultural enterprises through public–private partnerships, subsidies, financial support, and tax incentives, especially for agri-tech startups.

5.3. Contribution and future research

This report focuses on R&D investment throughout China’s agri-food system instead of solely concentrating on traditional agricultural production. The report uses publicly available statistics and R&D data collected from representative research institutes to demonstrate the patterns, priorities, and trends of public R&D investment in China’s agri-food system, thus providing empirical support for transforming public agri-food R&D to address the challenges of resources, the environment, health, and climate change. The report also highlights the role of the private sector in agri-food R&D. The Chinese experience is valuable and should be shared with other developing countries.

Future research could further improve the collection and analysis of data from the private sector and local agri-food research institutes as well as develop a suitable evaluation index system for transforming agri-food R&D.

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