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Drivers of Innovation and Development of Top Performing Agribusinesses in China

Impulsores de la innovación y el desarrollo de agronegocios de alto rendimiento en China

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Abstract

The paper identifies and prioritizes the drivers of innovation and development of agribusinesses in China. By applying systemic and logical approaches, as well as the decomposition analysis method, the author classified innovation drivers in the agribusiness sector and projects implementing various digital tools in agriculture. Statistical and other calculations were used to estimate innovation growth rates. The research findings can be applied by: central and local governments to develop programs for recombining innovation opportunities, as well as training programs for farmers.

Keywords: Drivers; farmers; innovation; R&D; smart farming.

Resumen

El documento identifica y prioriza los impulsores de la innovación y el desarrollo de los agronegocios en China. Al aplicar enfoques sistémicos y lógicos, así como el método de análisis de descomposición, los autores clasificaron los impulsores de innovación en el sector agroindustrial y los proyectos que implementan diversas herramientas digitales en la agricultura. Se utilizaron cálculos estadísticos y de otro tipo para estimar las tasas de crecimiento de la innovación. Los resultados de la investigación pueden ser aplicados por: gobiernos centrales y locales para desarrollar programas para recombinar oportunidades de innovación, así como programas de capacitación para agricultores.

Palabras clave: conductores; agricultores; innovación; R+D; agricultura inteligente.

JEL Classification/ Clasificación JEL: Q1, Q12, Q13.

1. Introduction

Innovations make up the most important driver of socio-economic development in any economy, affecting to a large extent the households' standards of living (Pradhan et al., 2020). Innovations result in:

- improved standards of living;
- new products and services and their improved quality;
- better technologies;
- new sectors of the economy;
- an emerging global marketplace (e.g., through online platforms), expanding people's information and communication capabilities.

Innovations contribute to long-term economic growth, reduce production costs and increase profits, save electricity, water, land and other natural resources, and reduce the negative environmental impacts associated with their consumption (Jahanger et al., 2022). Innovations that are in demand in the market enhance the companies' competitiveness. Therefore, innovations are becoming a global trend of economic development. Since agriculture is closely linked to the food system (agrifood economy), innovations in agribusinesses should be viewed from the perspective of the entire value chain, the commitment of all its participants (Stanco et al., 2020), and as drivers of the development of the socio-economic system (Tesheva, 2021). Members of a single value chain are integrated into a single technological process of forming agro-industrial associations (Bebudovna & Ganjiyevich, 2021).

In the face of severe food shortages and permanent population growth, advanced artificial intelligence, mobile Internet and Internet of Things technologies provide realistic solutions to this problem. Innovative development of such value chain is based on the smart farming approach, biotechnology, alternative technologies and sources of raw materials, robotics, precision agriculture, and the Internet of Things (IoT). Innovations ensure long-term economic growth. Intelligent decision support systems and real-time analysis, soil characterization mapping, smart irrigation systems, drones and robots for harvesting, weed detection, pest spraying, etc. increase the efficiency of agribusiness processes and ensure its sustainable development (Mohamed et al., 2021). Global trends in agribusiness development are widely researched by contemporary authors (Aznar-Sanchez et al., 2019; Chen et al., 2022; Jhariya et al., 2019; Jonkman et al., 2019) and boil down to the following patterns:

- value added in value chains is increasingly concentrated in knowledge-based sectors (genetics and breeding, industrial design, engineering, and the IT sector);
- agribusinesses depend less on the bioclimatic aspects and more on technologies to increase yields, maintain ecological integrity, productivity, and prevent losses;
- the demand for food is shifting toward products with predetermined improved properties;
- a transition to a knowledge economy is taking place. It is a new model of workforce education and training in crucial competencies, focusing on rapid adaptation to the new environment of digital transformation and increased robotization;
- the role of sustainability factors and product safety is increasing through the introduction and tightening of certification and standardization systems.
- the use of water and its unconventional sources, as well as crops readily adaptable to climate change, is increasing.

These trends may be implemented in particular economies through the impact of large integrating companies, influencing and controlling segments of food systems that make up global value chains and drive innovative technologies (Orlova, 2020). Top agribusinesses act as a bridge between dispersed smallholder farmers and markets, providing guidance and support to farmers in adjusting their agricultural production patterns, as well as reliable information on innovations, market, and control over distribution channels. Because of this, the conflicts between small and large agribusinesses are somewhat mitigated (Lu & Chen, 2021).

Vertical farming, among other agricultural innovations, is a revolutionary and probably quite sustainable method of farming. It has attracted attention globally, but the technology is especially needed in poorer countries. However, high costs hold back its adoption. China strives hard to switch to vertical farms, planning to build a 250-acre vertical farming area in Shanghai. Plenty Inc. startup intends to build 300 indoor farms in or near major cities in China to produce fruits and vegetables, due to the increased demand for safer food among the country's middle-class members, for which they are willing to pay more. Compared to conventional farms, vertical indoor farms prevent uncontrolled water and soil wastage and contribute to higher yields, helping to solve the world's most populous country's problem of reducing water and land use. China is one of only three countries with approx. 30% of the world's arable land, permanent grasslands and pastures. According to 2019 data, China owns 12% of global permanent grasslands and pastures, and 9% of the world's arable land. Extensive grazing lands compared to arable land might suggest intensive animal husbandry practices rather than harvesting (FAO, 2021).

Available studies set out the strategy for revitalization of the Chinese countryside, taking into account the fact that agriculture and land management are complex systems (Liu, 2018). According to such studies, the revitalization of rural areas belongs to the primary strategy of rural transformations and a harmonious integration between urban and rural areas by eliminating major social conflicts and major problems. Such transformations include: the country's upgrade through research and education; innovative development of agriculture, rural areas and farmers; extensive integration of interdisciplinary theories and applications, including geography, management, and sociology.

COVID-19 has left a toxic trail in virtually every economy and in every sector. Case studies of the pandemic's impact on agriculture and food security were conducted for Tanzania and South Africa. This has resulted in supply chain disruptions, lost revenue and reduced demand, global and national trade disruptions, changing consumer responses and dietary shifts. Farmers' responses and strategies to overcome these challenges depend on their access to capital and other markets, size and production model, and farm diversification. Smallholder farmers in South Africa, who produced a limited range of cash crops for local markets and depended on buying food from local stores, faced a loss of income and diminished food security. Large commercial producers, dependent on cash and the monoculture system of apple and potato production, suffered economic losses due to market instability and closure. Large farmers who had access to capital were able to buy agricultural inputs in advance, and those who had assets, such as livestock, could sell these assets. Yet, asset sales in response to the impact of COVID-19 may reduce the ability to cope with upcoming shocks, such as droughts in South Africa and flash floods in Tanzania. The diversified and mixed cropping systems in Tanzania, where farmers grew cash crops and food crops and were less dependent on global markets, were less affected by COVID-19 (Tripathi et al., 2021).

The countryside's urbanization is one of the drivers of innovations and development in agriculture. For example, the village of Huangshandian, located in the hilly area of Zhoukoudian in the Fangshan metropolitan area, southwest of Beijing and 10 kilometers from the Zhoukoudian World Heritage Site, has experienced a variety of industrial transformations since 2000, from traditional agriculture to mining and tourism services. The role of traditional agriculture declined gradually, with gradually emerging industries, environmental consciousness and other multifunctional values inherent in the urbanization process. Analysis suggests that economic restructuring plays a major role in rural restructuring (Tu et al., 2018). Spatial restructuring is particularly important for providing a framework for socio-economic development, and social restructuring becomes a support system for rural development. The interplay of the three aspects of restructuring resulted in regular development of the natural, environmental, economic and social systems, as well as integrated promotion of the production, household, environmental and cultural systems, which function in the rural area. Some changes in land management policies and institutional innovation were suggested. They address optimization of land allocation and facilitate the restructuring of rural areas in the metropolitan suburbs. The following steps were proposed:

- adaptation to the new model of the rural economy;
- acceleration of the institutional structure;

- reallocation of rural lands;
- the study of the tourism land management system; and
- inspiring reuse of degraded industrial and mineral lands.

The case study of 300 Brazilian agribusinesses (Leo et al., 2022) determined the winning combination of innovation opportunities for individual companies at various phases of the value chain. The findings revealed that agribusinesses' performance in underdeveloped value chains can be improved through transactions, management and growth. Further links in the chain - traders and retailers representing external drivers of innovation - require a separate analysis to find innovation opportunities for the entire agribusiness value chain. Upstream companies are advised to use their resources effectively to implement new management techniques and tools, while downstream companies should learn and convert new technologies into products and processes. To set up agribusinesses and avoid market dependence on commodities, a public policy in the area of innovative opportunities recombination should be formulated. Available literature on agribusinesses predominantly explains innovations at the value chain level, based primarily on scientific discoveries rather than firm-level innovations. Therefore, this study provides valuable empirical data that can help agribusinesses encourage innovations in agribusiness.

New business models, products, services and innovations are enhanced and accelerated when specific technology drivers are combined. Through the combined effect of technology, the landscape of the agribusiness industry is changing, with far-reaching positive implications, expressed in the innovation of the anthropogenic impact on nature and the growth of the productivity of the entire economy (Bebudovna & Ganjiyevich, 2021). By disrupting the status quo, the following new opportunities are created:

- automation and productivity growth along the entire value chain;
- chatbots for processing requests and expanding the customer base without human involvement;
- development of new and sustainable materials;
- digital modeling of molecular properties;
- assessment of new risks;
- application of mixed data from different sources, including computer vision via satellites.

A new business model is being implemented in agriculture to improve crop yields, develop a fertilization plan and optimize irrigation, whereby soil probes monitor temperature and humidity and then transmit data back to the server every 15 minutes via cellular network (McKinsey & Company, 2022).

To develop and confirm the premises about the positive combination of various drivers of innovation, McKinsey Global Institute has designed a model for developing workforce skills with a focus on innovative technologies. Such a model predicts significant changes in the workforce by 2030. More specifically, the need for manual labor, as well as social, emotional and cognitive (both basic and advanced) skills will be greatly reduced, while the demand for technological skills will greatly increase. Therefore, labor is combined with technological drivers of innovation.

In recent years, the EU has been proactive in research and laying the groundwork for agriculture's digitization. Digitization creates great opportunities in many industries and services and offers good benefits to both producers and consumers. Information and communication technology (ICT) in agriculture is currently booming. An overview of recent research activities and projects on this topic (primarily in the EU), as well as their accompanying problems, are presented in the study of Bacco et al. (2019), with discussion of the findings, research in progress, and unresolved problems. For example, China is facing the issue of the digital divide, caused by differences in socio-economic and technological drivers of an uneven distribution of digital tools across the country and agribusinesses. Information technology is expected to play an increasing role in agriculture:

- ground and aerial robotics may automate operations from planting to harvesting;
- productivity growth is expected with reduced use of chemicals, thereby reducing pressure on the soil;
- smart farming, supported by policies that encourage R&D efforts and relevant investments among farmers, may secure quick and effective growth in the coming years.

By combining local information with other data, such as information on weather and pollution, data on soil conditions become more accessible and reliable, enabling, for example, more effective pest control and reduced pesticide use. Such practices are particularly important in China, where there are sufficiently high concentrations of organophosphorus pesticides in fresh vegetables that pose a potential health risk to consumers (Yu et al., 2016).

That is why vegetables are mostly consumed either boiled or roasted to neutralize the effects of pesticide and fertilizer residues. To facilitate the adoption of smart farming, technology and non-technology actors must carefully consider the main barriers to digitization, particularly: data ownership and use issues; vertical solutions; lower digital skills and high costs for farmers; poor telecommunications infrastructure (Bacco et al., 2019).

There is enough food produced in the world to feed everyone on the planet today, although not everyone enjoys equal access to food. Food security in the not-so-distant future is no longer so obvious (Orlova, 2020). Low growth rates, environmental concerns, volatile energy prices, rising consumer expectations, along with declining profitability make up some of the challenges farmers face today. Innovative solutions making production environmentally friendly, as well as acceptable in social and economic terms are required to produce enough food of good quality.

The agri-food trade faces a number of technological challenges in terms of transactions with agricultural products. More specifically, it is very difficult to improve the effectiveness of transactions while maintaining market stability. Many stakeholders are involved: farmers, processors, retailers, wholesalers, and consumers with different and sometimes contradictory information. This might result in information asymmetry and market failure. In order to reduce market failures and create a fairer trading environment in the agriculture and food industry, ensuring equal treatment of small and medium-sized food and farming businesses, the European Commission has taken steps to prohibit unfair trade practices (Commission Staff Working Document Stakeholder Consultation, 2018). Such steps include overdue payments for perishable food items, unilateral or retroactive contract changes, last-minute order cancellations, etc. These problems reduce the effectiveness of transactions and jeopardize the food market's stability. Furthermore, sophisticated transactions, high transaction costs and long transaction times reduce their effectiveness. Therefore, a new solution should secure fairness and improve effectiveness of food transactions (Mao et al., 2018). A new food trading system relying on blockchain consortium technology is being developed to create a sustainable and credible trading environment and eliminate information asymmetry in the food trade. This technology solves the problems with different authentications and permissions for different roles in the food trade. The proposed system is transparent, thus improving trust. Blockchain technology is transforming many industries today through reliability, decentralization, and end-to-end credibility (Mao et al., 2019).

Blockchain technology has also been investigated in testing dairy products as they enter the food chain, which cannot be damaged or altered (Kasten, 2019). Implementation of this system can also be useful for testing other agricultural products and will provide excellent transparency of the food chain without any organizational costs for producers, labs and processors. This implies that it can be implemented by companies with very limited financial resources.

A very successful value chain in Thailand is contrasted with the weak one in Nigeria to highlight the policy implications for the Nigerian government (Adenle et al., 2017). Crucial drivers and risk factors affecting agribusinesses in Africa are explored. A supportive policy environment, which includes agricultural exporters, infrastructure investments, strategic innovations and governance, will play a major role in Thailand's competitiveness in the global market. Key ministries (of agriculture, science and technology, finance, and trade) in Nigeria could play a leading role in promoting agricultural practices, technology development, lending and coordination of business models, which requires a coordinated policy approach. A trade policy that encourages smallholder farmers is needed as well.

In China, as in many other economies, the pandemic shocks resulted in rising prices, especially for food. For example, in January 2020, food, tobacco and alcohol prices rose 15.2 percent year-over-year, which contributed nearly 4.52 percentage points to the increase in the consumer price index. Meat prices increased by 76.7% (with pork prices jumping by 116%), and prices for fresh vegetables increased by 17.1% (National Bureau of Statistics, 2020).

Study of Huai'an and Lin'an Pig Farmers' Willingness to Revitalize Production amid COVID-19 Shock revealed the extent to which pig farmers are ready to revitalize production activities after experiencing the pandemic shock. Overall, the crucial drivers of farmers' willingness to revitalize production include the farmers' education and experience in pig farming. Willingness to take revitalization steps was quite low - only 41%, with large farms showcasing the strongest willingness (51%), followed by medium (41%) and smallholder farms (32%). The farmers cited access to feed as the biggest difficulty they faced during the pandemic shock. The main reasons for not being willing to revitalize production included the riskiness of the pig farming industry and the difficulty of recovering from the continuous shock. Smallholder farmers wanted most of all support from the government, while large and medium-sized farmers demanded simplification of land allocation and environmental pollution assessment procedures for livestock farms. Furthermore, large farmers also demanded subsidies for new breeds (Zhuo et al., 2020).

The evolution of such an impact factor as smart farming (SF) was subject to limitations, including the possible integration between the diverse SF systems available on the market, and the varying levels of education, farmers' skills and their understanding of and ability to handle SF tools. Therefore, there is a market opportunity for businesses to study these problems and to solve them in collaboration with researchers. With that in mind, it does make sense to:

- identify the drivers of innovations and development of agribusinesses in China;
- prioritize them, arrange information about innovative technologies and products; and
- make arrangements for a convenient choice of projects depending on the company's pressing production problems, which will contribute to the introduction of SF methods in agriculture.

2. Materials and methods

The database for studying the drivers of innovation in China's agribusinesses included the documents of:

- international organizations such as the Organization for Economic Cooperation and Development (OECD), United Nations (UN), Food and Agriculture Organization (FAO), World Health Organization (WHO);
- China's government agencies - the Ministry of Agriculture and Rural Affairs, the Ministry of Human Resources and Social Security, and the State Council's Poverty Alleviation Office;
- monographs and research articles on the issues of innovation, farmers' support policies, research and development work in agriculture and the food industry.

The study was conducted in four phases (Table 1, Annex).

The hypothesis that the greater the degree of innovation and digitization in an agribusiness, the higher its ranking, was validated. The methodology for the analysis of R&D innovations is to substantiate their essential role for sustainable business development and the choice of indicators that affect the degree of innovativeness and, accordingly, the rating of the business. The correct orientation to the technological innovations compatible with the particular business determines the breakthrough point for the realization of its competitive and sustainable development, based on the growth of efficiency of all business processes in the value chain. The effectiveness of R&D in agribusiness is determined by the results of their commercialization and sets the vector of development not only of companies, but also of the entire socio-economic system (Tesheva, 2021). Research and development of innovations and their practical implementation are confirmed by approved patents for inventions and utility models, trademarks, and products successfully pass quality and safety certification. Innovations in agribusiness must undergo a certain development cycle from scientific development and testing to scaling in the field of agriculture, food security, and nutrition (Shilomboleni & De Plaen, 2019).

Peculiarities of innovations in the field of R&D are naturally determined by the specifics of R&D itself (applied or fundamental, industry-specific or country-specific). As a rule, the fundamental type of R&D is focused on generation of new knowledge, while the applied type - on their successful business implementation and solution of specific business tasks. The larger the scale of changes and system transformations that innovations are intended to bring about, the more important it is to take country specifics into account in their management. In the development and implementation of point innovation, affecting the parameters of products and embedded as new elements in an established business structure, it is necessary to take into account the industry-specific development of agribusiness.

The degree of innovativeness and efficiency of R&D objectively depends on the human intelligence factor (the number of employees with the necessary level of education and qualifications, their productivity as a ratio of the innovative product generated by them to the payroll); the factor of intangible assets (patents, trademarks, etc.), the cost factor (the higher it is, the lower efficiency of innovation). The methodology for analyzing R&D innovation includes the following indicators.

R&D type (country-specific, fundamental, sector-specific); the number of full-time employees, research institutes, patents, inventions; and the costs of equipment, wages and supplies. R&D expenditures are determined by the formula which compares and correlates these indicators. The ranking of China's top agribusinesses by growth scorecard, absolute change in growth score and change in estimated growth score index number is based on Teece's dynamic capabilities theory, according to which dynamic capabilities are crucial to the company's sustainable growth. These rankings are also consistent with Schumpeter's theory of innovation, according to which company's growth is a dynamic and discontinuous process, by introducing innovations into products, production methods, markets, sources of supply and organizations, allowing them to push the limits of business environment, generate additional profits and grow further. Classification of the drivers of innovation and, in particular, the allocation of resource factors therein is based on the resource theory, according to which an enterprise is a collection of various resources (labor, land, supplies, money, production resources, etc.). The classification system for studying the use of digital tools by agribusinesses is appropriate in the context of two approaches. The first one is the responsible innovation (RI) approach, that anticipates and evaluates the possible implications and social expectations of research and innovation and mitigates society's growing concern about the unintended implications of science and technology, particularly for food systems. The second one is the idea of digital agriculture, based on the integrated implementation of a number of digital tools within the interrelated ideas of precision agriculture and smart farming (SF), which makes it possible to smooth out the increasing agroclimatic risks.

This study discussed and analyzed innovations, with diagrams and charts visualizing the R&D trends, the revitalization prospects of pig farming and problems facing agriculture depending on the production capacity. Systemic and logical approaches, as well as the decomposition analysis method were used to develop a classification system for studying digital projects in agriculture. Statistical and other calculations were made to estimate the growth rate of innovations. The methods and methodology introduced in this study expand knowledge about innovations in agriculture, provide a basis for future research and can be used in management decisions on innovations.

3. Results

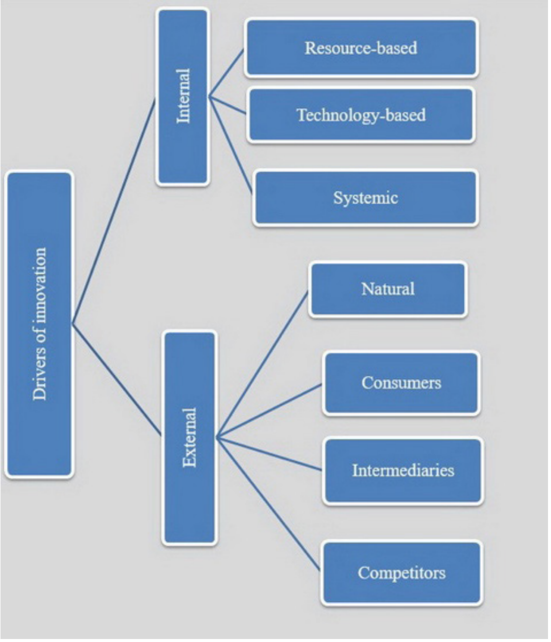
Internal drivers disclose the ability of a particular agribusiness to develop and implement its innovation opportunities. External drivers cannot be influenced by the company itself, but the company significantly depends on such drivers. A group of resource-based factors may include:

- R&D, labor, land, supplies, equipment and other factors;
- innovative and improved technologies of soil treatment, crop monitoring, etc.;
- systemic factors - solutions that promote, reinvigorate, intensify creative processes, innovations, unlock existing knowledge.

The abundance of R&D and other projects implementing SF methods in agriculture drives their arrangement and structuring. The authors proposed a classification system for research projects implementing various digital tools in agriculture (Figure 2). Many of these projects have already been implemented in agriculture. Such a system provides the required information and helps to choose a project depending on the company's pressing production-related problems and will contribute to the introduction of SF methods in agriculture.

By monitoring global technological trends and innovations, agribusinesses are clearly aware of the need to invest in new technologies, but in terms of their business models they primarily seek to maintain the positions already achieved. Such a strategy was chosen due to the instability of the business

Figure 1. Provides the classification of drivers of innovation



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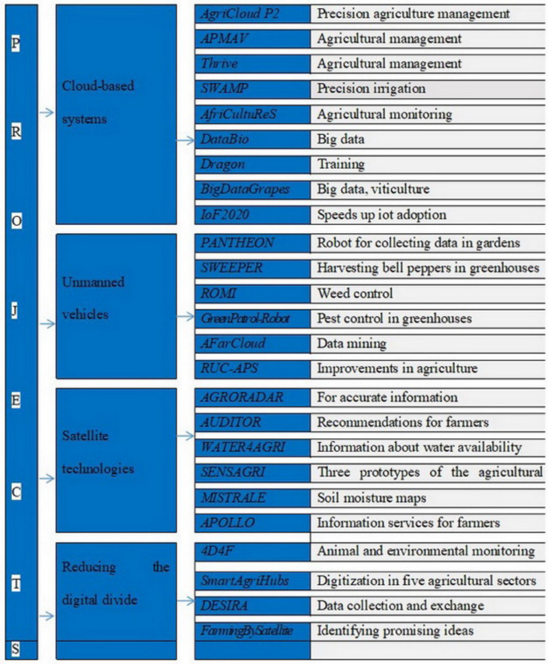
environment, unpredictable market trends, and, therefore, the short planning horizon. Attention is drawn to the fact that reviewing, classifying and selecting promising digital tools requires departure from the models of technology catch-up (which are based on proven business ideas) to long-term effective solutions.

Analysis of R&D and related activities of large and medium-sized businesses in China suggests their effectiveness and shows increases in the following indicators in 2000-2018:

- the number of patent applications (80 times);
- R&D expenditures (26.2 times);
- the number of inventions (22.7 times);
- the number full-time R&D employees (7.2 times);
- the number of research institutes (4.6 times);
- expenses for the development of new products (3.2 times).

The peak of innovation-induced growth in such indicators as R&D expenditures and new product development took place during 2000-2005, and in the number of inventions, R&D staff and research institutes - during 2005-2010. By the end of 2018, the growth rate fell to 10% for all indicators. Tables 2 and 3 show that the percentage of nationwide R&D expenditures reached 2.41% in 2020. In some agricultural sectors R&D expenditures amount to

Figure 2. A classification system for research projects implementing various digital tools in agriculture



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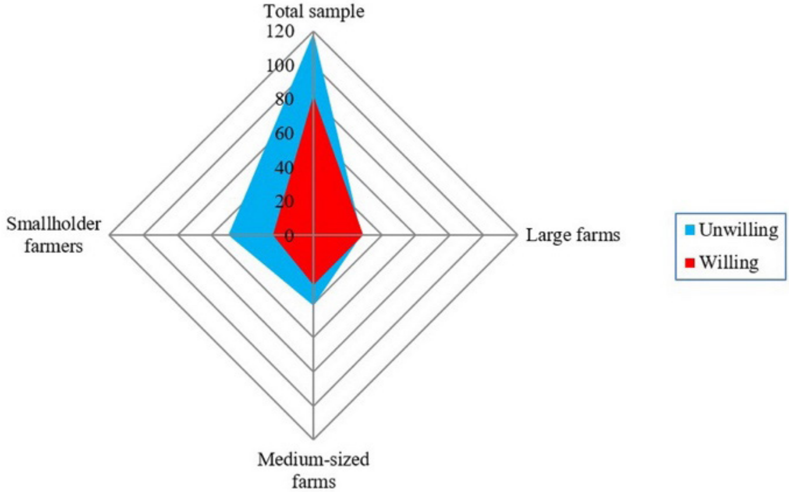
0.57% (processing food from agricultural products) and 0.81% (food industry). A comparison of these figures with the corresponding figure for the National R&D Fund suggests that these individual industry-specific components from such a large value chain as processing food from agricultural products and food industry account for 24% and 34% of total R&D expenditures.

In order to explain the choice of top businesses, some aspects of which are discussed in the paper, 34 listed agribusinesses in China were ranked by: estimated growth scores for 2018; absolute change in the estimated scores; and index number of changes during 2013-2018. Table 4 shows the top ten businesses in the three ranks.

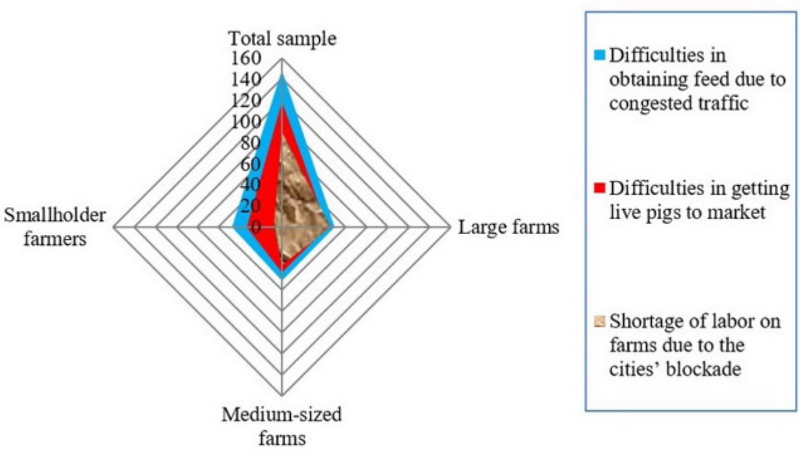
Xiangligufen is in the top three, while Beidahuang and Kaichuangguoji are in the top ten in all three rankings. Jinggulinye and Xinnongkaifa are in the top three, and Xinsaigufen, Pingtanfazhan, Guolianshuichan, Chuyingnongmu and Fuchenggufen are in the top ten in two rankings. The rankings of the top agribusinesses (usually very large and multi-branch companies) might have changed somewhat by now, among other things, given the impact of the pandemic, but the trend has continued, at least in the top ten. This is due to

Figure 3. Graphical model of farmers' readiness to recover from a pandemic shock as a function of production scale



Compiled based on the study of Zhuo et al. (2020).

Figure 4. Graphic model showing the main difficulties faced by farmers during the pandemic



Compiled based on the study of Zhuo et al. (2020).

the technology, scale and track record of the top agribusinesses and the fact that they have a significant advantage in technological innovations, mobility, and are market leaders. Therefore, the choice of the named companies corresponds to the logic of the study.

The effects of the pandemic shock were analyzed on (only niche) pig farms in terms of farmers' willingness to revitalize the industry and the difficulties they encountered in doing so. A graphical analysis of the pig farmers' willingness to revitalize production amid the COVID-19 pandemic shock, based on the survey of 201 farmers, describes the industry recovery opportunities depending on the pig farms' production capacity (Figure 3). The chart made it clear that large farms demonstrate the greatest willingness followed by medium farms and smallholder farmers with the least willingness. Figure 4 describes the main difficulties faced by farmers during the pandemic.

The chart shows that for large and medium-sized farms, shortage of labor caused by the cities' blockade was the main problem in the revitalization of the pig farming industry. For small farms, it is difficult to get live pigs to market due to the same reason.

4. Discussion

Undoubtedly, innovation is a catalyst for progress and a factor accelerating the socio-economic development of companies, industries and countries (Pradhan et al., 2020; Tesheva, 2021). Savings of natural resources, sustainable economic growth of agricultural enterprises, and their environmental sustainability are ensured through the successful implementation of innovations (Jahanger et al., 2022). As a systemic trend of economic development, agro-innovation involves all participants in the value chain in a partnership (Stanco et al., 2020), promoting the agro-industrial formations (Bebudovna & Ganjiyevich, 2021).

The present study also proceeds from the premise that digital intelligent innovation in agribusiness contributes to the growth of its efficiency and sustainable long-term development (Mohamed et al., 2021). It also builds on the classical economics problem of finite resources and unlimited growth of needs. Thus, 16% of the world's population (nearly a billion people) suffer from chronic hunger at a time when there is more than enough food to feed everyone on the planet. This is the problem of food security (McCarthy et al., 2018). Its solution depends on the ability to cope with growing food shortages amid an ever-growing global population by introducing innovations in agriculture and related industries. Food experts believe that this is possible only with collaboration of all stakeholders - farmers, processors, retailers, consumers and other actors in the food value chain. That is, innovations are affected by both internal and external factors, as classified by the factors. Truly sustainable global food security requires increased transparency (RFID), providing useful data (IoT, Big Data) to make more informed decisions to improve the food supply that are acceptable to businesses, consumers and governments. It makes sense to choose such data from the authors' classification of research projects on implementing digital tools in agriculture.

An analysis of terminology pertaining to smart farming (Pivoto et al., 2018) revealed various problems associated with the use of SF:

- development of technology for SF;
- management of these technologies and integration thereof into supply chains and farms;
- the impact of these technologies on the production system and the environment.

The experiential part of the study on the application of these technologies was conducted in case of farms in Brazil, although this market is in the early phase of SF technology implementation. Obstacles to the adoption of smart farming technologies include poor schooling of the rural workforce and incompatibility between different data sets to integrate them into supply chains. The first obstacle can be overcome by the workforce-related innovation driver (according to the proposed classification of innovation drivers). The second obstacle may be addressed by international committees and strategic alliances between companies.

Various locally driven solutions are proposed to address the effects of COVID-19 on agriculture and food security. For example, FAO and WHO propose to solve the problem by protecting public health and food security at the expense of economic growth. Tanzania and South Africa (Tripathi et al., 2021) want to create jobs in agriculture. Konya Province in Turkey (Uğur & Buruklar, 2021) focused on technical assistance, training, and social programs. China (Chengula, 2020) released strategic food reserves, created "green channels", eased import restrictions on livestock products (especially pork and poultry), with loans and other incentives provided for agribusinesses. Based on the case of China, which was the first to bring COVID-19 under control (Pu & Zhong, 2020), urgent steps to prevent or mitigate adverse effects may be suggested, including innovative methods to promote sales and minimize human interaction (e-commerce, online platforms of government, industry associations and businesses). The adequate and timely response of China's political authorities to the pandemic-induced problems in agriculture is evidenced by:

- the Notice of China's Ministry of Agriculture and Rural Affairs regarding the timely request for planting in spring (General Office of the Ministry of Agriculture and Rural Affairs of China, 2020);
- the Notice of the Ministry of Human Resources and Social Security and the State Council's Poverty Alleviation Office on dealing with the new coronary disease and further strengthening of poverty alleviation through jobs (Ministry of Human Resources and Social Security and the State Council Poverty Alleviation Office, 2020).

An in-depth analysis of the epidemic's impact on the agriculture and rural economies is given in the study of Liu (2018), where the crucial role of crisis management is emphasized. The authors propose to use the graphical model to analyze agriculture's willingness to recover from crisis situations and to develop recommendations to eliminate the consequences of crisis.

In many parts of the world, governments and businesses have increased investments in innovations amid the spread of COVID-19. This is evidenced by the Global Innovation Index (GII) 2021 (WIPO, 2021), which is a universal and comprehensive indicator of the economies' innovative status. Along with it, the authors propose to use the index of R&D expenditures, the methodology for the calculation of which is presented herein. This indicator can be defined for a country, a region, and even an industry. However, the indicator's flexible application is limited due to the lack of consistent reporting on the indicators based on which it is determined. Typically, R&D expenditures demonstrated greater resilience during the COVID-19-induced economic downturn than in previous downturns. The annual GII ranking of the world's economies shows that only a few countries (mostly high-income ones) consistently dominate the rankings. Only select middle-income countries, including China, Turkey, Vietnam, India and the Philippines, which are constantly improving their innovation systems and changing the innovation landscape, are catching up with their more innovative peers. In 2021, China ranked 12th in the world ranking of the Global Innovation Index, up 5 positions from 2017.

The blockchain practices discussed above are inherently innovative. However, all modern blockchains have problems that significantly reduce transaction efficiency given a strong throughput (Avdokushin & Wang, 2021). The use of blockchain as a distributed database, when implementing Big Data technology, provides transparency of the entire production cycle: information about the variety of seeds or breeds of animals, feed additives, storage conditions. Canada's Grain Discovery is one of the most prominent online agricultural markets relying on blockchain technology. China has also been involved in the joint development with the U.S. of a blockchain-based platform that allows the company to track pork and mango shipments in China and the United States (Ocheret, 2021).

Achieving food safety requires basic legal framework that should be uniform across the country, restoring the confidence of consumers disoriented by the large number of standards and local samples. China's Food and Drug Administration (CFDA) and the Ministry of Agriculture (MOA) could clarify basic requirements for the entire food supply chain. Afterwards, China will be able to gradually select the most promising solutions for implementation, setting up the food traceability system with Chinese "specificity" (Berti & Semprebon, 2018). A study conducted among focus groups in 12 European countries revealed that the consumers' perceptions of traceability technologies are primarily driven by the amount of provided information and trust (Qian et al., 2020).

Leadership positions in publications on smart farming issues depend on the country's R&D expenditures (Pivoto et al., 2018). China, the United States, South Korea, Germany and Japan are the largest contributors to smart farming research. They invest more in R&D, generate the most publications, and therefore are and will continue to be leaders in SF.

This is what the Beidahuang Group did, increasing R&D and technology expenditures and replacing traditional agriculture with innovative, intelligent agriculture. According to the ranking of top agribusinesses, this is the largest Chinese agricultural holding company with a land bank concentrated in China, South America and Australia. Its assets include 110 farms, rice and dairy companies, flour production facilities, oil and fats plants, and world-class potato starch production facilities (Beidahuang Potato Group). It also oversees the Heilongjiang Bayi Agricultural University, which offers a special agricultural and forestry education program to innovative and entrepreneurial talents who want to work on farms. The company is introducing many agricultural innovations, including system innovations that can be used to control the smart seeding process. Internet of Things and sensor equipment cover the entire fields, combine harvesters can be directly connected to remote sensors, and the farms' information technology is unrivalled.

The operations of another top agribusiness - Xinsaigufen - include:

- development, procurement, purchase, processing and sale of high-tech agricultural products with the study of these processes;
- sale of edible vegetable oils, agricultural equipment and accessories;
- cotton processing, production, purchase, processing and sale of seeds.

Yet, in the value chain of plant and seed farming, the role of the knowledge factor is increasing (Chen et al., 2022), as well as in innovative water-saving technologies in cotton production, contributing to the growth of the efficiency of water use and its unconventional sources (Aznar-Sanchez et al., 2019).

According to Fortune magazine, in 2021, XAG was the only agricultural company to make the list of the 20 most socially influential Chinese startups from various industries. XAG implements cutting-edge technology in agriculture, integrating science and technology, capital and agricultural operations. The company independently designed and manufactured several production lines, going through the entire cycle of agricultural production: drones with remote sensing; agricultural drones; autopilots; unmanned vehicles.

Many of China's top agribusinesses use efficient innovative technologies: no-till farming; multiple cropping; sprinkling and drip irrigation; mulch and others. China has another unique opportunity for effective innovations - the absolute willingness of people to accept, adapt and use innovation very quickly and on a large scale. This drives such an unprecedented rise in the Chinese economy.

5. Conclusions

The authors arranged and classified the drivers of innovation in agriculture. A classification system for research projects in implementing digital tools in agriculture (that classifies and structures the abundance of smart farming projects) was suggested. Such a system provides the required information and helps to choose a project depending on the company's pressing production-related problems and will contribute to the introduction of SF methods in agriculture. The paper analyzes the use of digital tools and research projects implementing digital tools in agriculture among China's top agribusinesses selected based on the growth scorecard.

Estimated effectiveness of R&D and related activities in large and medium-sized companies in China suggests that all indicators are increasing, but to varying degrees and at different rates. The number of patent applications, inventions, and, to a lesser extent, the number of full-time R&D employees, as well as the number of research institutes are increasing to a greater extent. That is, the amount of finished goods (number of patents, inventions) per one full-time employee, per one research institute increases, suggesting the effectiveness of R&D. To assess the innovations in entire economies, regions and specific industries, the authors proposed their methodology to estimate (along with the Global Innovation Index (GII), which is estimated for economies) the index of R&D expenditures.

COVID-19 caused changes in science, technology and innovation policies across the world. Priorities have shifted to sustainability and fostering innovation with new tools. Agricultural and food processing companies that have embraced digitization and other innovative technologies have demonstrated resilience and a willingness to rebuild production. It makes sense to analyze farmers' willingness to revitalize production, their problems and crisis-induced difficulties, as well as opportunities for the industry using a graphical model, as demonstrated in the case of pig farmers who faced the COVID-19 pandemic shock. The larger the farm, the greater its willingness to recover from a pandemic shock. The shortage of labor caused by the cities' blockade became the major problem faced by large and medium-sized farms in rebuilding the pig farming industry. Smallholder farmers found it difficult to get live pigs to market for the same reason.

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ANNEX

TABLE 1. RESEARCH PHASES

Research phase	Result
Studying the best practices of top agribusinesses and their innovations	China's top agribusinesses were ranked by three indicators: growth in 2018, absolute change in growth (2018 - 2013), index number of change in growth (2018 / 2013) A classification system for research projects implementing various digital tools in agriculture was developed
Monitoring the progress of changes in agricultural production, disruptions and other issues due to the pandemic shock	Graphical models of farmers' willingness to revitalize the pig farming industry and the prospects for such revitalization in various farms have been made. The difficulties pig farmers encountered in this process were discussed.
Drivers of business innovations were identified and streamlined	Classification of agricultural innovation drivers
R&D analysis	R&D at large and medium-sized agribusinesses in China were analyzed relying on the following indicators: costs, inventions, patents, staff, with specification of the relationship of these indicators. The innovation growth rates at the national and industry levels were estimated by the proposed formula:

Extent of R&D innovations (I_e) is calculated by the formula:
$I_e = C_{R\&D} / GDP \times 100\%$
Where $C_{R\&D}$ - total R&D expenditures;
GDP - gross domestic product.

TABLE 2. CHINA'S R&D EXPENDITURES, NATIONWIDE

Indicators	2016	2017	2018	2019	2020	2021*
National R&D Fund						
Total R&D expenses, CNY 100 million	15,677	17,606	19,678	22,144	24,393	27,864
R&D expenditures, %	2.10	2.12	2.14	2.24	2.41	2.44
National Foundations for Basic Research						
Foundations for Basic Research, CNY 100 million	823	925	1,090	1,336	1,467	1,696
percentage of basic research in R&D funds, %	5.25	5.54	5.54	6.03	6.01	6.09

*2021 - provisional accounting data.
Calculated by the National Bureau of Statistics (2020).

TABLE 3. INDUSTRY-SPECIFIC R&D EXPENDITURES

Indicator	2020
Processing food from agricultural products: R&D expenditure, CNY 100 million	276.6
R&D expenditures, %	0.57
Food production: R&D expenditures, CNY 100 million	157.3
R&D expenditures (%)	0.81

Calculated according to the National Bureau of Statistics of China and the author's formula (National Bureau of Statistics, 2020).

Table 4. Rankings of China's top agribusinesses in terms of estimated scores

By estimated growth score in 2018			By absolute change in the estimated growth score (2018-2013)			By index number of change in the estimated growth score (2018/2013)	
Company	Sector	points	Company	Sector	points	Company	index number
Xiangligufen	Production and wholesale of natural products, vegetable oils, aromatic pear	0.570	Jinggulinye	Organic seed production	0.218	Jinggulinye	1.768
Yashengjituan	Livestock	0.567	Xinnongkaifa	Cotton yarn	0.130	Xinnongkaifa	1.535
Minhegufen	Poultry farming	0.564	Xiangligufen	Production and wholesale of natural products	0.129	Xiangligufen	1.292
Shengnongfazhan	Grain farming	0.559	Xinsaigufen	Agro-industrial holding (cotton, oil)	0.094	Xinsaigufen	1.247
Yishenggufen	Cattle breeding, poultry farming	0.558	Pingtanfazhan	Agricultural materials	0.093	Pingtanfazhan	1.231
Kaichuangguoji	Aquacultures	0.544	Guolianshui-chan	Production and sale of seafood	0.070	Guolianshuichan	1.157
Beidahuang	Supply of agricultural crops, meat, milk and seafood	0.541	Chuying-nongmu	Livestock	0.061	Chuyingnongmu	1.142
Huayingnongye	Poultry	0.537	Fuchenggufen	Livestock	0.061	Yuntoushengtai*	1.135
Longpinggaoke	Corn	0.527	Kaichuangguoji	Agricultural engineering	0.060	Fuchenggufen	1.132
Luoniushan	Production and breeding of pigs, chickens, and eggs	0.523	Beidahuang	Production of organic products	0,057	Kaichuangguoji	1.124

* Gardening, landscaping.
Compiled by the author according to the study of Lu and Chen (2021).