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Research on the impact of domestic agricultural R&D on high-quality agricultural development in China

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A fresh wave of technical change is seen as one of the most effective ways to achieve sustainable agricultural development due to the declining carrying capacity of resources and the environment. China, a nation with a sizable population, has drawn immense research attention over the following question: How can China promote agricultural transformation and achieve high-quality agricultural development through technological innovation? Based on the panel data that considers 28 provincial-level administrative regions in mainland China from 2010 to 2018, the study utilizes two-way fixed models; thus, it tests the impact of domestic agricultural research and development on high-quality agricultural development. Furthermore, it utilizes the moderating effect to verify the relationship between the two aforementioned factors under the influence of foreign technology introduction, human capital, and financial support. We observed the following: First, the high-quality agricultural development that characterized all the Chinese regions exhibited a steady upward trend. The industrial system, ecological system, and management system exhibited considerable development, whereas the development of the production system was lagging. Second, domestic agricultural research and development has promoted high-quality agricultural development. Third, under the moderating effect of foreign technology introduction, human capital, and financial support, the promotion effect of domestic agricultural research and development on high-quality agricultural development has gradually weakened. This study presents various proposals; thus, it strengthens the role of domestic agricultural research and development in promoting high-quality agricultural development.

KEYWORDS

domestic agricultural research and development, high-quality agricultural development, moderating effect, foreign technology introduction, human capital

1 Introduction

Since Maltus (1798) proposed the issue of resource limitation and its relationship with population growth, the constraint of resource and environment carrying capacity on human activities has sparked widespread social debate, with one of the most important topics being agricultural carrying capacity. According to relevant research, global agricultural production has approached its upper limit of growth in the early 21st century, and the carrying capacity of the agricultural ecological environment has demonstrated a substantial overloading tendency. Furthermore, the environment is under increasing strain, as seen by regular soil deterioration, water resource pollution and depletion, and other ecological issues (Harris and Kennedy, 1999; Zhang et al., 2022). However, society believes that the coming technologies for improving seeds, reducing agricultural pollution, and preserving agricultural ecosystems will open up new development chances for sustainable agricultural development (Wang, 2014; Araújo et al., 2016; Aznar-Sánchez et al., 2020). China recently put forth a high-quality development strategy in an effort to achieve sustainable development more effectively, and it saw technological innovation as one of the key strategies for advancing high-quality agricultural growth (Wang and Qu, 2020). According to the trajectory of technological development, research and development (R&D) investment is regarded as one of the best strategies for technological progress (Lichtenberg and Siegel, 1989; Tsai et al., 2009). Nevertheless, whether or not R&D investment is effectively transformed into innovative achievements is influenced not only by investment intensity or return on investment (Ugur et al., 2015), but also by other external conditions such as the national institutional environment and governance system (Alam et al., 2020), human capital (Hu, 2021; Afcha and Lucena, 2022), and international technology spillover effects (Todo et al., 2011; Fujimori and Sato, 2015). Clearly, domestic agricultural R&D is essential for China to achieve the objectives of high-quality and sustainable agricultural development, and it is urgently necessary to maximize the efficiency of domestic agricultural R&D investment and increase the rate at which agricultural R&D contributes to high-quality agricultural development.

With the aim of effectively addressing path dependence issues under the long-term extensive development model, such as declining economic benefits and significant environmental constraints, high-quality development is a new measure for China to further implement its sustainable development strategy (Gu et al., 2020). China is likewise experiencing significant development challenges as it makes the switch from low-quality conventional agriculture to high-quality agriculture. On the one hand, China has utilized excessive amounts of fertilizers and energy in agricultural production (Chen et al., 2021). Consequently, the natural environment will be harmed, and agricultural production will not be enhanced; the marginal returns pertaining to agricultural production have peaked and are now in a phase of diminishing returns (Wang et al., 2023). On the other hand, resource and environment carrying capacity limitations are becoming increasingly severe for China's agricultural production system (Duan et al., 2020), including a decline in the carrying capacity of water resources (Li et al., 2018), a reduction in the amount of arable land, and soil degradation (Guan et al., 2022). In view of these challenges, some literature elaborated on the meaning and development objectives of high-quality agricultural development in China and employed evaluation index methodologies to conduct research (Liu and Reziyan, 2021; Cui et al., 2022). However, no universal assessment indicator has been developed; and it is limited to the province level or select typical places in China and does not reflect the national level. Apparently, the sophisticated implications of China's high-quality agricultural development also point to the multifaceted nature of its evaluation indicator system. As a result, to properly quantify the level of high-quality agricultural growth in China and identify the barriers to its development, this part must be supplemented.

Agricultural innovation is widely recognized as a critical pathway that can enable future agricultural systems to address challenges such as climate change, food security, and resource conservation (Dogliotti et al., 2014). However, the challenges faced by agricultural innovation systems (A.I.S.) are complex (Gutiérrez Cano et al., 2023): challenges such as technical, political, and institutional impediments must be overcome to realize emerging R&D opportunities (Halewood et al., 2018). On the one hand, research has shown that there is a large global investment gap of agricultural R&D (Rosegrant et al., 2022). In particular, developing nations frequently exhibit insufficient investments in research and development (Prasad et al., 2023); although the countries that constitute this region prioritize the role of research inputs in increasing agricultural output, they ignore the development and adoption of green technologies (Xu et al., 2022). On the other hand, pertinent research have noted that the risk and uncertainty of domestic agricultural R&D is the main factor contributing to the underinvestment in this field in developing countries. For instance, there is a dearth of supporting resources like human capital or R&D personnel; government policies fail to provide effective support (Manogna and Mishra, 2021); international technology spillover effects may have a certain inhibitory effect on domestic agricultural R&D (Adom et al., 2018; Wen et al., 2020). These external factors will undoubtedly have an impact on how domestic agricultural R&D projects are implemented, which will affect the quality of agricultural development. As a result, China still has a lot of challenges to overcome to maximize the support function of domestic agricultural R&D for high-quality agricultural development. In addition to further examining the impact of domestic agricultural R&D on high-quality agricultural development, further identification and judgment are needed to determine whether external factors like human capital, governmental policies, and international technology spillovers will have a moderating effect on the impact of domestic agricultural R&D on high-quality agricultural development.

In light of the shortcomings of the preceding research and the relevance of agricultural R&D for high-quality agricultural development in China, the innovation points of this study will focus on the following three aspects: Firstly, the meaning and traits of high-quality agricultural development in China will be described and, based on that, a rational and scientific framework for assessing such development will be proposed. Secondly, while previous research has confirmed the impact of agricultural R&D on agricultural growth, this study will expand on and emphasize the importance of agricultural R&D in achieving China's high-quality agricultural development goals, and will employ panel data econometric models for empirical analysis. Finally, using agricultural FDI, human capital, and fiscal support for agriculture as moderating variables, this study will look into the impact of these external factors on the relationship between domestic agricultural R&D and high-quality agricultural development, thereby providing a theoretical foundation for optimizing domestic agricultural R&D investment in China. This study is divided into 8 sections, and excluding the introduction, the rest of the segments are arranged as follows: the second section entails the theoretical analysis;

the third section entails the model and the measurement of high-quality agricultural development; the fourth section entails regional economic characteristics; the fifth section entails the empirical analysis; the sixth section entails the adjustment effect test; the seventh section entails the heterogeneity analysis; and the eighth section entails the main conclusions and policy recommendations.

2 Theoretical analysis

2.1 Domestic agricultural R&D and high-quality agricultural development

The impact of domestic agricultural R&D on economic development has generated immense research attention. The endogenous growth theory states that technological progress positively affects returns, and that R&D investment can endogenously promote technological progress; thus, sustainable economic growth is achieved (Romer, 1990). By creating and accumulating knowledge, which provides continual power and support for sustainable economic growth, domestic R&D can considerably promote technological, product, and process innovation (Griliches, 1980). Especially by encouraging innovative output, R&D enables the production possibility frontier to spread outward and increase potential productivity levels; furthermore, R&D activities enable enterprises to develop a more comprehensive experience and innovation ability, enabling people to discover and comprehend tacit knowledge and frontier technologies (Mansfield, 1988).

On the one hand, numerous studies that consider the production function classify R&D as a separate production factor, which confirms that R&D considerably affects productivity. In addition, through empirical research, numerous scholars have further verified that domestic agricultural R&D promotes the growth of agricultural output and agricultural total factor productivity in different countries (Alene, 2010; Baldos et al., 2019). Domestic agricultural R&D, which entails technological updates pertaining to novel varieties, agricultural equipment, and machinery, has enhanced grain and cash crop output (Ksingh, 2021), and domestic agricultural R&D crucially enables farmers to adapt to climate change, and to mitigate its adverse effects on agricultural production (Salim and Islam, 2010).

On the other hand, domestic agricultural R&D can promote innovation in ecologically friendly agriculture technologies; thus, resource conservation and sequential usage are accomplished. Domestic agricultural R&D can encourage the sustainable utilization and healthy development of arable land by optimizing the processes of irrigation, fertilizer application, pesticide application, cultivation, and management (Xie and Huang, 2021); Moreover, through the domestic agricultural R&D that characterizes recycling technology, industries can recover valuable bioactive compounds contained in the underutilized by-products of the food industry (Grillo et al., 2023), for example, the waste and by-products of fruits and vegetables can be utilized as bioactive compounds for food and biofuels (Zhu et al., 2023). The promotion of agricultural ecological technology or directly maximizing agricultural production, as can be seen, has increased awareness of the knowledge spillover effect of domestic R&D, which provides a novel opportunity for high-quality agricultural development.

> *Hypothesis 1*: Domestic agricultural R&D will have a positive promoting effect on high-quality agricultural development.

2.2 The moderating effect of foreign technology introduction on the relationship between domestic agricultural R&D and high-quality agricultural development

The extraordinary economic growth of emerging Asian economies like South Korea and Singapore in the final 30 years of the 20th century was further explained by Lin and Zhang (2005) on the basis of the endogenous growth model, according to which these countries made their own technological advancements by importing advanced technologies from developed countries. When underdeveloped nations lack the conditions to conduct R&D activities, introducing advanced agricultural technologies from abroad is a crucial step they can take to achieve technological catch-up, accelerate the shortening of the technological gap, and enhance the vitality of their agricultural technology (Wei et al., 2013). This is especially true in the context of global economic integration. By conducting innovation based on technology introduction, the technological innovation pathway becomes immensely clear and focused, reducing the uncertainty and risk that is associated with original innovation activities, avoiding redundant R&D investments, and shortening the knowledge accumulation process (Tang, 2016). Therefore, by examining the interaction between domestic R&D and foreign technology introduction, some studies have observed the following: in regard to the domestic R&D process, the learning ability will be enhanced, which enables enterprises to absorb foreign technology spillover effects and facilitates imitative innovation that is based on the absorption and emulation of advanced foreign technology (Freeman and Soete, 1997; Tang et al., 2014; Yu et al., 2015).

However, in addition to the high cost of foreign technology introduction, foreign technology introduction also tends to create path dependency, which reduces the incentive for domestic R&D in the host country (Haddad and Harrsion, 1993). The introduction of advanced technologies may yield a crowding-out effect that is occasioned by competition and low-scale core technology spillovers; thus, the difficulty with which local businesses in the agricultural sector survive is increased, and their willingness to innovate is decreased (Fu et al., 2011; Djokoto et al., 2022). Furthermore, agriculture entails national food security issues, such as the dominance and monopoly of agricultural knowledge in a developed nation, ecological environment threats, domestic capital competition, and trade imbalances, which exhibit a more hazardous "crowding-out" effect (Zhang and Dong, 2021). In the context of globalized development, foreign technology can potentially affect the process of domestic agricultural R&D, thus further affecting the high-quality agricultural development.

> *Hypothesis 2*: Foreign technology introduction will have a moderating effect on the impact of domestic agricultural R&D on high-quality agricultural development.

2.3 The moderating effect of human capital on the relationship between domestic agricultural R&D and high-quality agricultural development

Not only does R&D immensely affect productivity growth through its spillover effects, but the interaction between R&D and human capital also crucially promotes productivity growth (Xia, 2010). Human capital enhances the ability of enterprises to absorb and apply existing technologies or the ability with which they create novel ones (Griffith et al., 2004). Because the agriculture industry is labor-intensive, the enhancement of human capital crucially accelerates the transformation of agricultural science and technological achievements into real productivity. Acemoglu and Zilibotti (2001) observed that the degree of matching of technology and worker skill crucially affects the productivity differences between developed and lagging countries. Advanced human capital exerts a significantly positive effect on both total factor productivity and technological progress. On the one hand, human capital facilitates farmers' assessment of the information pertaining to the performance of novel technologies and how they operate, and the level of education positively influences the decision to adopt management-intensive technologies (El-Osta and Morehart, 1999). The human capital that is formed through rural education can effectively 'glue' the dynamic match between agricultural technology choices and resource factor endowments (Ye and Ma, 2020). With respect to farmers, when the agricultural education level is high, the demand for novel technologies increases, which positively affects motivation for innovation (Läpple et al., 2015; He et al., 2021). The preceding observations indicate that human capital crucially affects the adoption and acceptance of novel technologies, which also implies that the human capital of farmers influences the effect of domestic agricultural R&D on agricultural growth.

> *Hypothesis 3*: Human capital will have a moderating effect on the impact of domestic agricultural R&D on high quality agricultural development.

2.4 The moderating effect of financial support on the relationship between domestic agricultural R&D and high-quality agricultural development

Due to the "dual risks" (i.e., nature and the market), public intervention in agriculture is immensely crucial. Similarly, with respect to influencing agricultural R&D, financial support and policy measures are imperative. First, agricultural financial support facilitates the agricultural sector's ability to respond to the market economy and facilitates the efficient interaction between the demand for and the supply of novel technology (Cao and Zhao, 2017). Second, agricultural financial support could devise and disseminate innovative messages (Timpanaro et al., 2023), and enable farmers to broaden their information gathering and accumulation through agricultural extension programs or other public information services, hastening the adoption of novel technology and expanding their scope of usage (Feder and Slade, 1984). Third, by stabilizing economic development, agricultural financial support enhances private sector investment confidence and innovation enthusiasm. By overcoming the initial capital constraints pertaining to technological upgrading, internalizing related externalities, and reducing uncertainty and potential risks, financial support can enhance the probability of technology upgrading, guiding the direction and efficiency of technological innovation (Han et al., 2017).

However, some scholars state that China's tax-sharing fiscal decentralization system has dampened innovation efficiency. For regional scientific and technological innovation activities, the local government's "emphasizing production and ignoring innovation" self-interested investment preference inhibits it's function, which leads to the loss of regional innovation efficiency (Wu, 2017). In fact, since agricultural innovation is characterized by lower comparative returns and more robust social benefits, and exerts a more minor contribution to the local economy, local governments have been compelled to neglect the policy. Based on this, financial support has a moderating impact on the relationship between domestic agricultural R&D and high-quality agricultural development.

> *Hypothesis 4*: Financial support will have a moderating effect on the impact of domestic agricultural R&D on high-quality agricultural development.

Based on the preceding analysis, the study summarizes the mechanism of domestic agricultural R&D on high-quality agricultural development in Figure 1.

3 Model and measurement of the agricultural development level

3.1 Panel data model

Based on the endogenous growth theory, which affects innovation output, domestic agricultural R&D directly promotes economic growth. For estimating the impact of R&D on economic growth, which constitutes empirical research, the production function method is prevalent. According to Mohan et al. (2014) and Chandio et al. (2022), domestic R&D was input into the production function as a production factor. To build the $y_{it} = f_{it}\left(R\,\&\,D_{it}\right)$ function formulas, the dependent variable (y_{it}) represents the level of high-quality agricultural development, and domestic agricultural R&D represents the core explanatory variable ($R\,\&\,D_{it}$). For specific functional forms, studies have indicated that a linear relationship usually represents the relationship between R&D and economic growth (Scherer, 1965). Therefore, this study aims to establish panel data and two-way fixed models (controlling for both individual and time effects) for analysis, and the relevant factors that affect high-quality agricultural development are set as control variables. The specific model is constructed as follows:

$$y_{it} = \beta_0 + R\,\&\,D_{it} + perGDP_{it} + invest_{it} + wage_{it} + entrance_{it} + agriculture_{it} + u_{it} \tag{1}$$

where i denotes the province (i = 1,2…28), and t denotes the time. $perGDP_{it}$ denotes GDP per capita, $invest_{it}$ denotes investment

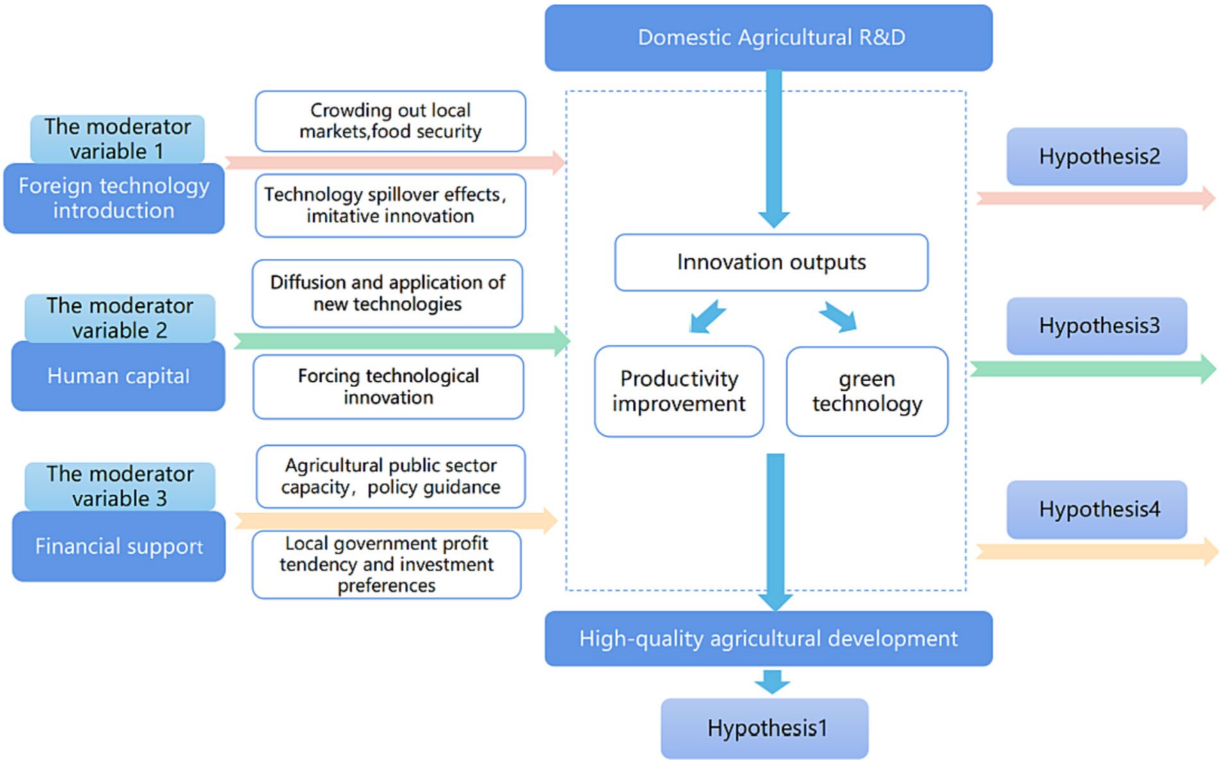

FIGURE 1
The mechanism of domestic agricultural R&D on high-quality agricultural development.

in fixed assets in the primary industry, $wage_{it}$ denotes the wage level, $entrance_{it}$ denotes the import trade of agricultural products, $agriculture_{it}$ denotes agricultural foundation, $\propto_{it}$ denotes region fixed effects, γ_{it} denotes the time fixed effects, and ε_{it} denotes the random error term.

Furthermore, domestic agricultural R&D not only directly impacts high-quality agricultural development, but it is also moderated by factors such as foreign technology introduction, human capital, and policy support. For empirical study, the moderating effect can be analyzed using the following regression equation $f = i + aX + bZ + cXZ + \gamma$, where X denotes the core explanatory variable, Z denotes the moderator variable, and XZ denotes the interaction term (Elmagrhi et al., 2018). If the regression coefficient c is significant, the moderating effect is significant (Haque and Ntim, 2020). This study introduces foreign technology introduction, human capital, and financial support as moderator variables. Formulas (2)–(4) are in (1), the interactive items of foreign technology introduction and domestic agricultural R&D, human capital and domestic agricultural R&D, and financial support and domestic agricultural R&D are added. fdi_{it} denotes foreign technology introduction, $human_{it}$ denotes human capital, $finance_{it}$ denotes financial support, and the remaining variables are the same as those utilized in Formula (1).

$$y_{it} = \beta_0 + fdi_{it} + R\,\&\,D_{it} + fdi_{it} \times R\,\&\,D_{it} + perGDP_{it} + invest_{it} + wage_{it} + entrance_{it} + agriculture_{it} + u_{it} \quad (2)$$

$$y_{it} = \beta_0 + human_{it} + R\,\&\,D_{it} + human_{it} \times R\,\&\,D_{it} + perGDP_{it} + invest_{it} + wage_{it} + entrance_{it} + agriculture_{it} + u_{it} \quad (3)$$

$$y_{it} = \beta_0 + finance_{it} + R\,\&\,D_{it} + finance_{it} \times R\,\&\,D_{it} + perGDP_{it} + invest_{it} + wage_{it} + entrance_{it} + agriculture_{it} + u_{it} \quad (4)$$

3.2 Construction of evaluation indicators for high-quality agricultural development

The scientific and rational construction of a high-quality development evaluation index system is a crucial component of the in-depth analysis of pertaining to high-quality development. For China's future holistic approach to sustainable development, which includes economic development, innovation efficiency, environmental impact, ecological services, livelihoods of people, urban-rural coordination and liberalization, high-quality development is an innovative aim (Huang et al., 2020; Pan et al., 2021). Because the agricultural sector exhibits unique development characteristics, Chi et al. (2022) stated that high-quality agricultural development is immensely dependent on resource utilization efficiency; therefore, by measuring agricultural ecological efficiency, researchers can evaluate the high-quality agricultural development level. According to Zhong (2018), due to high-quality development, China's agriculture sector now exhibits a novel direction and novel objectives. Building a modern agricultural industrial system, production system, and management system is imperative; thus, the following characteristics can be comprehensively reflected: high quality and high efficiency. To depict the meaning and characteristics of China's high-quality agricultural development more correctly, we also refer to other representative studies (Streimikis and Baležentis, 2020).

The index system for evaluating the level of high-quality agricultural development comprises the high-quality industrial system (A1), high-quality production system (A2), high-quality management system (A3), and high-quality ecological environment (A4). Table 1 depicts the layout of the indicator system, which comprises the first-tier indications (A1 to A4), second-tier indicators (B1 to B9), and third-tier indicators (C1 to C17). The specific indicators are as follows:

The performance of a high-quality industrial system entails increasing agricultural multi-functionality and developing novel opportunities for rural and agricultural economies, which entails the adoption of novel formats, novel industries, and novel models; thus, agricultural competitiveness can be enhanced. To actualize a high-quality industrial system, governments should enhance the industrial structure (B1) and the degree of industrial integration (B2), which represent two crucial components. Due to the continuous optimization of the industrial structure, grain production, agriculture, forestry, animal husbandry, and fishery can potentially develop in a balanced manner, which can meet the people's demand for agricultural products. For the primary, secondary, and tertiary industries that characterize rural areas, the increase in industrial integration demonstrates a highly balanced growth, a gradual enhancement of the entire agricultural industry chain, and a significant expansion of multi-functional agriculture.

The term "high-quality production system" refers to the extensive promotion of supply-side reform, which transforms production processes; thus, productivity enhancement (B3), vitality enhancement (B4), and infrastructure enhancement (B5) are facilitated. First, the increase in productivity indicates that the effect of scientific and technological advancements on agricultural production is gradually strengthening. Second, growing vigor is a prerequisite for enhancing farmers' excitement for production, facilitating sustainable agricultural development. Due to the ongoing increase in agricultural growth vigor, the security of China's agricultural product supply is ensured, and farmers' incomes are rising; thus, the urban areas–rural areas' income gap is reduced, and shared prosperity is actualized. Finally, due to the holistic infrastructure, a comprehensive agricultural production capacity, which includes standardized farmland, water conservation initiatives, cold chain facilities for storage and preservation, and rural road building, is actualized.

The high-quality management system is characterized by highly diversified agricultural management entities, innovative business models, and a fair business environment. The high-quality operation system includes two aspects, namely, the proportion of operating income (B6) and the level of marketization (B7). With respect to high-quality agricultural development, a high-quality operator team and a high-efficiency business model are crucial. Due to the increase in the proportion of operating income, an immense labor force and compound talents that exhibit operating experience are invested in agricultural production and operation. Additionally, when the level of marketization increases, consumers exhibit more freedom of choice, agricultural producers can operate independently, the supply and demand information that is open to the market is clearer, and market prices, which affect the distribution of agricultural products and production factors, are rational; thus, a variety of transactional and circulation strategies can be implemented.

Finally, the effective management of the ecological environment indicates that the input of agrochemicals such as fertilizers and pesticides (B8), through which the nutrients that facilitate the normal growth of crops are maintained, is low; thus, the production-side pressure that affects the ecological environment is reduced. The continuous rise in the number of green products (B9) indicates that the ability to produce environmentally friendly agricultural products is growing.

Based on the preceding analysis, Table 1 displays the assessment index system pertaining to the high-quality agricultural development that is developed herein. In conformance with the study conducted by Wang Z. et al. (2022), we calculated the indicator weights and scores pertaining to high-quality agricultural development, and utilized the entropy approach.

Step 1: Normalization. The range analysis was employed to standardize the original indicators selected since the indicators with different dimensions selected in this study are not suitable for direct comparison. The specific formula is as follows; the positive indicator is $Z_{ij} = \frac{x_{it} - \min\{x_{ij}\}}{\max\{x_{ij}\} - x_{ij}}$; the reverse indicator is $Z_{ij} = \frac{\max\{x_{ij}\} - x_{ij}}{x_{ij} - \min\{x_{ij}\}}$, where x_{ij} is the observation data of the ith evaluation object of the jth indicator; Z_{ij} is the corresponding standardized data.

Step 2: Calculate the proportion $p_{ij} = \frac{z_{ij}}{\sum_{i=1}^{m} z_{ij}}$ of the ith evaluation object of the jth indicator to the jth indicator, where $j = 1, 2, \ldots n$, and $i = 1, 2, \ldots m$.

Step 3: Calculate the entropy of the jth indicator using the formula $e_j = -k\sum_{j=1}^{n} p_{ij} In(p_{ij})$, where $k = \frac{1}{In(i)}$, $0 " e_{ij} " 1$, and In is a natural logarithm.

Step 4: The utility value of the jth indicator can be calculated as $d_j = 1 - e_j$.

Step 5: Calculate the weight of each indicator using the formula $w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}$.

Step 6: The comprehensive indicator and the indicator of each subsystem of the provinces can be calculated using the formula $y_i = \sum_{j=1}^{n} z_{ij}{}^{*} w_j$, with the national comprehensive indicator and the subsystem indicators represented using the average values of each province.

3.3 Other variables

The stock of domestic agricultural research and development represents the core explanatory variable of *domestic agricultural R&D*. Because most provinces do not count the stock of domestic

TABLE 1 High-quality agricultural development evaluation index system.

First layer	second layer	Third layer	Index content	Weight	Attribute
The high-quality industrial system (A1)	Industrial structure (B1)	Balanced development of agriculture (C1)	The proportion of total crop-plantation's output value in the total output value of crop-plantation, forestry, animal husbandry and fishery	0.046	−
		Balanced development of crop-plantation (C2)	$1-\frac{\text{Grain sown area}}{\text{Crop area}}$	0.038	+
	Industry convergence (B2)	Integration of primary and secondary industries (C3)	$\frac{\text{Gross output value of agricultural processed products}}{\text{gross agricultural output value}}$	0.189	+
		Integration of primary and tertiary industries (C4)	National leisure agriculture and rural tourism demonstration county	0.081	+
		Productive service level (C5)	Proportion of total output value of agriculture, forestry, animal husbandry and fishery services	0.067	+
The high-quality production system (A2)	Production efficiency (B3)	Land productivity (C6)	$\frac{\text{Agricultural value added}}{\text{sown area}}$	0.08	+
		Labor productivity (C7)	$\frac{\text{Value added of primary industry}}{\text{employees in primary industry}}$	0.045	+
		Agriculture TFP (C8)	Calculated according to the DEA model	0.008	+
	Growth vitality (B4)	Growth rate (C9)	Growth rate of total output value of agriculture	0.007	+
		Income (C10)	Per capita disposable income in rural areas	0.071	+
	Infrastructure (B5)	Mechanization level (C11)	$\frac{\text{Total mechanical power}}{\text{sown area}}$	0.066	+
		Effective irrigation level (C12)	$\frac{\text{Effective irrigated area}}{\text{sown area}}$	0.074	+
The high-quality management system (A3)	Management level (B6)	Operating income level (C13)	$\frac{\text{Operating Income}}{\text{Total Income}}$	0.031	+
	Marketization (B7)	marketization level (C14)	$1-\frac{\text{employees in state – owned enterprises in agriculture}}{\text{employees in agriculture}}$	0.012	+
The high-quality ecological environment (A4)	Resource utilization (B8)	Fertilizer application intensity (C15)	$\frac{\text{Fertilizer application rate}}{\text{sown area}}$	0.024	−
		Pesticide application intensity (C16)	$\frac{\text{Pesticide application rate}}{\text{sown area}}$	0.012	−
	Environmental governance (B9)	Green development (C17)	Number of green products	0.148	+

agricultural R&D, we employed the perpetual inventory method, consistent with the approach used by Wu (2006), for the calculation. Relevant parameters were set according to the findings of Li and Liu (2011):

Step 1: Calculate the agricultural R&D expenditure, which can be described using the product of the adjustment factor E'_{it} with the total R&D expenditure of each province. Where, $E'_{it} = 0.5^{*}\frac{R_t^A}{R_t^T} + 0.5^{*}\frac{Y_{it}}{GDP_{it}}$, R_t^A refers to the national agricultural R&D expenditure; R_t^T refers to the national R&D expenditure; Y_{it} represents the total agricultural output of each province; GDP_{it} represents the gross domestic product of each province.

Step 2: Construct the deflator of agricultural research expenditure. The calculation formula is $PR_t = 0.5^{*}CPI_t + 0.5^{*}IFPI_t$, where CPI_t represents the consumer price index; $IFPI_t$ is the price index of investment in fixed assets, with the weight set to 0.5.

Step 3: Calculate the knowledge stock of agricultural research investment in the base period (taking 2010 as the base period), using the formula $R_0 = E_0 / (g + 15\%)$, where 15% is the depreciation rate δ; g is the arithmetic average growth rate of domestic agricultural R&D expenditure from 2010 to 2018.

Step 4: Calculate the stock of *domestic agricultural R&D* using the formula $R\&D_t = E_{t-1} + (1-\delta)R\&D_{t-1}$; where $R\&D_t$ and

$R\&D_{t-1}$ represent the agricultural R&D stock of t period and $t-1$ period, respectively.

3.3.1 Control variables

(1) *Regional economic development level (per GDP)*: Liu et al. (2020) indicated that regions with high economic development levels can provide optimal conditions for high-quality agricultural development. Therefore, this study chooses GDP per capita to measure the level of regional economic development. (2) *Primary industry fixed asset investment (invest)*: Agricultural fixed asset investment can not only enhance infrastructure construction and production conditions, but it can also provide hardware facilities for the application of scientific and technological achievements; thus, it can enhance the comprehensive production capacity, transform production methods, and promote high-quality agricultural development (Li et al., 2015). (3) *The per capita disposable income of all residents (wage)*: Sun and Ma (2016) noted that the rapid increase in the demand for diverse, safe, and high-quality agricultural products further promotes agricultural supply-side reforms. Due to the continuous enhancement of the income of urban and rural residents, the consumption of agricultural products is shifting from low-level consumption to high-level consumption. To address the contemporary consumer demand, producers focus on green, diversified, and healthy agricultural products, which promote high-quality agricultural development. (4) *Import trade of agricultural products (entrance)*: The import trade of agricultural products can potentially reduce the profit incentives of domestic agricultural producers and weaken the internal driving force of domestic agricultural development (Li and Huang, 2021). Therefore, the increase in imported agricultural products may inhibit high-quality agricultural development. (5) *Agricultural foundation (agriculture)*: Law (2017) noted that by introducing modern facilities and standardized operations, large-scale operations can optimize agricultural productivity; thus, high-quality agricultural development is promoted. Therefore, agricultural development is expressed by the ratio of the added value of the primary industry to GDP, which represents the agricultural development scale.

3.3.2 Moderating variables

(1) *Foreign technology introduction (fdi):* Foreign direct investment (FDI), as a crucial method of introducing technology, accelerates knowledge and technology spillovers by demonstration-imitation effects, competition effects, personnel training, mobility effects, and linkage effects, which crucially enables late-comer nations to achieve technological advancements and enhance their innovation capacities (Macdougall, 1960; Kokko, 1992). Therefore, *foreign technology introduction* is expressed by the amount of FDI utilized in agriculture. Due to the lack of individual data in some regions, this study utilizes the actual foreign direct investment FDI is multiplied by the proportion of provincial agricultural production in the regional GDP as an approximate substitute indicator (Zhou, 2014). (2) The level of agricultural financial (*expenditure*) indicates the government's support for agricultural development, and it can effectively enhance agricultural production conditions. Because there is a difference in the statistical caliber of China's fiscal expenditures on agriculture and rural areas, before 2006, financial support for agriculture was subdivided into agricultural, forestry, and fishery expenditures, and from 2006 to the present year, it is uniformly calculated under agriculture, forestry, and water affairs (Zhu and Hu, 2019; Gao and He, 2021). Herein, to maintain the consistency pertaining to the data's scale structure, financial support (finance) is also expressed by the local financial expenditure on agriculture, forestry, and water affairs. (3) Rural human capital (*human*) is represented by the per capita education level, and the proportion of the labor force population at each level of education is multiplied by the corresponding years of education. The aforementioned factor is calculated based on the sample data of five education levels, namely non-school, primary school, junior high school, high school, and junior college or above, and the years of education are set at 0, 6, 9, 12, and 16 (Liu et al., 2016).

3.4 Data sources and descriptive statistics

Furthermore, we utilized data obtained from the following databases to conduct the empirical research (study period: 2010 to 2018): "China Science and Technology Statistical Yearbook," "China Rural Statistical Yearbook," "China Agricultural Green Development Report," and "China Industrial Statistical Yearbook." To ensure data completeness, we adjusted the provincial and temporal ranges as per the conducted study. Jilin, Sichuan, and Tibet utilized only the FDI contract amount, which cannot represent the actual investment amount; therefore, they are beyond the scope of this study. Moreover, the national leisure agriculture and rural tourism demonstration counties and green products exhibit statistics as of 2018. With respect to measuring high-quality agricultural development, which can directly reflect the development level of rural tourism in China and the status quo of green agricultural products, these two indicators are crucial. This study utilized the agricultural output value index and consumer price index to avoid the impact of price fluctuations; thus, it can adjust the price with reference to comparable prices (base period: 2010). Table 2 depicts the descriptive statistics of each variable.

4 Features of China's high-quality agricultural development

The comprehensive index of each province and the national average comprehensive index are displayed in Table 3 in accordance with the high-quality agricultural development evaluation index system and calculation technique previously mentioned. According to the comparison results in Table 3, it can be seen that in 2010, the comprehensive index of Chongqing was the highest (39.94), while the lowest was recorded in Hainan (14.57). In 2018, the lowest index was recorded in Tianjin (22.47), while the highest was recorded in Shaanxi (52.4). From the national average level, high-quality agricultural development exhibited an increasing trend from 2010 to 2018; the total index increased from 25.18 to 35.95, and it exhibited a yearly average of 30.56. The largest growth rate was 7.50 in 2012, and the average annual growth rate was 4.57. This result is in line with relevant literature, revealing that the level of high-quality agricultural development in China is constantly improving (Lu et al., 2022; Qin et al., 2022).

Since the National Bureau of Statistics divides China's territory into eastern, central, and western regions, it is of significance to compare the high-quality development level of agriculture in different regions in this study. However, due to the similarity in economic development and geographical location between the central and

TABLE 2 Descriptive statistics results.

Variable sample	Size	Average value	Standard deviation	Minimum	Maximum
y	252	30.5578	7.9119	12.7179	52.4012
R&D	252	56.5621	56.0208	1.4808	279.9127
fdi	252	50.9646	61.8114	1.2746	255.2802
Finance	252	0.0460	0.0230	0.0067	0.1009
Human	252	7.9404	0.7571	5.4321	10.5820
Entrance	252	227.3448	338.0701	0.0048	1712.0870
per GDP	252	397.5930	197.0674	112.8273	1142.5630
Invest	252	458.1890	414.7091	1.2262	2295.5500
Wage	252	202.8637	99.0919	70.0873	631.7224
Agriculture	252	0.0995	0.0549	0.0029	0.2584

Data source: China Bureau of Statistics (http://www.stats.gov.cn/).

TABLE 3 The high-quality agricultural development in various regions of China.

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Beijing	27.93	26.8	29.39	29.51	30.93	33.15	36.46	35.4	39.32
Tianjin	19.6	20.02	20.96	22.42	23.35	24.95	22.08	22.35	22.47
Hebei	17.65	20.25	20.46	21.94	25.16	26.42	27.31	28.94	32.89
Shanxi	20.35	24.52	23.42	25	25.28	25.91	31.61	31.19	29.85
Neimenggu	26.09	24.88	27	27.42	31.29	35.18	32.18	30.95	32.09
Liaoning	23.15	21.98	23.36	23.23	23.61	28.55	28.79	30.42	30.93
Heilongjinag	20.26	24.96	27.86	27.78	30.26	32.4	33.76	37.01	38.56
Shanghai	31.35	30.49	34.94	36.65	34.31	34.87	37.8	38.86	43.8
Jiangsu	24.29	25.88	28.95	26.65	28.99	32.67	31.46	31.4	34.87
Zhejiang	24.24	24.31	26.26	29.49	28.64	30.48	31.65	31.14	33.67
Anhui	21.68	24.21	26.76	25.86	29.45	30.98	35.4	38	41.39
Fujian	20.48	22.19	23.71	24.77	27.13	29.97	30.88	32.61	36.04
Jiangxi	33.28	34.21	36.18	37.92	42.31	43.48	44.74	47.31	50.2
Shandong	19.96	21.81	21.94	22.07	23.04	23.65	27.8	30.77	34.62
Henan	31.86	36.31	36.62	33.14	34.57	37.59	37.54	34.23	37.16
Hubei	25.46	25.78	25.78	26.09	26.99	34.24	30.67	30.6	33.23
Hunan	24.58	26.57	29.37	29.4	31.25	34.92	32.99	34.9	35.67
Guangdong	21.22	22.27	24.01	23.98	24.72	26.78	27.09	28.32	30.77
Guangxi	22.1	22.28	25.2	26.15	27.02	29.74	30.54	30.38	31.01
Hainan	14.57	12.72	16.28	17.27	16.93	20.42	21.83	19.53	22.56
Chongqing	39.94	39.89	44.15	44.11	48.87	50.48	49.11	51.85	52.29
Guizhou	17.72	18.7	21.22	20.68	22.17	24.34	26.85	28.21	26.71
Yunnan	34.13	34.55	35.5	37.11	38.58	40.26	39.74	36.59	37.09
Shaanxi	37.21	42.24	41.88	46.62	48.35	48.55	48.4	49.19	52.4
Gansu	26.04	28.75	30.01	33.48	36.63	36.28	37.45	40.46	41.5
Qinghai	22	22.78	24.44	24.43	25.69	26.75	26.91	28.35	27.64
Ningxia	23.87	23.51	24.93	26.35	26.21	26.79	28.94	28.33	32.35
Xinjiang	33.92	32.5	39.87	47.52	39.93	42.17	42.92	42.36	45.54
Nation	25.18	26.26	28.23	29.18	30.42	32.57	33.32	33.92	35.95
The East	22.21	22.58	24.62	25.34	26.15	28.47	29.47	30.01	32.75
The Midwest	27.4	29.02	30.94	32.06	33.61	35.65	36.2	36.85	38.35

western regions, these two regions were merged for research. In this way, the research sample was divided into two major regions: the Eastern and Midwest regions, and the regional comprehensive index was represented by the average of the comprehensive index of each province in the region. The quality of agricultural development in the East regions, which exhibited an annual average of 26.85 and an average annual growth rate of 2.46%, increased from 22.21 to 32.75, and it exhibited the highest growth rate in 2018. The quality of agricultural development in the Midwest regions, which exhibited an annual average of 33.34 and an average annual growth rate of 4.31%, increased from 27.40 to 38.35, and in 2012, it exhibited the highest growth rate. Overall, the average level of development is higher in the Midwest than in the East region, which is consistent with the results of many studies. First of all, Yafei et al. (2022) discovered that from 2004 to 2020, the Midwest regions experienced the highest average yearly growth rate of green total factor productivity (GTFP) in agriculture, followed by the eastern region of the nation. The agricultural GTFP in Shanghai, a developed city in the east, was less than 1. Relevant research has demonstrated that the economically developed south-eastern coastal districts of China are the central locations of the areas with greater total emissions of surface pollutants from fertilizers (Jin et al., 2019; Lei et al., 2020). Secondly, the level of regional economic development and industrialization does not significantly influence the promotion of high-quality agricultural development, and since secondary and tertiary industries primarily dominate the eastern part of China, the allocation of agricultural resources should be further optimized (Liu et al., 2021). Lastly, the Chinese government exhibits different assessment objectives and strengths for agricultural development in agricultural and non-agricultural counties. Because non-agricultural counties exhibit weaker targeted incentives for agricultural development than agricultural counties, the marginalization of agricultural development in non-agricultural counties is occurring more rapidly (Gong et al., 2023). As primary agricultural producing areas for both bulk agricultural goods and distinctive agriculture, the agricultural development potential in the Midwest regions, where the support for regional and rural agricultural policies is continuously increasing, has been explored. In regard to the intensive level, production scale, structural balance, and ecological environment, many significant advancements have been affected.

Figure 2 indicates the sub-system development trend. The development level of the agricultural production system exhibits a downward trend. By contrast, the industrial system and the ecological system exhibit a gradual upward trend with a large growth rate, and the growth of the management system is relatively slow. In recent years, China has actively promoted the balanced development of agriculture and agricultural pollution control. However, low production efficiency and a flawed management system continue to significantly impede China's high-quality agricultural development. On the one hand, because China's agricultural sector has transited into the "high cost" period, the cost of raw materials has immensely increased. On the other hand, issues including erratic land transfers, challenges with agricultural financing, and an inadequate social service system restrict the growth of agricultural business entrepreneurs (Shi et al., 2023).

5 Empirical test and results

5.1 Benchmark regression results

The empirical findings are depicted in Table 4. This study employs OLS and fixed effects tests and considers individual and temporal variations, respectively. According to the FE estimation results in the second column, the values of F-statistic and P are 98.81 and 0.0000, respectively, indicating a statistical significance of the entire regression model. Moreover, the adjusted coefficient of determination is 0.9411, suggesting a good overall fitting performance that 94.11% of the changes in high-quality agricultural development can be explained by the explanatory variables of the model. The core explanatory variable, which is also the coefficient of domestic agricultural R&D, is 0.0179 ($t = 1.96$, $p = 0.052 < 0.10$),

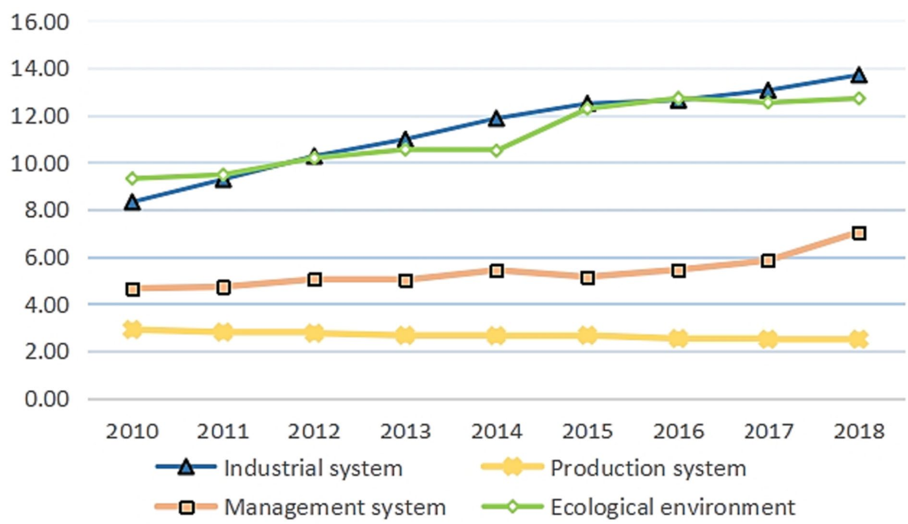

FIGURE 2
The high-quality development trend of the agricultural subsystem.

TABLE 4 Benchmark regression results.

	OLS (1)	FE (2)
R&D	0.0235* (1.84)	0.0179* (1.96)
Entrance	−0.0107*** (−4.78)	−0.0037*** (−3.11)
per GDP	−0.0237*** (−4.15)	0.0080** (2.13)
Investment	0.0039*** (3.08)	−0.0012* (−1.76)
Wage	0.0610*** (6.61)	−0.0191** (−2.11)
Agriculture	−40.6504*** (−3.66)	33.1276** (2.49)
Cons	30.9736*** (13.72)	21.0339*** (11.68)
Time fixed effects	NO	YES
Regional fixed effects	NO	YES
N	252	252
R^2	0.29	0.9411

The numbers that are placed within brackets denote *t* statistic values; ***, **, or * denotes significance at the 1%, 5%, or 10% level, respectively.

showing that domestic agricultural R&D considerably promotes high-quality agricultural development at a 10% significance level. For every 1% increase in domestic agricultural R&D, the high-quality agricultural development level increases by 1.79%. Based on this, Hypothesis 1 holds. The result supports the observations of Zhang et al. (2014), who noted that as domestic agricultural R&D investments increase, the quality of China's agricultural development will be effectively improved. Based on Chinese official statistics, the development of agricultural science and technology has been vigorously promoted with unprecedented intensity, and the contribution rate of agricultural science and technology increased from 52% in 2010 to 60% in 2020. The growth of "green" productivity in China's agricultural sector is mainly driven by innovation in planting technology, efficient resource use, and pollutant treatment (Liu and Feng, 2019; Huang et al., 2022; Chandio et al., 2023c). Since 2000, the Chinese government has boosted its investment in agricultural research and has listed the key goals of domestic agricultural R&D projects, including adapting to climate change, increasing production, conserving resources, and reducing environmental pollution (Zhang et al., 2013). During the 13th Five-Year Plan period, a total of RMB 61.019 billion has been invested in agricultural research institutions; furthermore, the government has funded the development of key laboratories that are associated with the Ministry of Agriculture and Rural Development and the Chinese Academy of Agricultural Sciences and enhanced the agricultural extension system. On the other hand, regarding their number, intensity, strength of policy objectives, and strength of policy measures, China's policies for agricultural science and technology innovation have exhibited an overall fluctuating trend of increase. This behavior creates a favorable political environment that facilitates innovation, which supports high-quality agricultural development (Ma and Lv, 2012; Teng et al., 2018). Because China has recently prioritized innovation-driven development at the national level, the advancement of domestic agricultural R&D can be actualized.

With regard to control variables, the *per GDP*, at a 5% significance level, promotes high-quality agricultural development. For every 1% increase in *per GDP*, the level of high-quality agricultural development increases by 0.8%. This result indicates that the improvement of economic development level is beneficial for high-quality agricultural development. The *investment* at a 10% significance level exerts an inhibitory effect on high-quality agricultural development. For every 1% increase in *investment*, the high-quality agriculture development level declines by 0.12%. This finding indicates a reduction in high-quality agricultural development as agricultural fixed asset investment rises. A reasonable explanation is that although the investment in fixed agricultural assets enhances the construction of agricultural infrastructure, it is unable to maximize the overall agricultural production system and development quality. The *wage* at a 5% significance level exerts an inhibitory effect on high-quality agricultural development. For every 1% increase in *wage*, the high-quality development level of agriculture declines by 1.91%. This finding suggests that high-quality agricultural growth will be inhibited by an increase in resident income. The demand for more high-quality agricultural products will rise as per capita income rises, but China's agricultural production system may take longer to adjust to this change in demand, making it unable to implement more effective solutions. The *entrance* exerts an inhibitory effect on high-quality agricultural development at a 1% significance level. For every 1% increase in *entrance*, the high-quality agricultural development declines by 0.37%. This finding confirms the strong "crowding out" effect of agricultural product import trade on domestic agricultural products, showing that as the amount of agricultural product imports rises, high-quality agricultural development would be inhibited. The agricultural basis exerts a positive effect on high-quality agricultural development at a 5% significance level. For every 1% increase in *agriculture*, the high-quality development level of agriculture declines by 33.13%. This finding supports the notion that agricultural scale and intensive development can enhance the system's scale benefits and maximize production efficiency. It also shows that high-quality agricultural development will increase as agricultural production scale rises.

5.2 Stability analysis

The stability tests performed herein are reported in Table 5. First, we changed the manner in which domestic agricultural R&D is measured. Based on Wu's (2008) methodology, the depreciation rate of R&D stock is set at 25%, and the domestic agricultural R&D stock of each province and city are re-measured. The first column indicates that the regression coefficient of independent innovation is significantly positive at the 10% level, which is consistent with the aforementioned results. Subsequently, we deleted the 2010 sample. During the "Eleventh Five-Year Plan" period, China continued to strengthen the framework for farmer-based policies; thus, it combated the effects of severe natural disasters, and those of the global financial crisis (Tang et al., 2019). After deleting the 2010 sample, the results pertaining to the second column are still robust against the regression. Third, the regression model was modified. To test the impact of domestic agricultural R&D on high-quality agricultural development, the Tobit model was utilized (Shuai and Fan, 2020). Column (3) indicates that the regression results obtained using the Tobit model are consistent with the benchmark regression results, which indicates that the regression results obtained herein are robust. Fourth, we eliminated four municipalities, directly under the Central Government, and Column (4) indicates that the regression results remained robust.

TABLE 5 Stability test results.

	(1)	(2)	(3)	(4)
R&D	0.0175* (1.96)	0.0174* (1.7)	0.0179** (2.14)	0.0199* (1.74)
Entrance	−0.0037*** (−3.11)	−0.0034*** (−2.82)	−0.0037*** (−3.41)	−0.0034** (−2.15)
per GDP	0.0080** (2.14)	0.0086** (2.23)	0.0080** (2.33)	0.0032 (0.62)
Investment	−0.0012* (−1.75)	−0.0016** (−2.23)	−0.0012* (−1.92)	−0.0011 (−1.53)
Wage	−0.0192** (−2.12)	−0.0181* (−1.76)	−0.0191** (−2.32)	−0.0179 (−0.93)
Agriculture	33.0863** (2.48)	28.2167* (1.75)	33.1276*** (2.72)	35.0202** (2.54)
Cons	21.0921*** (11.76)	23.1561*** (11.03)	21.0339*** (12.8)	21.4192*** (9.15)
Time fixed effects	YES	YES	YES	YES
Regional fixed effects	YES	YES	YES	YES
N	252	224	252	216
R^2	0.9507	0.9524	0.4318	0.9303

The numbers that are placed within brackets denote *t* statistic values; ***, **, or * denotes significance at the 1%, 5%, or 10% level, respectively.

TABLE 6 Endogenous test results.

	First-stage (1)	Two-step (2)
Lg R&D	0.9705*** (117.74)	
R&D		0.01964** (2.11)
Entrance	0.0020** (2.00)	−0.00355*** (−3.21)
per GDP	0.0040 (1.27)	0.00846** (2.41)
Investment	0.0008 (1.40)	−0.00158** (−2.52)
Wage	−0.0105 (−1.23)	−0.01823* (−1.95)
Agriculture	0.2497 (0.02)	28.65045** (1.97)
Cons	10.9802*** (4.91)	34.88050*** (14.07)
Time fixed effects	YES	YES
Regional fixed effects	YES	YES
N	224	224
R^2	0.999	0.9524

The numbers that are placed within brackets denote *t* statistic values; ***, **, or * denotes significance at the 1%, 5%, or 10% level, respectively.

5.3 Endogenous test

This study tested the endogeneity of the core explanatory factors by utilizing the first-order lag pertaining to domestic agricultural R&D as an instrumental variable in a regression (Table 6). Compared with the basic regression results, the sign and significance of the explanatory variable coefficients remained constant, and only the regression coefficients varied marginally. This demonstrates that the endogeneity of the model's primary explanatory variables is not a significant concern.

TABLE 7 Moderating effect test results.

	(1)	(2)	(3)
R&D	0.0320** (2.08)	−0.0795 (−1.46)	0.1265*** (3.27)
fdi	0.0248** (2.57)		
fdi × R&D	−0.0001* (−1.90)		
Human		−1.8513*** (−2.81)	
Human × R&D		0.0129* (1.73)	
Finance			44.2015 (1.63)
Finance × R&D			−0.8625*** (−2.93)
Entrance	−0.0036*** (−2.99)	−0.0044*** (−3.57)	−0.0046*** (−3.68)
per GDP	0.0095** (2.52)	0.0094** (2.47)	0.0067* (1.79)
Investment	−0.0017** (−2.41)	−0.0016** (−2.35)	−0.0014** (−2.08)
Wage	−0.0224** (−2.48)	−0.0289*** (−3.02)	−0.0198** (−2.22)
Agriculture	38.4562*** (2.87)	33.6726** (2.56)	33.9540** (2.57)
Cons	19.4284*** (10.11)	36.5235*** (6.27)	15.9419*** (6.42)
Time fixed effects	YES	YES	YES
Regional fixed effects	YES	YES	YES
N	252	252	252
R^2	0.9424	0.9428	0.9429

The numbers that are placed within brackets denote t statistic values; ***, **, or * denotes significance at the 1%, 5%, or 10% level, respectively.

6 The moderating effect test

The estimated outcomes of the moderating effect models (2)–(4) are presented in Table 7. After the adjustment variable *foreign technology introduction* is introduced in Column (1), the values of F-statistic and P are 96.51 and 0.0000, respectively, demonstrating that the regression model is appropriately set and has statistical significance. In addition, the adjusted coefficient of determination is 0.9424, indicating a good overall fitting performance that 94.24% of the changes in high-quality agricultural development can be accounted for by the explanatory variables in the model. Moreover, the coefficient of the interaction term between foreign technology introduction and domestic agricultural R&D is −0.0001 ($t = -1.90$, $p = 0.059 < 0.10$). The results indicate that agricultural FDI, a method of foreign technology introduction, exerts a negative moderating impact on the link between domestic agricultural R&D and high-quality agricultural development, and is significant at the statistical level of 10%. Hypothesis 2 holds. Moreover, When foreign direct investment increases, the promoting effect of domestic agricultural R&D gradually decreases. This result is consistent with the observations of other researchers, who stated that foreign capital and multinational companies exert a crowding-out effect on the production and marketing of agricultural products in the host country by virtue of their technological and price advantages, which suppresses the incentive of Chinese small and medium-sized enterprises to innovate (Wen, 2015). Local agricultural producers, for instance, will rely on increasingly mechanized or energy-intensive technologies to maintain productivity and competitiveness (Kastratović, 2019), thus neglecting investment in technological innovation. Furthermore, due to technological barriers in the agriculture sector and the increased difficulty associated with imitation and transformation costs, the technological spillover effect of agricultural FDI is insignificant.

With regard to Column (2), after introducing the moderator variable *human capital*, the values of F-statistic and P are 97.20 and 0.0000, respectively, and the adjusted coefficient of determination is 0.9428. This indicates a statistical significance and a good fitting performance of the entire regression model. Furthermore, the interaction term coefficient between human capital and domestic agricultural R&D is 0.0129($t = 1.73$, $p = 0.085 < 0.10$), which is positive at the 10% significance level. Based on this, Hypothesis 3 holds, indicating that as human capital increases, domestic agricultural R&D will exhibit an increasing impact on high-quality agricultural development. However, due to the negative coefficient of domestic agricultural R&D variables, human capital strengthened the inhibitory effect of domestic agricultural R&D on high quality agricultural development. This observation may be occasioned by the following relationship: different levels of human capital exert different regulating effects on the relationship between domestic agricultural R&D and high-quality agricultural development, which produce both negative and positive regulatory effects. The preceding result is inconsistent with the expected results. Theoretically speaking, increasing farmers' demand and adoption of new technology will accelerate the transformation and diffusion of agricultural innovation successes (Messinis and Ahmed, 2013; Karimov, 2014). Relevant research, however, has revealed that China has a rural human capital trap, in which rural inhabitants with better skills and education levels are more likely to migrate to cities (Zhao H. et al., 2019). This phenomenon of "elite outflow" actually reduces the human capital of some agricultural sectors. Zhao (2019) also postulated that domestic agricultural R&D may be correlated with the heterogeneity of human capital. The impact of primary, secondary, and advanced rural human capital on the progress of agricultural technology is more differentiated.

Column (3) indicates that regarding supporting agriculture, after the introduction of the adjustment variable *financial support,* the values of F-statistic and P are 97.20 and 0.0000, respectively, and the adjusted coefficient of determination is 0.9429. This indicates a statistical significance and a good fitting performance of the entire regression model. Furthermore, domestic agricultural R&D exerts a positive impact on high-quality agricultural development at the 1% significance level. However, the coefficient of the interaction between financial support and domestic agricultural R&D is −0.8625 ($t = -2.93$, $p = 0.004 < 0.01$) at the 1% significance level. This result indicates that financial policy has a negative moderating effect on the relationship between domestic agricultural R&D and high-quality agricultural development. Hypothesis 4 holds. Furthermore, when the level of financial support is low, the promotion role of domestic agricultural R&D is more apparent. This outcome is consistent with that of Wang L. et al. (2022). Undoubtedly, China's fiscal expenditure is essential to the development of the agricultural sector, particularly in the construction of agricultural infrastructure and the promotion and training of agricultural technology, all of which have had a positive and productive impact on agricultural growth and technological advancement. For example, the Chinese government has increased infrastructure construction in recent years, bringing new opportunities for intelligent and digital agricultural development in China. Information and internet technology have accelerated the application and diffusion of new technologies through the transmission of information, knowledge, and so on, thereby enhancing farmers' skills (Chandio et al., 2023a,b). However, the negative regulatory impact of fiscal policy on the relationship between domestic agricultural R&D and high-quality agricultural development can be explained. First of all, since the 21st century, China's agricultural technological progress has been dominated by physical technological progress, while the problem of loss of technological efficiency has been prominent. Policy incentives have led to the expansion of input factors and the upgrading of equipment, promoting agricultural technology. With diminishing marginal returns on factors, the impetus for physical technological progress in agricultural capital has gradually weakened. Second, excessive government involvement will stifle economic transformation (Aydin and Esen, 2018), as seen in China's case where local governments control important factor pricing and distribution rights, leading to distortions in the factor market. Long-term factor price distortion has a negative impact on the course and conduct of independent innovation by businesses (Lin and Chen, 2018). Fiscal measures like farmer subsidies and fertilizer price controls have distorted the market for fertilizer factors (Bai et al., 2019), increasing farmers' reliance on fertilizers while suppressing their motivation for research and development of green inputs. Third, under the preference of self-interested investment and the pressure from local interest groups, local governments may prioritize the construction of public infrastructure and services in underdeveloped areas (Adam et al., 2014). To some extent, they may negate scientific and technological efficiency, which leads to losses in agricultural technological innovation.

7 The heterogeneity analysis

According to the preceding content, there are considerable discrepancies in the level of high-quality agricultural growth between China's eastern and central western areas. This study further investigates the differences in the impact mechanism of domestic agricultural R&D on high-quality agricultural growth between areas, and the results are displayed in Table 8. In the East region, the regression coefficient of domestic agricultural R&D is 0.0148 ($t = 1.77$, $p = 0.080 < 0.10$), which shows that domestic agricultural R&D considerably promotes high-quality agricultural development at a 10% significance level. For each 1% increase in domestic agriculture R&D, the level of high-quality agricultural development increases by 1.48%. In the Midwest region, the regression coefficient of domestic agricultural R&D is 0.0417 ($t = 1.72$, $p = 0.088 < 0.10$), which shows domestic agricultural R&D considerably promotes high-quality agricultural development at a 10% significance level. For every 1% increase in domestic agricultural R&D, the high-quality agricultural development increases by 4.71%. This observation further indicates that domestic agricultural R&D supports and guides high-quality agricultural development, and this promoting effect is more evident in the Midwest region. There are some differences between the results obtained herein, and those pertaining to other studies. Based on related studies, the efficiency of research investment is generally

TABLE 8 The impact of the domestic agricultural R&D that characterizes the two regions on high-quality agricultural development.

	The East regions	The Midwest regions
R&D	0.0148* (1.77)	0.0471* (1.72)
Entrance	−0.003*** (−2.80)	−0.008 (−0.50)
per GDP	0.004 (1.17)	0.0087 (1.08)
Investment	0.002 (1.56)	−0.0024** (−2.45)
Wage	0.007 (0.51)	0.0187 (0.41)
Agriculture	−59.211 (−1.39)	52.1277*** (2.93)
Cons	23.959*** (7.31)	13.5584** (2.58)
Time fixed effects	YES	YES
Regional fixed effects	YES	YES
N	108	144
R^2	0.938	0.9298

The numbers that are placed within brackets denote t statistic values; ***, **, or * denotes significance at the 1%, 5%, or 10% level, respectively.

higher in eastern China than in central and western China. The preceding observation indicates that the eastern region exhibits the highest overall investment in agricultural research (Li, 2009; Wan et al., 2022), and that this phenomenon may be occasioned by factors such as GDP and government subsidies (Zhao L. et al., 2019; Cui et al., 2021). However, China has highly prioritized the advancement of science and technology in the Midwest. In addition, the construction of science and technology platforms and research investment in the Midwest has been strengthened, which is conducive to accelerating domestic agricultural R&D spillover effects and promoting high-quality agricultural development.

For the two regions, the estimated outcomes of the moderator effect models are depicted in Table 9 (1)–(6). For columns (1) and (4), after introducing the moderator variable *foreign technology introduction*, the regression coefficient pertaining to domestic agricultural R&D in the East region is 0.0315 ($t=2.06$, $p=0.042<0.05$), which is significant at the 5% level, and the coefficient of the interaction term between foreign technology introduction and domestic agriculture R&D is −0.0001 ($t=-1.63$, $p=0.107>0.10$), which does not pass the significance test. For the Midwest region, the regression coefficient of domestic agriculture R&D is 0.0641($t=1.74$, $p=0.085<0.10$), which is significant at the 10% level, and the coefficient of the interaction term between foreign technology introduction and domestic agricultural R&D is −0.0006 ($t=-2.04$, $p=0.044<0.05$), which is significant at the 5% level. The findings suggest that while the introduction of foreign technology had no moderating impact on the relationship between domestic agricultural R&D and high-quality agricultural development in the East region, it had a large negative moderating impact in western China. With the increase of foreign technology introduction, the promoting effect of domestic agricultural R&D will be weakened on the high-quality agricultural development in the western region.

For columns (2) and (5), after introducing the moderator variable *human capital*, the regression coefficient of domestic agriculture R&D is −0.0585 ($t=-1.22$, $p=0.225>0.10$), under the East region sample, and the coefficient of the interaction term between human capital and domestic agricultural R&D is 0.0097 ($t=1.47$, $p=0.146>0.10$). For the Midwest region, the regression coefficient of domestic agriculture R&D is −0.0472 ($t=-0.33$, $p=0.745>0.10$), and the coefficient of the interaction term between human capital and domestic agricultural R&D is −0.0111($t=0.57$, $p=0.569>0.10$). The above results all fail the significance test in the East and the Midwest regions. Simultaneously, human resources do not affect the relationship between domestic agricultural R&D and high-quality agricultural development.

For columns (3) and (6), after introducing the adjustment variable *financial support*, the regression coefficient of domestic agricultural R&D is 0.0996 ($t=2.41$, $p=0.018<0.05$), under the East region sample, and it is significant at the 5% level, whereas the regression coefficient of domestic agricultural R&D is 0.2092 ($t=2.65$, $p=0.009<0.01$), under the Midwest sample and significant at the 1% level. For the East and the Midwest regions, the coefficients of the interaction between financial support and domestic agriculture R&D are −0.6795 ($t=-2.21$, $p=0.030<0.05$) and − 1.4543 ($t=-2.13$, $p=0.035<0.05$), respectively, which are significantly negative. This outcome demonstrates that financial support exerts a significantly negative moderating effect on the relationship between domestic agricultural R&D and high-quality agricultural development in the two regions.

8 Conclusions and recommendations

To foster high-quality agricultural development, the government should emphasize the leading role of scientific and technological innovation. Therefore, this study, which considers panel data from 28 provincial-level administrative regions in China from 2010 to 2018, carefully examines the effect of domestic agricultural R&D on high-quality agricultural development, and the following conclusions and recommendations are obtained.

1 The high-quality agricultural development in China has made great progress and exhibits a steady upward trend with an average annual growth rate of 4.57%. Based on the regional development perspective, the high-quality agricultural development level of the Midwest regions is higher than that of the Eastern regions. The development trend of the industrial and ecological systems is improving; however, the rising costs and imperfect rural factor markets have led to the slow development of production and management systems. We propose that China should continue to promote moderate-scale agricultural operations, and that to effectively reduce labor costs, the country should replace labor with machinery and equipment.

2 With respect to China, domestic agricultural R&D has positively and effectively promoted high-quality agricultural development, and this role is more apparent in the Midwest region. China, a developing nation, should continue to increase domestic agricultural R&D by expanding the investment channels to solve the problem of insufficient domestic agricultural R&D stock. For instance, China should guide more social capital to participate in domestic agricultural R&D and promote the involvement of technology innovation businesses in crucial agricultural technology research. On the other hand, the country should maximize the spatial distribution of domestic agricultural R&D investments, and increase domestic agricultural R&D spending in robust agricultural provinces and regions to enhance the impact of the knowledge spillover of agricultural R&D.

TABLE 9 Two-region moderating effect test results.

	The East regions			The Midwest regions		
	(1)	(2)	(3)	(4)	(5)	(6)
R&D	0.0315** (2.06)	−0.0585 (−1.22)	0.0996** (2.41)	0.0641* (1.74)	−0.0472 (−0.33)	0.2092*** (2.65)
fdi	0.0289* (1.8)			0.0793*** (3.06)		
fdi × R&D	−0.0001 (−1.63)			−0.0006** (−2.04)		
Human		−2.0566*** (−3.10)			−1.9237 (−1.40)	
Human × R&D		0.0097 (1.47)			0.0111 (0.57)	
Finance			62.0645* (1.73)			37.6901 (0.75)
Finance × R&D			−0.6795** (−2.21)			−1.4543** (−2.13)
Entrance	−0.0025** (−2.51)	−0.0034*** (−3.44)	−0.0035*** (−3.32)	−0.0061 (−0.39)	−0.0074 (−0.46)	−0.0094 (−0.59)
per GDP	0.0037 (1.00)	0.0066* (1.79)	0.0037 (1.01)	0.0232** (2.55)	0.0102 (1.25)	0.0047 (0.52)
Investment	0.0007 (0.61)	0.0006 (0.58)	0.0004 (0.37)	−0.0025*** (−2.62)	−0.0025** (−2.55)	−0.0019* (−1.94)
Wage	0.0147 (1.02)	−0.0069 (−0.49)	0.0043 (0.31)	−0.0795 (−1.44)	0.0043 (0.09)	−0.0029 (−0.06)
Agriculture	−113.8219** (−2.19)	−49.2926 (−1.21)	−72.8450* (−1.72)	56.9124*** (3.14)	48.5924*** (2.7)	47.3765*** (2.66)
Cons	21.9733*** (6.41)	47.1242*** (5.75)	22.2023*** (6.51)	18.5219*** (3.47)	30.8453** (2.29)	10.2559* (1.84)
Time fixed effects	YES	YES	YES	YES	YES	YES
Regional fixed effects	YES	YES	YES	YES	YES	YES
N	108	108	108	144	144	144
R^2	0.9392	0.9437	0.9406	0.9346	0.9298	0.9315

The numbers that are placed within brackets denote t statistic values; ***, **, or * denote significance at the 1%, 5%, or 10% level, respectively.

3 Technology introduction exerts a negative moderating impact on the link between domestic agricultural R&D and high-quality agricultural development. When technology introduction increases, the promoting effect of domestic agricultural R&D on high-quality agricultural development gradually decreases. Meanwhile, this negative regulatory effect is more prominent in western China. Therefore, China should focus on introducing core agricultural technologies; simultaneously, the country should strengthen technological exchanges and cooperation.

4 Human capital enhances the inhibitory effect of domestic agricultural R&D on high-quality agricultural development. Meanwhile, this negative moderating effect is more prominent in western China. Despite improvements in rural human capital, the departure of highly educated personnel remains a significant issue, which has reduced the human capital of the agricultural labor force. With regard to farmers, China should immensely consider the promotion and training associated with novel technologies; thus, it can increase the penetration rate of novel technologies. Additionally, there should be more talent entrance guidelines that attract people with higher educations to work in agricultural development.

5 The relationship between domestic agricultural R&D and high-quality agricultural development is negatively moderated by financial policy. The promotion of domestic agricultural R&D will be decreased with an increase in financial support for agriculture, and this negative moderating is both present in the eastern and central western regions. Therefore, China should strengthen the reform of the fiscal decentralization system, strengthen the oversight of the local governments' fiscal expenditures, and strengthen their leadership and guaranteeing role in domestic agricultural R&D; thus, the country can address the contemporary issue of local governments negating agricultural innovation.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

DY: Data curation, Formal analysis, Writing – original draft. YW: Investigation, Writing – review & editing. CL: Methodology, Supervision, Visualization, Writing – original draft. GZ: Investigation, Methodology, Writing – review & editing. FX: Investigation, Visualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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