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Article

Measurement, regional differences, and driving factors of high-quality development level of crop seed industry in China

Lingmei Han[1,*], Hesong Li[1], Hongtao Shen[2,*]

[1] School of Business, Henan University of Science and Technology, Luoyang 471000, Henan, China
[2] Technology Center, China Tobacco Henan Industrial Co., Ltd., Zhengzhou 450000, Henan, China
*** Corresponding authors:** Lingmei Han, 9901617@haust.edu.cn; Hongtao Shen, shtluoyang@126.com

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Abstract: Objective: To promote the development of China's crop seed industry with high quality, guarantee food security and sustainable agricultural development, scientific design of the evaluation index system for high-quality development of the seed industry and conduct of metric analysis are the keys to promoting the revitalization of the seed industry and the construction of a strong agricultural country. **Methods:** This paper focused on the high-quality development of China's crop seed industry as the main research object by combining previous research findings of studies based on the connotation of high-quality development of the crop seed industry and constructed the evaluation index system of high-quality development of China's crop seed industry which covers five dimensions, namely, innovation-driven development, green and sustained development, coordinated and comprehensive development, opening-up and strengthened development, and share-and-promote development, The Entropy method, Dagum's Gini coefficient, Kernel's density estimation, and panel regression methods were used to comprehensively analyze the spatial and temporal evolution, regional differences, and driving factors of the level of high-quality development of the crop seed industry in 30 provinces (municipalities and autonomous regions) of China from 2011 to 2020. **Conclusions:** After systematic analysis, it was concluded that (1) the overall level of high-quality development in China's crop seed industry has stabilized, and progress has been made. (2) The overall inter-regional differences among the four major regions showed a gradual upward trend, with the inter-regional differences serving as the primary source of the differences and the contribution rate of various inter-regional differences demonstrating an upward trend. (3) Innovation capacity, the cultural and educational level of rural residents, the development of rural infrastructure, national financial support, and market-oriented approach are important factors driving the high-quality development of the crop seed industry in Chinese provinces (districts and municipalities).

Keywords: food security; crop seed industry; high-quality development; regional differences; driving factors; seed industry development

1. Introduction

1.1. Basic overview

The seed industry, which serves as the "chip" of agriculture, is a basic and strategic core industry of the country. It is an important part of the modern agricultural industrial system and plays a fundamental role in promoting the long-term stable development of agriculture and ensuring national food security.

The international seed industry pattern is evolving rapidly, making it highly intensive and rapidly innovating in breeding technology. The development of China's crop seed industry continues to encounter constraints and uncertainties. China has actively promoted the development of the crop seed industry since 2013, establishing a distinct objective of "improving the quality, efficiency, and competitiveness of the seed industry." With the implementation of a series of policies and projects to promote the development of the modern seed industry, remarkable results have been attained in the high-quality development of the crop seed industry of China. Considering the current situation of regional imbalance in developing the crop seed industry, deducing the regional differences and spatial and temporal evolution characteristics in the high-quality development of the crop seed industry, and examining the driving factors will help to accurately understand the real situation and distribution characteristics of the high-quality development of China's crop seed industry, is crucial.

The seed industry focuses on crop seeds, and it functions as an integrated system that incorporates social services, government management, public support, industry self-regulation, and other components. This study focuses on China's crop seed industry as the research object, based on the five high-quality development philosophies combined with the characteristics of the crop seed industry, to design the index system and evaluation model. This model comprises 20 basic indexes derived from the five dimensions of innovative, coordinated, green, open, and shared development. The study also systematically analyzes the regional characteristics of the high-quality development of China's crop seed industry to establish the basis for the revitalization of the seed industry in China, to provide the operational ideas and methods for national and local food security, and to serve as the point of reference for the high-quality development of the related industries.

1.2. Review of literature

Currently, research on development quality is more likely to commence by examining the speed, efficiency, and equilibrium of macroeconomic development. Alternatively, the studies may focus on the characteristics and conditions contributing to the realization of qualitative development concerning units, organizations, and structures comprising the economic system. As a new development philosophy, the goal of high-quality development is to improve the development quality, consider the ecological environment, coordinate the economic development structure, build a modern economic system, and improve living standards.

Based on the existing literature, domestic scholars possess more research on high-quality development. The connotation of high-quality development can be summarized in three aspects: taking the five development philosophies as the theoretical foundation, leadership, and ultimate goal; taking ecological protection and economic development as the core and promoting coordinated economic development, ecological protection, ecological priority, and green development as the connotation of high-quality development; taking economic development as the core, as it is believed that the essence of high-quality development is high-quality economic development, and the core is to satisfy the people's pursuit of life and ecology. There are two main research directions for measuring and comparing the level of high-quality economic development: First, based on the guiding principle of the new development philosophy, Wei and Li (2018), Xu (2018), and Chen et al. (2020)

constructed an indicator evaluation system including five dimensions; "innovative, coordinated, green, open, and shared", and calculated the index of high-quality development of China's economy. Second, another group of scholars used a single-dimensional indicator as a proxy for the level of economic quality development. Extensive research has been conducted on the connotation of high-quality development in agriculture, constructing an indicator system, and the differences in spatial distribution. However, despite the close relationship between the seed industry and agriculture, in-depth research on the connotation of high-quality development in the seed industry and developing an indicator system is still under discussion.

To summarize, substantial scholarly investigation has been done on high-quality economic development, yielding fruitful research outcomes. In contrast, relatively few studies have been conducted on the high-quality development in China's seed industry, with the crop seed industry in particular lacking substantial scholarly attention. Therefore, based on the high-quality development research perspective, we constructed an evaluation system for the high-quality development of China's crop seed industry and selected a variety of measurement methods to carry out a systematic analysis to provide a basis for efficiently guiding the practice of seed industry revitalization and improving the scientific decision-making ability of relevant departments.

1.3. Technique routine chart

To better achieve the research objectives, this paper first establishes an index evaluation system for the high-quality development level of the crop seed industry. Next, the entropy method is used to estimate the high-quality development level of the crop seed industry in various regions of China. Following this, an analysis of the prevailing regional disparities and the dynamic evolution process is conducted based on the high-quality development level of the crop seed industry in different regions. Finally, the factors influencing the high-quality development level of China's crop seed industry are explored. The specific technical route as shown in **Figure 1**.

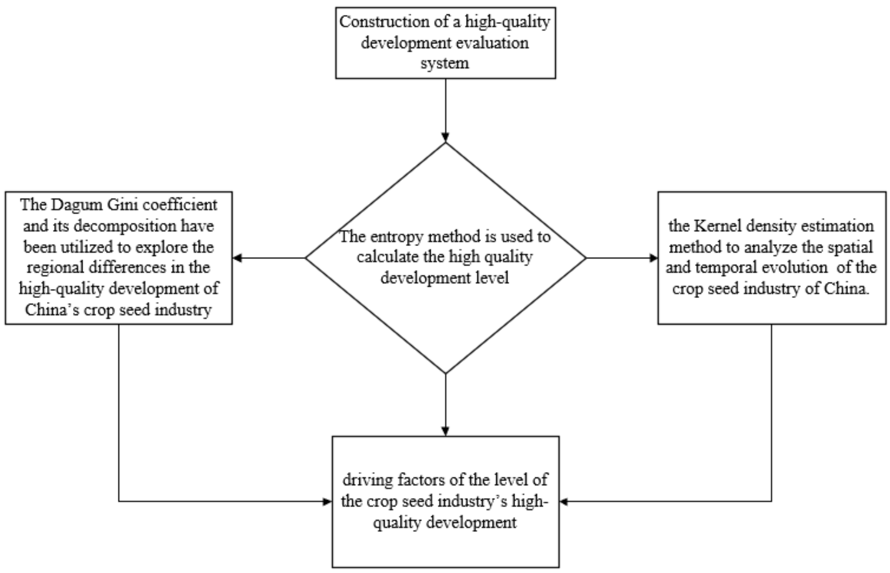

Figure 1. Technique routine chart.

2. Study area and data sources

2.1. Study area

The research object of this study is the crop seed industry. The sample area for this research comprised 30 provinces (municipalities and autonomous regions), excluding Hong Kong, Macao, Taiwan, and Tibet Autonomous Region, due to the data not published in these regions. According to the division standard of the National Bureau of Statistics and the research requirements of this investigation, the eastern region comprises Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan (10 provinces and municipalities). The central region includes Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan (six provinces and municipalities). The north-eastern region includes Heilongjiang, Jilin, and Liaoning (three provinces). The western region includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang (11 provinces, municipalities, and autonomous regions).

Regarding the selection of some evaluation indicators, it should be noted that within the innovation dimension, the number of new varieties' registrations and authorizations were both selected due to the different nature and scope of the concepts to reflect and compare the number of high-quality varieties for breeding. In the green dimension, which is reflected in resource conservation and environmental friendliness, soil environment indicators reflect the effect of seed resistance to pests and diseases on the number of pesticides and fertilizers applied to the field soil environment; green and efficient seeds can reduce the application of pesticides and fertilizers. In the coordination dimension, industry structure and financial support reflect the high-quality development of the crop seed industry, which is closely related to the degree of regional economic development. In this study, the level of financial support for the crop seed industry is assessed using the ratio of agriculture-related loan amounts (provinces, municipalities) to the Gross Domestic Product (GDP) (provinces, municipalities) due to the lack of data on crop seed industry loans. The open and sharing dimension considers the scale of crop seed industry assets as a key indicator of the seed industry development level, whereas the number of varieties and areas promoted reflect the varieties' universality.

2.2. Date sources

Based on the connotative characteristics of crop seed industry high-quality development that we have defined, this study established an evaluation index system that comprehensively reflects the level and trend of China's crop seed industry high-quality development in five dimensions (innovation, greenness, coordination, openness, and sharing) in accordance with the new development philosophy. According to this indicator framework, we primarily collected raw data for the quantification of each indicator in 30 provinces (municipalities and autonomous regions) from 2011 to 2020. The sources were all statistical yearbooks of past years, including the *China Statistical Yearbook*, *China Rural Statistical Yearbook*, *China Rural Finance Service Report*, *Statistical Yearbook of China Commodity Exchange Market*, and statistical yearbooks of 30 provinces (municipalities and autonomous regions) (2012–2021). We collected and organized relevant data pertaining to the crop seed industry through the *China Seed Information*, the *China Agricultural Information*, and the *China Seed Industry Big Data Platform*. To address the issue of missing data, we used the interpolation method and nearby approximations.

3. Construction of a high-quality development evaluation system for China's crop seed industry

3.1. Connotation and characteristics

Some scholars explain the connotation of high-quality development from the view of microeconomic development and believe that high-quality development is based on economic construction. In contrast, other scholars study the definition and connotation of high-quality development from the perspective of the new development philosophy (innovative, coordinated, green, open, and shared). The connotation of high-quality development in the seed industry has not been clearly defined in the literature. Based on the research perspective, the combing of the existing literature, and with reference to the connotation of China's livestock industry's high-quality development defined by Xiong et al. (2022), this study defined the high-quality development of China's crop seed industry as; to ensure ongoing growth of the crop seed industry's scale and meeting the demand for the continuous improvement of the crop seed industry's green total factor productivity, we shall establish a new pattern of synergistic development of all links and chains for the crop seed industry including the conservation of germplasm resources, scientific research on breeding, seed market management, among others. This will culminate in the formation of a modern crop seed industry system that is innovation-driven, green, sustained, coordinated, comprehensive, opening up, strengthening, share-and-promote development for building a strong seed industry foundation for the modernization of agriculture and rural areas, and the better life of people.

3.2. Evaluation system construction

Based on the fact that the development of the crop seed industry is affected by multiple factors such as natural (like water resources, climate, regional temperature difference, light, regional germplasm resources), economical (like the degree of economic development), social, scientific and technological progress (scientific and technological innovation capacity, as well as R&D(research and development) inputs), the composition of indicators for evaluating high-quality development of the crop seed industry is more systematic, complex, and diversified. Based on comprehensive consideration of the connotation and characteristics of high-quality development in the crop seed industry given in the study, combined with the characteristics of the current development stage of China's crop seed industry and the indicator system for high-quality development of agriculture proposed by Huang Xiujie et al. (2020), and adhering to the principles of feasibility, systematicity, scientificity, comprehensiveness, as well as data availability and openness, a relatively scientific and comprehensive evaluation indicator system was constructed in this study as shown in **Table 1**. The designed system consisted of five first-level indicators and 20 basic indicators on the scale of provinces (municipalities and autonomous regions), conformed to the high-quality development of the current crop seed industry in China.

Table 1. Crop seed industry high-quality development index system.

First-level indicator	Factor indicators	Basic indicators	Proxy Variables and Calculation Methods	Indicator properties
Innovation-driven development	Breeding technology	The number of new varieties registered	Number of new varieties registered in the year	Positive (+)
		The number of new varieties authorized	Number of new varieties authorized in the year	Positive (+)
		Crop seed efficiency	Total crop production/total area under crop cultivation	Positive (+)
		Crop seed properties	Demand for crop seeds/area under crop cultivation	Negative (−)
	R&D capability	R&D expenditures	Expenditure on R&D in science and technology × Proportion of primary sector	Positive (+)
		No. of R&D staff	FTE of R&D personnel × Proportion of primary sector	Positive (+)
Green and sustained development	Soil environment	Crop seed fertilizer requirements	Crop fertilizer application/area cultivated	Negative (−)
		Crop seed pesticide requirements	Crop pesticide application/area cultivated	Negative (−)
	Breeding time	Average breeding time	National average crop seed breeding years	Negative (−)
	Seed economic capacity	Crop seed requirements	National crop seed demand × percentage of area cultivated by province	Negative (−)
Coordinated and comprehensive development	industrial structure	Agricultural output structure ratio	Agricultural output/gross output of farming, forestry, livestock and fishing	Negative (−)
	Financial support	Level of financial support for the crop seed industry	Amount of agriculture-related loans (by province and municipality)/GDP (by province and municipality)	Positive (+)
		The financial support level for farming, forestry, livestock and fishing	Loans for farming, forestry, livestock, and fishing (by province and municipality)/GDP (by province and municipality)	Positive (+)
Opening-up and strengthened development	Openness of the seed industry	Competitiveness of the crop seed industry	Imports/exports of crop seed industry	Negative (−)
		Number of papers on breeding technology	Web of Science number of papers on breeding technology	Positive (+)
		Crop seed industry asset size	Crop seed industry market scale × share of planting area by province and municipality	Positive (+)
Share-and-promote development	Regional promotion rate	Number of varieties promoted	Number of seed varieties of major promoted crops	Negative (−)
		Area of main varieties promoted	Total area of major crop seed varieties promoted	Positive (+)
	Industry-Research Integration	Percentage of registration of seed enterprises (cooperation)	Number of new varieties registered by seed enterprises (or cooperation)/total number of varieties registered	Positive (+)
		Percentage of breeding promotion agencies	Breeding, promotion agencies/total crop seed enterprises	Positive (+)

3.2.1. Innovation-driven development

Crop seed industry innovation is a high-tech, heavily funded, long-term innovation consisting of breeding innovation technology and innovation R&D

capacity. Breeding innovation technology consists of four basic indicators: the number of newly registered and authorized varieties, and the efficiency and performance of crop seed. R&D capacity is expressed in terms of R&D expenditures and the number of R&D personnel.

3.2.2. Green and sustained development

Green development selected the demand of crop seed fertilizer and seed pesticide represent the soil environment, while the average breeding time and seed demand represent the economic capacity of seeds. The selection of the soil environment is based on the ability of seeds to resist pests and diseases, which affects the application of pesticides and fertilizers in the late-stage field and, in turn, affects the ecological environment of the soil. Conversely, using green and efficient seeds can reduce the amount of pesticides and fertilizers applied.

3.2.3. Coordinated and comprehensive development

It is proposed that the structure of the agricultural industry be selected to represent the development of the seed industry. Although this method may not precisely reflect the structure of crop seed industry development, it is possible to convey the notion that the development of the crop seed industry relies on the performance of agricultural production. Simultaneously, financial support plays a pivotal role in developing an industry. Based on the characteristics of the crop seed industry, its time cycle of development is long, and reliance on the market liquidity alone makes it difficult to supply sufficient capital for its growth; therefore, national financial support is particularly important.

3.2.4. Opening-up and strengthened development

The volume of imports and exports of crop seeds reflects the level of international competitiveness within the seed industry. In this case, the fact that exports exceeded imports indicates that the foreign seed industry market has a higher demand for Chinese crop seeds, reducing China's dependence on foreign seeds. A significant indicator to show the research output of scientific research institutes is the number of scientific and technological papers published, In this case, the number of Web of Science breeding technology papers is the theoretical basis for the development of the crop seed industry. The market size of the crop seed industry is an important index to measure its opening up intensity; the larger the market size, the more foreign capital can be attracted and the more favorable conditions for the development of seed industry enterprises.

3.2.5. Share-and-promote development

The shared development dimension is expressed by the regional promotion rate and the degree of integration of industry and research. It comprises four basic indicators: the number and areas of main promoted varieties, the proportion of registration numbers obtained by seed industry enterprises (including cooperation with research institutes), and the proportion of breeding organizations related to the four basic indicators. The number of promoted varieties is the key to reflecting the differentiation of crop seeds; however, a large number of promoted varieties results in the majority of seed traits being identical and lacking significant advantages.The larger the area of individual varieties promoted, the more prominent the universality of that variety becomes. Furthermore, under a certain crop sowing area, the area of individual varieties promoted directly represents the sharing degree of seeds.

4. Study methods

4.1. The entropy method

The entropy method is an objective assignment method commonly used in the comprehensive evaluation of multiple indicators, which requires complete data and determines the weights according to the degree of correlation between the indicators. The concept of "entropy" to determine the weights was first proposed by the German physicist Clausius in 1865. Entropy measures uncertainty and indicates the degree of order within things. The process and steps of calculating the weights of indicators by the entropy method are as follows:

First of all, in the evaluation index, it is necessary to convert the raw data into dimensionless standardized values, and the formulas for its positive and negative indicators are as follows:

$$\text{Positive indicators:} \quad Z_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \tag{1}$$

$$\text{Negative indicators:} \quad Z_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \tag{2}$$

where Z_{ij} is the dimensionless value, x_j^{max} and x_j^{min} are the maximum and minimum values of the j indicator, respectively, x_{ij} represent the value of the j (j = 1, 2, ..., m) indicator in the i (i = 1, 2, ..., n) district.

The second step is to calculate the weight p_{ij} of the i province under the j indicator and to calculate the entropy value e_j and weight w_{ij} of the j indicator; the formulae are as follows:

$$p_{ij} = \frac{x_{ij}^{'}}{\sum_{i=1}^{n} x_{ij}^{'}} \tag{3}$$

$$e_j = -\frac{1}{ln(n)} \sum_{i=1}^{n} p_{ij}\, ln(p_{ij}) \tag{4}$$

$$w_{ij} = \frac{1 - e_j}{\sum_{j-1}^{m} (1 - e_j)} \tag{5}$$

Finally, the composite index score for the level of the high-quality development of the crop seed industry was calculated with the following formula:

$$F_i = \sum_{j=1}^{m} w_j x_{ij}^{'} \tag{6}$$

4.2. Dagum Gini coefficient decomposition method

The Gini coefficient is a common indicator for measuring the income disparity among residents of a country or region. The closer the Gini coefficient value is to 1, the more unequal the income distribution, and the closer it is to 0, the more equal the income distribution. Compared to the traditional Gini coefficient, the Dagum Gini coefficient is often used to analyze regional differences and can decompose the research value into intra-regional disparity, inter-regional disparity, and hyper-variable density. In this study, the Dagum Gini coefficient and its decomposition have been utilized to explore the regional differences in the high-quality development of China's crop seed industry. The formula of the Dagum Gini coefficient is as follows:

$$G=\frac{\sum_{j=1}^{k}\sum_{h=1}^{k}\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}\left|y_{ji}-y_{hr}\right|}{2\mathrm{n}^2\mu} \tag{7}$$

where G represents the overall Gini coefficient, k represents the number of regions (the study area of this study is the four regions of the East, Central, Northeast, and West, so $k = 4$), n is the number of provinces (autonomous regions and municipalities) selected in this study ($n = 30$) and μ represents the average of the evaluation value of the examined province's crop seed industry high-quality development (autonomous regions and municipalities).

y_{ji} and y_{hr} denote the level of high-quality development of the crop seed industry of the province (autonomous region, municipalities) $i(r)$ in the$j(h)$ group, $n_j n_h$ and denote the number of provinces (autonomous regions, municipalities) in the region$j(h)$. The Gini coefficient G_{jj} region j and the Gini coefficient G_{jh} of region j and region h are calculated as follows:

$$G_{jj}=\frac{\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}\left|y_{ji}-y_{hr}\right|}{2n_j^2\mu_j} \tag{8}$$

$$G_{jh}=\frac{\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}\left|y_{ji}-y_{hr}\right|}{n_j n_h\left(\mu_j+\mu_h\right)} \tag{9}$$

Meanwhile, this study decomposed the overall Gini coefficient into intra-regional variance contribution G_w, net value variance contribution G_{nb} and hypervariable density contribution G_t, which is denoted as:

$$G_w=\sum_{j=1}^{k}G_{jj}p_j s_j \tag{10}$$

$$G_{nb}=\sum_{j=2}^{k}\sum_{h=1}^{j-1}G_{jh}D_{jh}\left(p_j s_h+p_h s_j\right) \tag{11}$$

$$G_t=\sum_{j=2}^{k}\sum_{h=1}^{j-1}G_{jh}\left(1-D_{jh}\right)\left(p_j s_h+p_h s_j\right) \tag{12}$$

where $p_j=\frac{n_j}{n}$, $s_j=\frac{n_j\mu_j}{(n\mu)}$, $p_h=\frac{n_h}{n}$, $s_h=\frac{n_h\mu_h}{(n\mu)}$, D_{jh} represents the relative impact of the level of high-quality development of the crop seed industry between region j and region h, calculated as follows:

$$D_{jh}=\frac{d_{jh}-p_{jh}}{d_{jh}+p_{jh}} \tag{13}$$

$$d_{jh} = \int_0^{\infty} dF_j(y) \int_0^{y} (y-x)\, dF_h(x) \tag{14}$$

$$p_{jh} = \int_0^{\infty} dF_h\,(y) \int_0^{y} (y-x)\, dF_j(x) \tag{15}$$

In Equations (13)–(15), d_{jh} denotes the difference in the level of high-quality development of the crop seed industry between regions, i.e., the expectation of all sample values plus the total value of $y_{ji} - y_{hr}>0$ in regions j and h, p_{jh} denotes the hypervariable first-order moments, i.e., the expectation of all sample values plus the total value of $y_{hr} - y_{ji} < 0$ in regions j h and that satisfy $y_{hr} - y_{ji} < 0$, and F_j (F_h) denotes the cumulative distribution function of the region $j(h)$.

4.3. Kernel density estimation method

Kernel density estimation is classified as a non-parametric test method. Parameter estimation assumes that the sample set conforms to a certain probability distribution and then fits the parameters in the distribution according to the sample set. Non-parametric estimation refers to the absence of any prior empirical knowledge. It determines the location of the distribution, shape, polarization, and other features through the characteristics and properties of the data. In this study, we proposed using the Kernel density estimation method to analyze the spatial and temporal evolution of the level of high-quality development of the crop seed industry of China. The formula of the Kernel density estimation is as follows:

$$f(x) = \frac{1}{Nh}\sum_{j=1}^{k} K\left[\frac{(X_i - x)}{h}\right] \tag{16}$$

where N is the number of samples, h is the bandwidth, X_i is the independently distributed observations, $K(x)$ kernel function ($K > 0$). The following relationship exists between the bandwidth h and the number of samples: $\lim_{N\to\infty} h(N) = 0$, $\lim_{N\to\infty} Nh(N) = N \to \infty$. To ensure the clarity of the results, the Gaussian kernel function is used to calculate and analyze; the formula is as follows:

$$K(x) = \frac{1}{\sqrt{2\pi}} exp\left(-\frac{x^2}{2}\right) \tag{17}$$

5. Results and analysis

5.1. Analysis of the spatio-temporal dimension of the level of crop seed industry high-quality development and the dimension of high-quality development

Combined with the high-quality development index system of the crop seed industry constructed in **Table 1**, **Table 2** lists the comprehensive index of the high-quality development level of China's crop seed industry from 2011 to 2020 and in the selected 30 provinces (municipalities and autonomous regions), except for two provinces (autonomous regions) of Qinghai and Ningxia, the remaining 28 provinces (municipalities and autonomous regions) have realized significant growth in high-quality development of the crop seed industry.

Table 2. 2011–2020 high-quality development comprehensive index of crop seed industry of China.

Region	Province	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Averages
Eastern Region	Beijing	0.2198	0.2170	0.2176	0.3105	0.3481	0.3522	0.4074	0.3982	0.4216	0.4775	0.3370
	Tianjin	0.1571	0.1530	0.1675	0.1560	0.1604	0.1636	0.1809	0.1707	0.1851	0.1849	0.1679
	Hebei	0.2600	0.2588	0.2816	0.2855	0.2971	0.2952	0.3274	0.3684	0.3714	0.4204	0.3166
	Shanghai	0.1433	0.1371	0.1513	0.1467	0.1503	0.1422	0.1434	0.1620	0.1721	0.1696	0.1518
	Jiangsu	0.3046	0.3154	0.3423	0.3496	0.3621	0.3660	0.3590	0.3977	0.4468	0.4736	0.3717
	Zhejiang	0.1921	0.1963	0.2220	0.2186	0.2218	0.2208	0.2286	0.2386	0.2518	0.2637	0.2254
	Fujian	0.1649	0.1665	0.1794	0.1822	0.1898	0.1973	0.1909	0.2325	0.2354	0.2558	0.1995
	Shandong	**0.3222**	**0.3253**	**0.3584**	**0.3638**	**0.3902**	**0.3780**	**0.4142**	**0.4406**	**0.4526**	**0.4994**	**0.3944**
	Guangdong	**0.2159**	**0.2158**	**0.2419**	**0.2490**	**0.2630**	**0.2819**	**0.2900**	**0.3099**	**0.3354**	**0.3672**	**0.2770**
	Hainan	**0.1316**	**0.1278**	**0.1282**	**0.1195**	**0.1327**	**0.1256**	**0.1308**	**0.1346**	**0.1380**	**0.1521**	**0.1321**
The whole region		0.2111	0.2113	0.2290	0.2381	0.2515	0.2523	0.2673	0.2853	0.3010	0.3264	0.2573
Central Region	Shanxi	0.1810	0.1879	0.1952	0.1913	0.1945	0.2006	0.2181	0.2213	0.2337	0.2408	0.2064
	Anhui	0.2435	0.2566	0.2673	0.2655	0.3117	0.3111	0.3205	0.3444	0.3425	0.4168	0.3080
	Jiangxi	0.2074	0.2051	0.2240	0.2314	0.2437	0.2515	0.2557	0.2636	0.2682	0.2935	0.2444
	Henan	**0.3023**	**0.2972**	**0.3319**	**0.3482**	**0.3469**	**0.3516**	**0.4142**	**0.4689**	**0.4655**	**0.5110**	**0.3838**
	Hubei	0.2392	0.3116	0.2526	0.2553	0.2632	0.2611	0.2955	0.2944	0.3370	0.3619	0.2872
	Hunan	0.2347	0.2450	0.2624	0.2621	0.2607	0.2899	0.3273	0.3352	0.3927	0.3662	0.2976
The whole region		0.2347	0.2506	0.2556	0.2590	0.2701	0.2776	0.3052	0.3213	0.3399	0.3650	0.2879
North-east region	Heilongjiang	**0.3019**	**0.3049**	**0.3394**	**0.3459**	**0.3687**	**0.3773**	**0.3863**	**0.4207**	**0.4849**	**0.4921**	**0.3822**
	Jilin	0.2077	0.2027	0.2250	0.2289	0.2299	0.2298	0.2257	0.2487	0.2635	0.2935	0.2355
	Liaoning	0.2168	0.2160	0.2222	0.2308	0.2466	0.2357	0.2708	0.2815	0.2853	0.3092	0.2515
The whole region		0.2421	0.2412	0.2622	0.2685	0.2817	0.2810	0.2942	0.3169	0.3446	0.3649	0.2897
Western region	Inner Mongolia	0.2197	0.2214	0.2468	0.2419	0.2491	0.2460	0.2469	0.2552	0.2432	0.2836	0.2454
	Guangxi	0.1955	0.1943	0.2053	0.2046	0.1974	0.2121	0.2460	0.2588	0.2903	0.2869	0.2291
	Chongqing	0.1628	0.1588	0.1650	0.1604	0.1674	0.1723	0.1645	0.1728	0.1781	0.1840	0.1686
	Sichuan	**0.2771**	**0.2839**	**0.2863**	**0.3025**	**0.3054**	**0.3103**	**0.3238**	**0.3233**	**0.3692**	**0.4025**	**0.3184**
	Guizhou	0.1668	0.1631	0.1700	0.1795	0.1805	0.1838	0.1840	0.1945	0.1994	0.2003	0.1822
	Yunnan	0.2092	0.1828	0.1970	0.2162	0.1926	0.2181	0.1939	0.2560	0.2559	0.2639	0.2186
	Shaanxi	0.2005	0.1915	0.2026	0.2051	0.2044	0.2129	0.2180	0.2158	0.2188	0.2336	0.2103
	Qinghai	0.1557	0.1482	0.1574	0.1507	0.1474	0.1462	0.1514	0.1330	0.1483	0.1504	0.1489
	Ningxia	0.1503	0.1424	0.1494	0.1492	0.1512	0.1479	0.1466	0.1539	0.1467	0.1530	0.1491
	Xinjiang	0.2131	0.2085	0.2156	0.2074	0.2134	0.2095	0.2073	0.2080	0.2116	0.2398	0.2134
	Gansu	**0.1914**	**0.1840**	**0.2008**	**0.2080**	**0.2180**	**0.2299**	**0.2424**	**0.2424**	**0.2372**	**0.2656**	**0.2220**
The whole region		0.1947	0.1890	0.1996	0.2023	0.2024	0.2081	0.2113	0.2194	0.2272	0.2421	0.2096

Comprehensive analysis the calculation results, in 2011, China's crop seed industry high-quality development index only four provinces of Jiangsu, Henan, Shandong and Heilongjiang reached more than 0.3, while in 2020, most of the provinces (municipalities) in the eastern region of the crop seed industry high-quality development index are more than 0.3; Crop seed industry high-quality development level of 0.19 or less provinces (municipalities and autonomous regions) from 2011, Tianjin, Shanxi, Shanghai, Fujian, Hainan, Chongqing, Guizhou, Qinghai, Ningxia 9 provinces (municipalities and autonomous regions) reduced to 2020, Tianjin, Shanghai, Hainan, Qinghai, Ningxia, Chongqing, 6 provinces (municipalities and autonomous regions), and is mainly located in the western region, indicating that the high-quality development level of the crop seed industry in China has been steadily rising overall, but the development of the western region is slower, basically in line with the ranking of the five dimensions of the high-quality development of the crop seed industry.

5.1.1. Time dimension analysis

From a temporal perspective, the comprehensive index of high-quality development of the crop seed industry in the four major regions of eastern, central, north-eastern, and western region exhibited continuous and steady growth from 2011 to 2020. Particularly, in 2020, the comprehensive index of Heilongjiang, Shandong, and Henan provinces surpassed 0.49, placing them at the forefront of the country and indicates that the crop seed industry of China has maintained a steady upward development trend. Overall, the comprehensive index value of the level of high-quality development of China's crop seed industry from 2011 to 2020 is predominately attributable to the contributions of innovation and sharing. Conversely, the extent to which greenness, coordination, and openness contribute to the high-quality development of the crop seed industry varies greatly according to the geographic and environmental conditions and the characteristics of economic development in different regions.

5.1.2. Spatial dimension analysis

From a spatial perspective, while the comprehensive index of the level of high-quality development in the crop seed industry is 0.2421 in the western region in 2020, the other three regions have achieved values exceeding 0.3. During the 10 years, the growth rates of the comprehensive index of high-quality development in the crop seed industry in the eastern, central, north-eastern, and western regions were 54.6%, 55.5%, 50.7%, and 24.3%, with average values of 0.2573, 0.2879, 0.2897, and 0.2096, respectively. These values indicated that the high-quality development of China's crop seed industry from 2011 to 2020 exhibited more pronounced regional development unbalanced characteristics. The results showed that the eastern, north-eastern, and central regions are performing well in terms of the level of the high-quality development of the crop seed industry, while the western region is developing more slowly due to the constraints of the farmland soil base, climate, and topographical conditions.

5.1.3. Analysis of the five dimensions of high-quality development

According to the five philosophies of high-quality development—innovative, coordinated, green, open, and shared—30 provinces were chosen (municipalities and autonomous regions) to compute numerical results for each dimension of high-quality development of crop seed industry: ① The dimension of innovation development presents a decreasing pattern as it progresses from the central to the eastern, north-eastern, and western regions. Innovation-driven development as the core driving force for the high-quality development of the crop seed industry is the key to maintaining long-term and sustainable progress, and the promotion of technological breakthroughs in breeding and the integration of germplasm resources protection in the western region is conducive to the enhancement of the high-quality development of the crop seed industry. ② The green development dimension indicates that the comprehensive index value for each region is relatively average. In 2020, except for Inner Mongolia, all other regions had values above 0.3, nearly double compared to 2011. Notably, the green sustainable development index in the western region increased rapidly from 0.0181 in 2011 to 0.0355 in 2020, demonstrating that the concept of ecological, green, and sustainable development is deeply rooted in people's hearts and has been well practiced. ③ The coordinated development dimension exhibits minimal difference across regions, with being high in the west and low in the east. The results showed that the value of the coordinated dimension was only second to innovation in the Western region, suggesting that it is also a key point for the high-quality development of the crop seed industry in the Western region. ④ In the dimension of opening-up and shared development, the central and north-eastern regions showed higher degree of openness than the western region. However, Gansu province in the western region demonstrated excellent crop seed industry development and strong innovation capacity.

The comprehensive index of the level of high-quality development in the western region is low in openness and sharing capacity across all five dimensions. However, from the growth rate of 38.77% during 2011–2020, it ranked second only to Sichuan and Guangxi. Furthermore, in the openness dimension, the eastern region performed the best, which corresponds to the fact that the regional economic development is more open in reality. Moreover, from the perspective of the 30 sample regions, the open development of the four provinces (municipalities), Beijing, Henan, Heilongjiang, and Sichuan, in the crop seed industry is relatively good.

In summary, the substantial growth in the high-quality development of the crop seed industry across all regions of China can be primarily attributed to innovation. According to the calculation results, the value of the innovation dimension in each region accounts for the heaviest share in the comprehensive index value of the high-quality development of the crop seed industry, with the value of the innovation dimension in Beijing, Hubei, Heilongjiang, Sichuan, and other places accounted for more than 50% of the value of the overall comprehensive index in each region.

5.2. Analysis of regional differences in the level of the high-quality development of the crop seed industry

Table 3 describes the regional differences and the evolution trend in the level of high-quality development of the crop seed industry in China. The decomposition of the Dagum Gini coefficient pertaining to the high-quality development of the crop seed industry across the four regions (eastern, central, north-eastern, and western regions) showed that there was an increasing trend in the relative differences regarding the level of high-quality development of China's crop seed industry during the 10 years from 2011 to 2020. The overall Dagum Gini coefficient increased by 55.3% from 0.132 to 0.205. The Dagum Gini coefficient in the four regions in the 10 years from 2011 to 2020 was on an upward trend. Specifically, the eastern region witnessed a very small increase of 33.33%, followed by the central region with 54.12%, the north-eastern region increased by 40.7%, and the western region showed the largest increase with 60.42%. These figures indicate that the differences in the development of the crop seed industry within the western region are progressively increasing each year, and the rate of increase is faster. As the level of high-quality development of the crop seed industry is affected by many factors, especially breeding technology level, breeding institutions, expertise of R&D staff, breeding R&D funds, and more, inter-regional imbalances exist between provinces (cities), showing obvious rising trend in inter- and intra-regional differences in the high-quality development of crop seed industry of China. The observed increase in variation in the high-quality development of the seed industry in the western region may be due to a combination of social and natural conditions, such as the unequal distribution of technological innovation resources, varying degrees of land resources abundance, and different gravitational effects of breeding R&D personnel across the region, resulting Dagum Gini coefficient has been in an upward trend and a larger increase across the region. Although the provinces (municipalities and autonomous regions) in eastern regions have relatively better conditions for seed industry R&D, driven by industrial comparative advantages, they continue to prioritize manufacturing, information technology industry, service industry, and other high-return industries. The Dagum Gini coefficient for the level of high-quality development of the crop seed industry within the eastern region also shows an increase due to the economic advantages of its location.

Table 3. Dagum and its decomposition of the crop seed industry's high-quality development level in China from 2011 to 2020.

Year	**Total**	**Intra-regional Gini coefficient**				**Inter-regional Gini coefficient**				**Contribution rate (%)**		
		East	**Centre**	**West**	**Northeast**	**East & West**	**Centre & West**	**East & Northeast**	**East &Centre**	**G_w**	**G_{nb}**	**G_t**
2011	0.132	0.168	0.085	0.096	0.086	0.145	0.124	0.149	0.146	26.54	33.48	39.99
2012	0.148	0.176	0.100	0.107	0.094	0.158	0.162	0.155	0.162	25.48	40.84	33.68
2013	0.148	0.182	0.089	0.105	0.099	0.164	0.146	0.160	0.155	25.77	38.78	35.46
2014	0.159	0.199	0.096	0.111	0.097	0.186	0.153	0.170	0.166	25.75	36.62	37.63
2015	0.169	0.203	0.100	0.115	0.109	0.198	0.167	0.177	0.169	25.15	40.36	34.50
2016	0.168	0.204	0.096	0.116	0.117	0.198	0.166	0.181	0.168	25.21	38.72	36.07
2017	0.184	0.216	0.111	0.129	0.121	0.214	0.199	0.186	0.182	24.91	43.12	31.97
2018	0.190	0.211	0.132	0.134	0.121	0.221	0.206	0.185	0.189	24.65	43.90	31.45
2019	0.199	0.214	0.126	0.148	0.143	0.229	0.221	0.203	0.184	24.33	45.23	30.44
2020	0.205	0.224	0.131	0.154	0.121	0.243	0.227	0.197	0.195	24.61	43.92	31.47
Average	0.170	0.200	0.107	0.122	0.111	0.196	0.177	0.176	0.172	25.24	40.50	34.27

During the study period, a higher mean value of the Dagum Gini coefficient of the high-quality development level of the crop seed industry is exhibited by the eastern region compared to the whole country. This is due to the fact that the eastern region includes developed and economically strong regions of Beijing, Tianjin, and Shanghai, in addition to the strong agricultural provinces such as Shandong and Jiangsu. The development of the seed industry is characterized by the greatest spatial imbalance within the region, as evidenced by the mean Dagum Gini coefficient of 0.2 during the study period, which is nearly double that of the central region. The mean values for the central, western, and north-eastern regions are comparatively lower than the overall level, indicating that the differences in the high-quality development of China's crop seed industry are primarily due to inter-regional differences. Notably, the Dagum Gini coefficient of the north-eastern region within the four regions was 0.143 in 2019 but decreased to 0.121 in 2020, representing a reduction of 15.38%. This showed the highest reduction among the four regions during the study period and suggests that continued promotion of differential reduction in intra-regional crop seed industry development plays an important role in achieving intra-regional equalization in the high-quality development of China's seed industry. The development differences in the Northeast region increased during the study period but were not as obvious as in the East, Central, and West. The differences within the East region were most pronounced, but it was the smallest increase during the study period, and the West region demonstrated a year-on-year increase. Reducing the level of high-quality development differentiation of the seed industry within the West region is the main task for the balanced development of the China seed industry in the future. The intra-regional differences in the central region were distinct in 2011–2018. There was a "U"—shaped change in the seed industry development differences in the last three years of the study period (2018, 2019, 2020), reflecting the slowing down of intra-regional differences in the seed industry development in the central region from 2018 to 2020. Based on the pivotal influence of the central region on national food security, it is imperative to optimize the improvement of the overall level of development of the crop seed industry in the future, which will assist in the high-quality development of China's seed industry and build a firm foundation for food security.

The difference between the eastern and western regions is the primary cause of the difference in the level of high-quality development of China's crop seed industry, as shown in **Table 3**. The mean value of the Dagum Gini coefficient was 0.196, which is significantly higher than the overall mean value of 0.170. The differences between regions showed an upward trend during the study period, with the difference between the central and western regions rising by 83.06%, the difference between the eastern and western regions increasing by 67.59% and that between the eastern and north-eastern regions and the eastern and central regions experienced comparatively modest increases of 32.21% and 33.56%, respectively, suggesting that from 2011 to 2020 the differences between regions with the western region are the main source of inter-regional differences.

The results of Dagum's Gini coefficient decomposition of the level of high-quality development of the crop seed industry revealed that the overall differences in it mainly originated from inter-regional differences, hypervariable density contribution, and intra-regional differences, in that order. The study period witnessed a decline in both the intra-regional variance contribution and the hypervariable density contribution, from 26.54% and 39.99% in 2011 to 24.61% and 31.47% in 2020, with the difference that the intra-regional variance contribution has been declining almost year by year, while the hypervariable density contribution has been a multi-segmented variation of decline and increase. From 2015 to 2020, the contribution of inter-regional variance was greater than the contribution of intra-regional variance and hypervariable density. The contribution of inter-regional variance increased by 10.44% over the 10 years, whereas in 2011, it contributed 6.51% less than hypervariable density. However, this trend shifted in 2012, and the variance value gradually increased after 2015. Inter-regional variation contribution was greater than the hypervariable density contribution of 12.45% in 2020. Overall, inter-regional differences can be the main cause of the overall difference, with the most significant increase occurring between the western and central regions during the study period.

5.3. Analysis of the spatio-temporal evolution of the level of high-quality development of the crop seed industry

Figures 2 and **3** display the dynamic evolution trend of the high-quality development of China's crop seed industry through the Kernel density estimation method and MATLAB software. **Figure 2** represents the spatio-temporal evolution of the overall high-quality development level of China's crop seed industry from 2011 to 2020. **Figure 3** represents the spatio-temporal evolution trend of the high-quality development of China's crop seed industry in four regions.

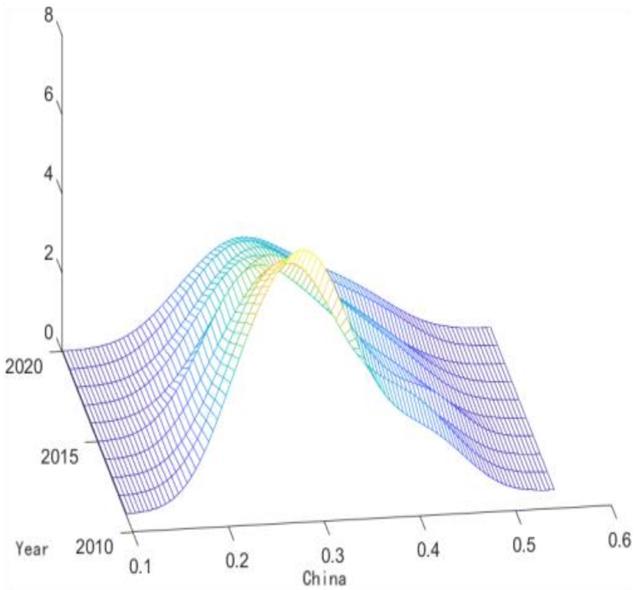

Figure 2. Spatio-temporal evolution of the high-quality development level of the crop seed industry in China.

As illustrated in **Figure 2**, there is a rightward shift in the center of the distribution curve and the range of changes in the level of high-quality development of China's crop seed industry over 2011–2020. This indicated that the high-quality development level of China's crop seed industry is constantly improving, consistent with the comprehensive index calculated using the entropy method in the previous section. From the distribution pattern, the height of the main peak shows a downward trend while the width continues to expand, indicating that the overall difference in the level of high-quality development of China's crop seed industry is expanding. The overall distribution curve shows a tendency to evolve from a "single peak" to a "main peak + side peaks," and the peak in 2020 is declining while the width continues to expand, indicating that the difference in the level of high-quality development of China's crop seed industry is being strengthened.

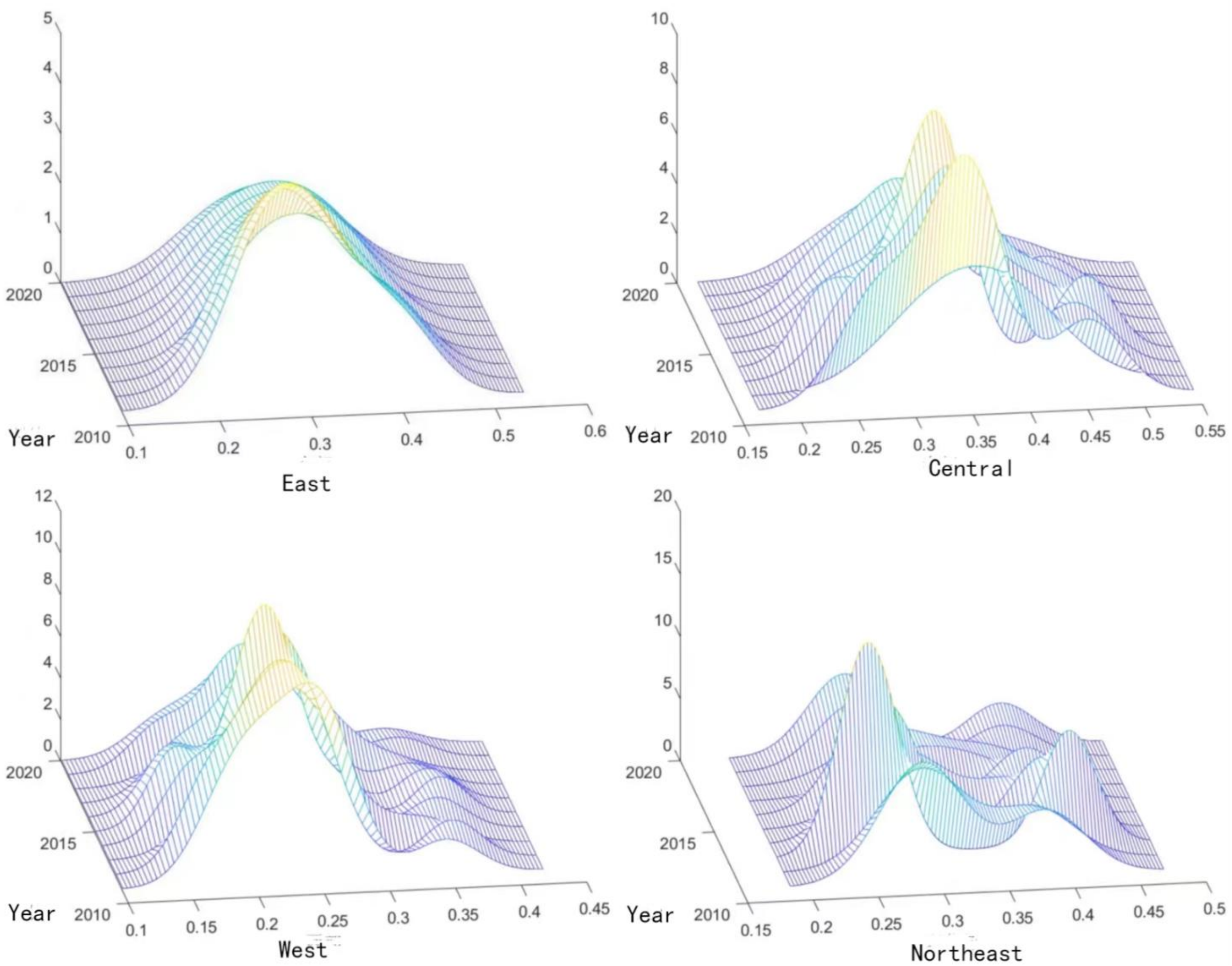

Figure 3. Spatio-temporal evolution of high-quality development level of the crop seed industry in four regions.

As indicated in **Figure 3** (from top to bottom and from left to right: East, Central, West, and Northeast), the dynamic evolution trend of the level of high-quality development of the crop seed industry in the four regions is observed to have a rightward shift in both the center of the curve and the interval of change of the Kernel density estimation. This implies that the high-quality level of development of the crop seed industry in the various regions is increasing. With regard to the distribution pattern, the performance of each region is different. The distribution pattern of the eastern region is similar to the overall pattern in that the width tends to increase, and the peak tends to decrease. This indicates that the degree of dispersion of high-quality development of the seed industry in the eastern region has increased. Nevertheless, the peak of the wave shows a "single-peak" pattern, which signifies that the level of high-quality development of the crop seed industry in the eastern region does not appear to be a polarized phenomenon. The distribution pattern in the west and northeast is opposite to the east. The distribution curve shows a trend from "single peak" to "main peak + side peaks", indicating that the level of high-quality development of the crop seed industry in the west and northeast did not have the polarization phenomenon in the early stage, but it occurred in the late stage. The width of the distribution curve in the eastern region tends to narrow. The distribution pattern shows a tendency for the height of the main peak to decrease and then increase and for the "main peak + side peaks" to evolve into a "single peak", which indicates that the extreme difference in the level of high-quality development of the crop seed industry in the eastern region has narrowed. The phenomenon of polarization has gradually disappeared.

5.4. Analysis of driving factors of the level of the crop seed industry's high-quality development

5.4.1. Model selection

According to the above-mentioned entropy method for measuring the level of high-quality development of China's crop seed industry, as well as the decomposition of Dagum's Gini coefficient and the estimation of Kernel density, it is evident that notable spatial differences exist in the level of high-quality development of China's crop seed industry. Furthermore, these differences tend to widen; consequently, to comprehensively promote the high-quality development of the crop seed industry, it is urgent to explore the driving factors. The following econometric model was constructed based on available panel data:

$$y_{it} = \alpha_k x_{it} + \alpha_0 + \theta_t + e_{it} \tag{18}$$

where the left side of the equation represents the dependent variable, which means the index of the level of high-quality development of the crop seed industry in year t in the i-th region. On the right side of the equation x_{it} denotes the explanatory variables, α_k denotes the coefficients of the influences (k = 1.2.3.4.5.6), and α_0, θ_t, e_{it} denotes the intercept term, the time effect, and the random disturbance term, respectively.

Based on prior research findings, the driving factors affecting the high-quality development of China's crop seed industry are multidimensional and exert different degrees of influence among the explanatory variables on the right side of the equation. ① Ji (2021) proposed that the degree of marketization is positively correlated with the business environment. Moreover, the improvement of the business environment contributes to the development of factors and factor supply within the crop seed industry. Consequently, an increase in the degree of marketization helps to improve the marketing environment of the crop seed industry and accelerate the flow of various resources and factors. The measurement of the degree of its marketization is determined by five factors, as outlined by Fan et al. (2003): government-market relationship, development of non-state economy, development of product market, development of factor market, development of market intermediary organizations and maintenance of a legal environment of the market. ② Collaborative innovation in the seed industry is inseparable from the protection of intellectual property rights and specialized division of labor, which requires the recognition and protection of intellectual property rights by all residents (Hu, 2021); furthermore, the high-quality development of the crop seed industry will inevitably require a large number of high-level talents. Therefore, while improving the education level of residents is conducive to the protection of intellectual property rights in seed breeding science and technology innovation, it also contributes to progress in seed production, seed enterprise management, marketing, and other domains. The education level of residents is measured by the number of people who have completed high school or above in each region/total local population. ③ Xu (2018) argued that the degree of industrial economy development is supported by the national fiscal policy, which provides an impetus for developing related industries. Meanwhile, Cui (2022) showed that developing seed industry needs the support of the country's strong policy. Therefore, the level of national financial assistance to agriculture reflects the national agricultural policy. The crop seed industry is a high capital input industry; consequently, its high-quality development can not be separated from the state's financial support, which is measured by the ratio of agricultural, forestry, and water financial expenditure to the local general public budget expenditure. ④ Liu (2020) proposed that the standardization and branding of agricultural products can help improve the overall competitiveness of agriculture. This reflects the excellent seed traits of agricultural products to a certain extent. The price of agricultural products can objectively reflect the returns of individual farmers and large-scale farms. Additionally, high agricultural product prices are conducive to stimulating agricultural production momentum, thereby indirectly promoting the high-quality development of the seed industry, which is measured by the growth rate of agricultural product prices in the text. ⑤ China promulgated the *Regulations for the Protection of New Varieties of Plants* in 1997 and acceded to the UPOV 1978 Convention in 1999. The number of applications for new varieties of plants signifies the capacity of agricultural technological innovation, so the number of applications for new varieties of plants in each province and city was selected to measure the capacity of scientific and technological innovation in the crop seed industry each year. ⑥ Wei (2018) proposed that the degree of infrastructure can directly or indirectly affect the development of various industries. The degree of correlation between breeding bases facilitates resource sharing, and good infrastructure improves the capacity of seed industry management services (Li, 2021). These findings are sufficient to reflect the importance of rural infrastructure construction for the high-quality development of the crop seed industry. The specific measurements are expressed by the density of the distribution of the road and railway network. Accelerating the construction of highways and railways between regions nationwide will improve the efficiency of the logistics transaction of the crop seed market.

In summary, six factors have been identified as explanatory variables for the driving factors of high-quality development of China's seed industry: (1) the level of marketization; (2) the level of culture and education of rural residents; (3) the level of state financial support; (4) the price index of agricultural products producer; (5) the ability of scientific and technological innovation; (6) the level of rural infrastructure construction.

5.4.2. Analysis of model results

We used STATA17 software and panel data from 30 provinces (municipalities and autonomous regions) from 2011 to 2020 as a sample to conduct regression analyses. First, the data were subjected to the unit root test, which yielded the *p*-value of each explanatory variable below 0.05, indicating smooth data. Subsequently, the correlation analysis was conducted, and the results revealed no statistically significant correlation between the variables. Finally, the model was subjected to Hausman's test, and the results indicated that the fixed effect model was better than the random effect model; thus, the fixed effects model was selected to explore the driving factors of the high-quality development level of the crop seed industry. As **Table 4** shows the regression results, the second column is the regression results of Pooled OLS, and the third column is the FE regression results.

Table 4. Sample regression results.

Variables	Pooled OLS	FE	GMM
Marketization level	0.0025 (0.0026)	0.0054 (0.0034)	−0.005** (1.719)
The cultural and educational level of the rural population	0.0951** (0.0421)	0.2631*** (0.0680)	0.087 (1.823)
National financial support level	0.2729** (0.1377)	−0.3151** (0.1463)	
Producer price index for agricultural products	−0.0085 (0.0602)	0.0319 (0.0359)	−0.028 (−0.477)
Science, technology, and innovation capacity	0.0354*** (0.0031)	0.0171*** (0.0031)	0.040** (9.592)
Rural Infrastructure Development Level	0.0379*** (0.0049)	0.0467*** (0.0152)	0.037** (8.089)
Constant term	−0.0192 (0.0332)	0.0479* (0.0258)	0.057** (3.175)
Sample size	300	300	300
Hausman test		25.69***	
Wald test			492.418***
Adj R-squared	0.6796	0.5424	0.672

Note: *, **, *** indicate $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively, with standard errors in parentheses.

Table 4 shows that the level of high-quality development of China's crop seed industry is affected by various factors. Among these factors, the level of culture and education, the level of national financial support, scientific and technological innovation capacity, and the level of infrastructure construction significantly correlate with the level of high-quality development of the seed industry. Still, the level of national financial support is the only factor negatively correlated with the high-quality development of the crop seed industry. Other factors, like the producer price index for agricultural products and the degree of marketization, show a positive correlation but are insignificant. The specific performance is as follows:

(1) The cultural and educational level of the rural population has a significant positive impact on the level of high-quality development of the crop seed industry. A 1% increase in the level of culture and education results in a 0.2631% increase in the level of high-quality development of the crop seed industry. The reason lies in the fact that the integration and development of the whole industrial chain of the seed industry, from the innovation of breeding technology and the implementation of new technology for seed production to the promotion of new crop varieties and the construction of high-standard farmland, are all closely related to the cultural and educational levels. Simultaneously, improving these levels will enhance the awareness of intellectual property protection in the seed industry, further consolidating the legal basis for revitalizing the seed industry and stimulating its innovation power.

(2) The level of national financial support is the only influence factor negatively correlated with the high-quality development of the crop seed industry. A 1% decrease in the level of financial support will increase the level of high-quality development of the seed industry by 0.3151%. The reason could be that while the financial expenditure on agriculture, forestry, and water in the 30 samples (provinces and municipalities)

during 2011–2020 shows a rising trend every year, the amount is still relatively small when compared to the annual rise rate of the total financial expenditure of the provinces (municipalities and autonomous regions).

(3) There is a significant positive effect of seed industry science and technology innovation capacity on the level of high-quality development of the crop seed industry. A 1% increase in this capacity promotes the crop seed industry's high-quality development level by 0.0171%. Based on the significant homogenization of scientific and technological innovation in China's crop seed industry, the seed industry enterprises are numerous, small, and scattered, the market competition is disorderly, and counterfeiting and imitation infringement,enhancing the level of innovation in the seed industry and strengthening the efficiency of innovation has become the key to improving the level of high-quality development of China's crop seed industry. Therefore, the high-quality development of the crop seed industry requires multidimensional innovation. This scientific and technological innovation refers to the level of breeding technology as well as to the level of storage, processing, and marketing

(4) The level of rural infrastructure development also positively and significantly affects the high-quality development of China's crop seed industry. A 1% increase in the level of infrastructure development will boost the level of high-quality development of the seed industry by 0.0467%. China's arable land area is estimated at 1,917.9 million mu（about 315.95 million acres). However, seed categories are rarely promoted on more than 10 million mu (about 1.65 million acres). There is also a lack of information exchange between areas of crop seed development. When highways, railways, and operational efficiency are strengthened, it will be necessary to strengthen the construction of rural feeder roads to enhance the development of inter-regional exchanges between the crop seed industry in the future.

(5) Although the agricultural producer price index has a positive effect, the degree of marketization and the level of high-quality development of the crop seed industry are insignificant. Thus, an increase in the agricultural producer price index positively affects the level of high-quality development of the seed industry, but the performance is insignificant. The market mechanism is the most effective way of resource allocation, and an increase in the degree of marketization will significantly improve industrial efficiency and promote the process of industrial modernization development. However, based on the multiplicity of influence factors of the marketization degree, the performance is not significant enough.

5.4.3. Analysis of robustness

To verify the robustness of the results, we first performed systematic GMM (Gaussian Mixture Model) estimation on the sample panel data selected to represent the driving factors in the study. The level of national financial support was used as a hypothetical instrumental variable for the analysis. The results were analyzed using STATA17, as shown by the coefficients displayed in the fourth column of data in the sample regression of **Table 4**. The level of financial support for agriculture, forestry, and water by the state and local governments varies according to the degree of economic development, and this value may increase or decrease to varying degrees for various reasons every year. However, scientific and technological innovation capacity and infrastructure development continue to have a significant positive impact on the high-quality development of the crop seed industry, indicating that the systematic GMM estimation results are the same as the fixed-effects (FE) regression results. The results of the GMM model have passed the Wald chi-square test, proving that the above results are steady and valid.

5.4.4. Analysis of regional differences

Table 5 displays regression analyses conducted for each of the four regions to examine regional differences in the driving factors of the level of the high-quality development of the crop seed industry. Among them, scientific and technological innovation capacity has a significant positive driving effect on the high-quality development of the crop seed industry in the four major regions, except for the Northeast region. The level of infrastructure construction also has a significant positive driving effect on the high-quality development of the crop seed industry. Sub-regionally, the high-quality development of the crop seed industry in the eastern region is also driven by the degree of marketization and the level of culture and education. The central region is driven more significantly by the level of national financial support, and the coefficient is larger. The level of culture and education is the only variable in the north-eastern region other than scientific and technological innovation capacity that has a positive driving effect on the high-quality development of the crop seed industry. The degree of marketization in the western region has a positive driving effect on the high-quality development of the crop seed industry, but the effect is not significant, reflecting the region's low degree of marketization. Therefore, to promote the high-quality development of the crop seed industry, China must address the urgent needs of different regions by implementing national policies, tailor-made and precise measures, and comprehensively promoting the revitalization of the seed industry.

Table 5. Four regional regression results.

Variables	East FE	Centre RE	North-east FE	West FE
Marketization level	0.0205*** (0.0077)	0.0075 (0.0066)	0.0118 (0.0087)	0.0006 (0.0025)
Cultural and educational level of the rural population	0.2502** (0.1120)	−0.1945 (0.1266)	0.8240** (0.2940)	−0.1229* (0.0650)
National financial support level	−0.2125 (0.4126)	1.0858* (0.6033)	0.0172 (0.3675)	−0.1563 (0.1190)
Producer price index for agricultural products	0.0378 (0.0777)	−0.0247 (0.1189)	0.1037 (0.0683)	−0.0053 (0.0328)
Science, technology, and innovation capacity	0.0145** (0.0063)	0.0347*** (0.0055)	0.0360*** (0.0124)	0.0100*** (0.0026)
Rural Infrastructure Development Level	0.1028** (0.0514)	0.0487*** (0.0136)	−0.2619* (0.1323)	0.0817*** (0.0123)
Constant term	−0.1731** (0.0735)	−0.1205 (0.0879)	0.2536* (0.1357)	0.0733*** (0.0188)
Sample size	100	60	30	110
Adj R-squared	0.6122	0.9163	0.9899	0.7070

Note: *, **, *** indicate $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively, with standard errors in parentheses.

6. Discussion and suggestions

6.1. Discussion

The above research indicates that the overall level of development of China’s crop seed industry is showing a steady upward trend, reflecting the preliminary results of China’s seed industry revitalization action plan. The differences among the four major regions are gradually increasing, due not only to differences in resource endowments for seed industry development in different regions, but also closely related to comparative advantages within each region. Innovation ability, cultural and educational level of rural residents, rural infrastructure construction, national financial support, and marketization level are the main factors driving the high-quality development of crop seed industry in 30 provinces (regions, cities) in China. Especially, innovation ability, as the first driving force for seed industry development, is consistent with the research views of previous scholars. However, due to the limitations of data acquisition, there are still deviations in the authenticity and comprehensiveness of its research evaluation and further research can be conducted in the future.

(1) Overall, the comprehensive index of high-quality development of the crop seed industry among Chinese provinces, in addition to Qinghai and Ningxia, demonstrates a sustained growth overall and a steady upward development trend in 2011–2020. The spatial distribution of the four regions based on the level of the high-quality development of the crop seed industry reveals a more obvious regional development imbalance, showing the pattern of central > northeast > east > west. Thus, the central region showed the fastest rate of improvement in the high-quality development of the national crop seed industry.

(2) The Dagum Gini coefficient for the high-quality development of China’s crop seed industry exhibited an upward trend during the study period, indicating that the overall spatial and regional differences in China’s crop seed industry have gradually increased from 2011 to 2020. The primary sources of these differences are among the four regions, with the contribution of differences between regions tending to increase, while the contribution of intra-regional differences and hyper-variable densities generally decreases. However, inter-regional differences mainly exist between the eastern and western regions and the central and western regions. The results of Kernel density estimation show that the level of high-quality development of the crop seed industry is increasing, with a strengthening degree of dispersion of the whole country and the east and a polarization trend towards the level of high-quality development of the crop seed industry in the west and northeast region.

(3) Factors such as innovation capacity, culture and education level, infrastructure development level, national financial support level, and marketization degree all have a driving effect on the level of high-quality development of China’s crop seed industry. There are regional differences in the influence of each factor on the high-quality development of the seed industry, among which the cultural and educational level has the largest influence coefficient.

6.2. Suggestions

6.2.1. Regional level: Promoting the key points

The crop seed industry is a special industry that provides the basic means of production for crop production. It is a strategic industry that affects national security, especially food security. As an important link and cornerstone of agricultural production, the crop seed industry is closely linked to agriculture, industry, and other sectors related to the national economy and public welfare. The sustainable development of China’s agriculture, especially the development of the grain industry, depends on revitalizing the crop seed industry. Currently, China needs to attach great importance to developing the seed industry based on a full understanding of the spatial and temporal characteristics and the regional differences in the high-quality development of the crop seed industry. The factors endowment conditions of each region combine the capital inputs, breeding technology innovation, germplasm resources information, and the conditions of the natural elements, which formulate an optimal allocation of resources with a focus on promoting high-quality development of the crop seed industry.

6.2.2. Industry level: Deepening market reforms

Innovation in breeding technology of the crop seed industry is essential for continuous seed improvement and replacement, breeding excellent varieties, and enhancing production efficiency. Additionally, we must strengthen the market-led reform of the seed industry, change the crop seed industry resources, talent, capital, and other elements to commercial breeding, and strengthen the basic research team building of germplasm resources. Simultaneously, we must establish a crop seed industry innovation system that closely integrates industry, academia, and research to complement market demand and place enterprises as the main body.

6.2.3. Policy level: Precision in policy-making

We should strengthen top-level design, continuously improve the level of seed management and seed development by the law, improving the market environment for seed industry development through financial and policy support, promote crop seed production, and the transformation and upgrading of the crop seed industry in all regions, and form a high-quality development situation that is green, innovative, coordinated, open and shared.

6.3. Limitations of the study

Ensuring food security is an eternal topic, and revitalizing the seed industry is strategically important to ensuring national food security. The implementation of a comprehensive and scientific seed policy is the key to achieving food security, while the formation of a market-oriented and efficient seed innovation system is imperative, based on the fact that the seed industry is a high-tech industry characterized by high-tech content, high value-added, and high capital investment. With the escalation of climate disruption and natural disasters, the importance of food security is growing. Skilfully addressing these challenges and ensuring national food security from the source has become indispensable to a country’s ability to respond to various contingencies. The current state of high-quality development in China’s crop seed industry is not adequately and equitably reflected in the scientific practice of all stakeholders regarding the seed industry. Consequently, the effort to build the overall evaluation index system for the high-quality development of China’s crop seed industry is hindered by data acquisition confusion, making the bias in accurately reflecting the current level of high-quality development of China’s crop seed industry and regional differences is inevitable. Despite attempts at systematic analyses using different methodologies, there are still limitations to the authenticity and comprehensiveness of the evaluations.

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