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Building Resilient Food Security Against Global Crisis: New Evidence From China

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ABSTRACT

The existing literature addresses the importance of food system disruptions and the risk of the global food crisis. However, there is insufficient understanding of response strategies and their effectiveness evaluations. This study offers a comprehensive introduction to China's food security policies and evaluates their effectiveness in enhancing the nation's risk resistance capability. Utilizing the Entropy Weight Method (EWM) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), we evaluated China's provincial food security resilience (FSR) from 2003 to 2020 and adopted the ArcGIS platform to map spatiotemporal trends. Our findings reveal significant improvements in FSR nationwide, with a notable average annual growth rate of 1%–5%. However, regional disparities persist, with higher resilience observed in eastern provinces compared to the west. The study emphasizes the effectiveness of China's food security policies, which have synergistically enhanced grain production, agricultural mechanization, and farmers' economic conditions. The article offers policy recommendations aimed at bolstering China's FSR and challenges with global implications. Our study contributes to the broader discourse on global food security by offering a nuanced understanding of the effectiveness of policy interventions in a major agricultural economy.

1 | Introduction

The United Nations prioritizes "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" as the second of its 2030 Sustainable Development Goals (UN 2015). This emphasizes the imperative for global society to address this critical issue, which is integral to the shared destiny of humanity. However, due to expanding world population and rising per capita income, global food supply is expected to face unprecedented challenges in the coming decades (Mc Carthy et al. 2018; Barrett 2021; Rahut et al. 2022). Furthermore, the limited arable land area (Chen 2007; Huang and Yang 2017) and environmental degradation (Huang and Rozelle 1995) set a ceiling for grain output. More unfortunately, political instability and climate change exacerbate the issue, resulting in hunger, inequality, and escalating global governance problems (Wheeler and Von Braun 2013; Deaton and Lipka 2015; Yang, Qin, and Tu 2015; Lu et al. 2019; Gunaratne, Radin Firdaus, and Rathnasooriya 2021). The "Hunger Map 2020" released by the United Nations World Food Programme highlights the regional concentration of food shortages in Africa, South Asia, and Latin America. If prevailing trends continue, the global population of individuals experiencing hunger is projected to reach 840 million by 2030 (World Food Programme 2020).

China is emerging as a pivotal country in stabilizing global food security. Remarkably, Chinese agriculture has managed to satisfy the food requirements of nearly 19% of the world's population, utilizing only 7% of the earth's arable land (Xue et al. 2021). In an era marked by advancing globalization, China's approach to addressing its food challenges increasingly influences geopolitics and global governance. Understanding China's efforts to ensure food security is not only crucial for the country's development but also offers valuable insights for other nations, especially emerging economies. Research on China's strategies to secure food security and resist supply shortage risks has mainly focused on the perspective of agricultural technology and farming system (Gregory and George 2011; Fan et al. 2012; Li, Clark et al. 2020; Liu et al. 2022; Jin and Zhong 2022; Luo et al. 2022). However, only a few scholars have emphasized the crucial role of food policy, particularly in the context of China's unique national conditions (Huang and Yang 2017). Existing literature suggests that China's food policies are purposeful and complementary, aiming to synergize for stronger domestic food security (Li, Wang, and Jia 2012; Mukhopadhyay, Thomassin, and Zhang 2018; Huang and Yang 2017). China's grain trade policies are unlikely to cause global food shortages and rising prices, supporting global food security (Hansen, Tuan, and Somwaru 2011). Huang et al. (2017) found that China's grain trade will not starve the world by observing China's grain imports and analyzing relevant policies, which provides evidence to answer Brown's (1996) question: Who will feed China? Solid governmental support for agriculture in China is critical for the country's self-sufficiency and contributes to global food security (Wong and Huang 2012; Zhao 2022), although some scholars criticize this "political priority" food security strategy that is opposed to international food trade (Clapp 2017). However, there are gaps in the literature. Lack of evaluation of the effectiveness of China's food security policies in the context of rising global risks, especially measuring and analyzing China's provincial food security resilience (FSR) (Ansah, Gardebroek, and Ihle 2019). The concept of resilience has been explored across various research fields, including ecology, urban studies, engineering, and interdisciplinary areas (Bullock et al. 2017; Ji and Wang 2023). This article specifically examines resilience within the context of food security, defining it as the capacity to sustain sufficient food production and ensure decent livelihoods for farmers amid chronic and acute environmental disturbances.

This article aims to (1) discuss and analyze global food security challenges and China's food policy and (2) investigate China's provincial FSR empirically. Based on China's provincial FSR data from 2003 to 2020, we adopted the Entropy Weight Method–Technique for Order of Preference by Similarity to Ideal Solution (EWM–TOPSIS) method to construct a multi-dimensional evaluation index system for FSR and analyzed the results using spatiotemporal data through the ArcGIS platform. Our findings not only contribute to academic discussions but also offer practical insights for policymakers in China and globally, as they seek to enhance food security strategies in increasingly volatile environments.

The rest of this article is organized as follows: Section 2 briefly introduces the research methods we adopted. In Section 3, the basic knowledge framework of the global food crisis and China's current major food policies is discussed. Then, in Section 4, we present the analysis step of FSR evaluation and specific data selection and sources. In Section 5, we apply the EWM–TOPSIS model to calculate China's provincial FSR and illustrate intuitively the results by applying ArcGIS. Finally, some conclusions and future work that are related to this study are discussed in Section 6.

2 | Research Methods

We applied a mixed-method approach to address the gaps. First, an integrated review method is applied to discuss and introduce food security challenges and China's major food policies; then, we adopted EWM–TOPSIS to evaluate provincial FSR and finally illustrated the results through geographic information spatial analysis technology. Specifically, we initially propose a Snowball method to review the global crisis and China's response, especially focusing on the food policies that the Chinese government introduced. The EWM–TOPSIS model applied in this article is extensively applied in interdisciplinary research fields, such as transportation (Zhang and Ng 2021) and urban planning (Ji and Wang 2023). The EWM was initially proposed by Shannon and Weaver in 1947 and was further developed by Zeleny in 1982, as noted by Kumar et al. (2021). Compared with subjective weighting tools such as the analytic hierarchy process and the Delphi method, EWM determines the weight according to the degree of change in the original data, thereby providing a more objective weighting of indicators. The TOPSIS was initially introduced by Hwang and Yoon in 1981, with subsequent improvements made by Yoon and Hwang in 1987 and 1993, respectively. TOPSIS is a common approach for solving multiobjective decision-making problems using the ideal method (Zhang and Ng 2021). Furthermore, EWM offers significant advantages over the average weighting method (equal weights for each index) used in TOPSIS. The research findings will be visually displayed and interpreted using the ArcGIS platform. Developed by the Environmental Systems Research Institute, ArcGIS is a multifunctional tool for visualizing and analyzing geographic data (Scott and Janikas 2009). One of its frequent uses includes showing regional data derived from evaluative studies (Wang et al. 2021; Li, Zhao, and Kong 2022; Li et al. 2024).

3 | Food Security Challenges and China's Response Strategies

3.1 | Global Food Crisis and China's Situation

Global crises are continuously challenging the threshold of food security, further straining the already inadequate resources (Su et al. 2023). The COVID-19 pandemic represents the most prolonged, widespread, and impactful health crisis on human society since the 21st century, and its associated risks continue to persist to this day (El-Sadr, Vasan, and El-Mohandes 2023). The pandemic's negative impact on food security is multifaceted, manifesting in reduced food accessibility due to economic recession, instability in agricultural production, disruptions in supply chains, and restrictions on food trade (Laborde et al. 2020; Okolie and Ogundeji 2022). Official United Nations data indicate that in 2020, COVID-19 left nearly 2.4 billion people worldwide without the ability to access sufficient food (UNICEF 2021). Additionally, human-induced factors potentially interrupt progress toward a hunger-free world. The ongoing war in Ukraine has directly impacted the food supplies and prices in regions such as the Middle

East and North Africa (MENA) and sub-Saharan Africa, which are heavily dependent on imports of Russian and Ukrainian wheat (Glauben et al. 2022; Leal Filho et al. 2023). Since the end of 2021, the prices of commodities like grain and vegetable oil have soared to new heights, surpassing even the levels observed during the 2007 global food crisis (Glauben et al. 2022). Given that local food production and exportation are constrained, combined with both Ukraine and Russia playing vital roles in the global agricultural trade system, this negative effect is likely to continue spreading, further endangering global food security (Bhadra, Gul, and Choi 2023). Unable to obtain sufficient food from the land, people have turned their attention to the ocean, which has led to significant growth in global capture fisheries and aquaculture production in recent decades (Zhang, Chen et al. 2023). However, Japan's move to release wastewater from the Fukushima nuclear power plant into the ocean in 2023 may limit this expansion of food sources. Even though the Japanese government promised that this treated wastewater has little impact on health, more doubts, and temporary bans, especially from neighboring governments and consumers, continue to be raised and imposed (Lu et al. 2021; Pu, Jiang, and Fan 2022; Xu et al. 2023). This situation will seriously affect the seafood trading market (Wang et al. 2022) and subsequently hit the global food supply. The above global crisis uncovers the complexity of technical, institutional, biophysical, economic, social, and political factors affecting food supply, accessibility, quality, and sustainability in situation emergencies invariably lead to unpredictable consequences for the already fragile global food security system. Consequently, ensuring food security remains a critical issue in global governance. In this context, China is advancing its food resilience strategy to address these challenges.

The Chinese government has consistently prioritized ensuring food security and enhancing its food risk resistance capability as their important political task. On one hand, as one of the most populous countries in the world, China's ability to secure sufficient food for its people has significant implications for global food security. On the other hand, China's unique political and cultural context promotes authorities to guarantee food supplies. The food policy-led risk management model currently in place has been successfully implemented, yielding notable results. According to data from the World Food Programme, China's hunger index is categorized as a "blue zone," similar to that of European and American countries, signifying a very low prevalence of undernourishment among the general population (World Food Programme 2020). Furthermore, the Chinese government, in its latest "Food Security in China" white paper released in October 2019, declared that China's food supply is stable, and self-sufficiency is largely guaranteed (State Council Information Office 2019). Although China has achieved success in food self-sufficiency in the past, this does not necessarily indicate immunity to future food insecurity as the demand for crops for nonfood purposes is increasing significantly, posing new challenges to the country's food supply (Ghose 2014).

3.2 | China's Major Food Policies Since the Millennium

The evolution of food policy in the People's Republic of China was marked by a vital shift with the onset of economic reforms in 1978. Initially, under a centrally planned economy, the "Unified Purchase and Sale" policy requested that Chinese peasants sell fixed grain quantities to the state at government-guided prices (Oi 1986; Knight 1995). This policy was crucial for redirecting resources from agriculture to industry, supporting urban sustenance and national savings, which facilitated heavy industrialization but placed significant strain on peasants (Chen 1995; Oi 1999; Tuan, Zhong, and Ke 2004; Lin and Yu 2008). Post-1978 reforms introduced market-oriented attempts (Findlay and Chen 2001), reflecting a broader, more multifaceted approach to food policy. This new phase included the implementation of policies like the Crops' Minimum Purchase Prices (CMPP), Complete Abolition of the Agricultural Tax, and Direct Grain Subsidy, aimed at boosting grain production and supporting agricultural advancement through market mechanisms.

3.2.1 | Crops' Minimum Purchase Prices

Since 2000, declining grain prices in China have reduced farmers' incomes and led to decreased sown areas, raising concerns about food security (Zhan et al. 2012). In response, China implemented the CMPP in 2004 for rice and in 2006 for wheat (Yu, Elleby, and Zobbe 2015; Huang and Yang 2017), aiming to stabilize food production and increase agricultural earnings. The "Harvest Paradox" or "Paradox of Plenty" (Dauvin and Guerreiro 2017) highlights how higher production does not always lead to greater income due to inelastic food demand. Price controls like CMPP, while boosting farmer income and stabilizing grain supply, also introduce inefficiencies and reduce economic welfare by creating deadweight losses, particularly affecting producer surplus (Finley, Holt, and Snow 2019; Zhang, Hueng, and Lemke 2023). Li, Liu, and Song (2020) argue that these controls result in surplus grain and financial strain, necessitating significant state purchases at noncompetitive prices.

3.2.2 | Complete Abolition of the Agricultural Tax

Before China's economic reforms in 1978, its urban economy and industry were underdeveloped, with capital accumulation largely derived from suppressing food prices and taxing agriculture (Yao 2000). Unlike Western methods of external accumulation, China relied on internal sources. Post-reform, China's economy surged, diminishing agriculture's GDP contribution, and reducing its economic role (Day and Schneider 2018; Zhang and Diao 2020). In 2005, China ended the millennia-old "royal grain" tax (Wang and Shen 2014), boosting farmers' disposable income by reducing their financial burdens by over 145 billion yuan (Wang 2019) and encouraging agricultural productivity improvements through modernized practices (Yu and Jensen 2010). The abolition of the agricultural tax also improved farmland mobility, fostering large-scale farming, and encouraging farmers to work in cities (Geoghegan, Kinsella, and O'Donoghue 2017; Wang and Zhang 2017; Zhang et al. 2022). This shift was intended as a secondary distribution of national wealth to narrow urban–rural income gaps. However, the tax reform had drawbacks, including heightened fiscal pressures on local governments, as agricultural taxes previously contributed significantly to local revenues (Takeuchi 2013; Mao and Cao 2021). This loss exacerbated public service challenges (Kennedy 2007) and led to increased reliance on industrial tax enforcement and informal fees (Liu 2018), which sometimes traded environmental health for fiscal gains (Kong and Zhu 2022). Additionally, official reports from China's Ministry of Agriculture and Rural Affairs and the Hunan Provincial Bureau of Statistics indicate that the benefits of agricultural tax reductions for farmers are partially offset by the rising costs of agricultural inputs, including fertilizers (China MoA 2005; Hunan Statistics 2005). Figure 1 illustrates the dynamic trends of China's Price Index of Agricultural Means of Production (AMPI) and its sub-index—price index for chemical fertilizers from 2001 to 2008. The data indicate a significant increase in the prices of agricultural inputs during the period of Chinese agricultural tax reform. Changes in China's major grain prices and planting income from 2000 to 2020 are shown in Table 1.

3.2.3 | Direct Grain Subsidy

China's shift from taxing to subsidizing agriculture marks a significant evolution in its agricultural policy (Gale, Lohmar, and Tuan 2005). Since 2004, the subsidies have included direct grain subsidies, comprehensive subsidies for agricultural materials, subsidies for improved seeds, and subsidies for the purchase of agricultural machinery (Niu et al. 2022). In 2016, these were integrated into the Agricultural Support and Protection Subsidy to simplify and enhance the efficiency of support (Chen, Zhang, and Mishra 2023). The direct grain subsidies (DGS), aimed at mitigating the impact of price volatility on farmers, are paid based on the area cultivated with grain (Wang 2011; Yu, Elleby, and Zobbe 2015). Figure 2 illustrates agricultural producer support expenditures by the Chinese government from 2000 to 2022. Notably, since 2012, annual fiscal allocations have consistently exceeded 170 billion US dollars, as reported by the OECD (2023).

However, in open economies, China's DGS has led to accusations from other countries of market distortion and noncompliance with World Trade Organization agreements (Anderson and Strutt 2014). The implementation of DGS is analyzed using the prisoner's dilemma framework, illustrating the strategic choices between the government and farmers concerning subsidies and production levels (see Chen 2023). The results suggest that without sufficient incentives, the current subsidy strategy might lead to reduced grain production, contrary to policy goals. Other challenges with the current subsidy model include inadequate levels to stimulate substantial agricultural engagement, lack of differentiation in subsidy rates, which does not favor large-scale farming, and the issue of subsidies benefiting landowners rather than the actual cultivators (Huang, Guo, and Wu 2019; Chen and Zhao 2019; Qian 2023).

4 | Evaluation of China's Provincial Food Security Resilience

This study evaluates three policy initiatives, which began in the early 21st century, reflecting the Chinese government's dedication to developing a comprehensive food security system. These policies target four primary goals: increasing grain production, improving peasants' economic status, expanding the scale of grain cultivation, and enhancing the rate of agricultural mechanization (Huang and Yang 2017). These objectives generally align with the four dimensions of food security as outlined by the Food and Agriculture Organization: food availability, accessibility, utilization, and stability (FAO 2008). This section integrates the food security goals and resilience concept to construct an evaluation index system.

4.1 | Indicator System and Data Sources

Based on the previously mentioned primary dimensions for advancing food security and insights from existing literature, and considering the rationality, representativeness, and data availability, we developed China's provincial FSR evaluation index system. Inspired by Kang et al. (2017), Zhan et al. (2020) and Liu et al. (2023), this system primarily comprises four evaluation dimensions: grain production, grain sown area, agricultural output value, and agricultural production conditions, along with 11

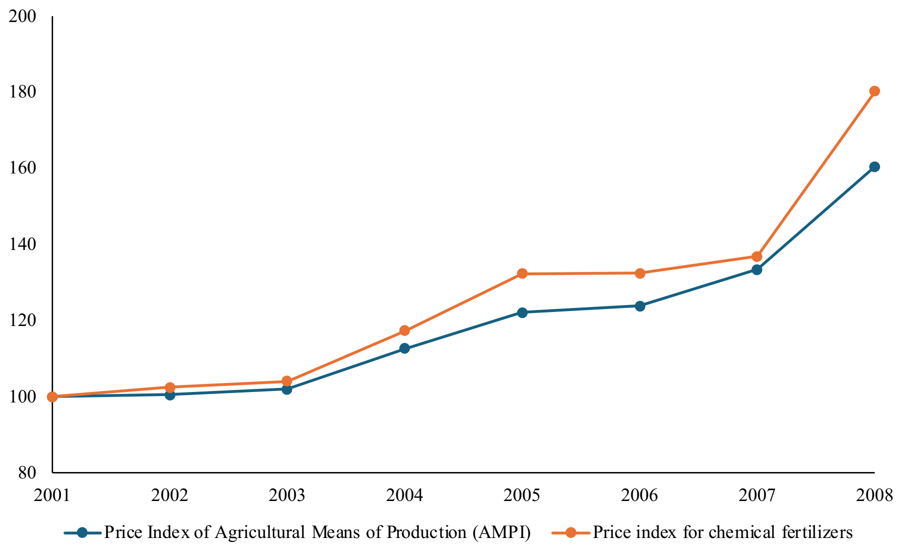

FIGURE 1 | 2001–2008 Price index of agricultural means of production (price based on 2001); data are from the National Bureau of Statistics of China (2023).

TABLE 1 | Changes in grain prices and planting income in China from 2000 to 2020 (CNY in current price); data are from the State Administration of Grain and Material Reserves (2022).

	Rice		Wheat	
Year	**Market price per 50 kg**	**Net profit per hectare**	**Market price per 50 kg**	**Net profit per hectare**
2000	51.7	751.5	52.9	−432
2001	53.7	1221	52.5	−412.5
2002	51.4	564	51.3	−790.5
2003	60.1	1423.5	56.4	−454.5
2004	79.8	4276.5	74.5	2544
2005	77.7	2890.5	69	1191
2006	80.6	3036	71.6	1765.5
2007	85.2	3436.5	75.6	1879.5
2008	95.1	3534	82.8	2467.5
2009	99.1	3264	92.4	1882.5
2010	118	4647	99	1983
2011	134.5	5569.5	104	1768.5
2012	138.1	4285.5	108.3	319.5
2013	136.5	2322	117.8	−192
2014	140.6	3072	120.6	1317
2015	138	2631	116.4	261
2016	136.8	2130	111.6	−1233
2017	137.9	1989	116.6	91.5
2018	129.4	988.5	112.2	−2391
2019	127.2	306	112.3	226.5
2020	137.5	730.5	114.2	−249

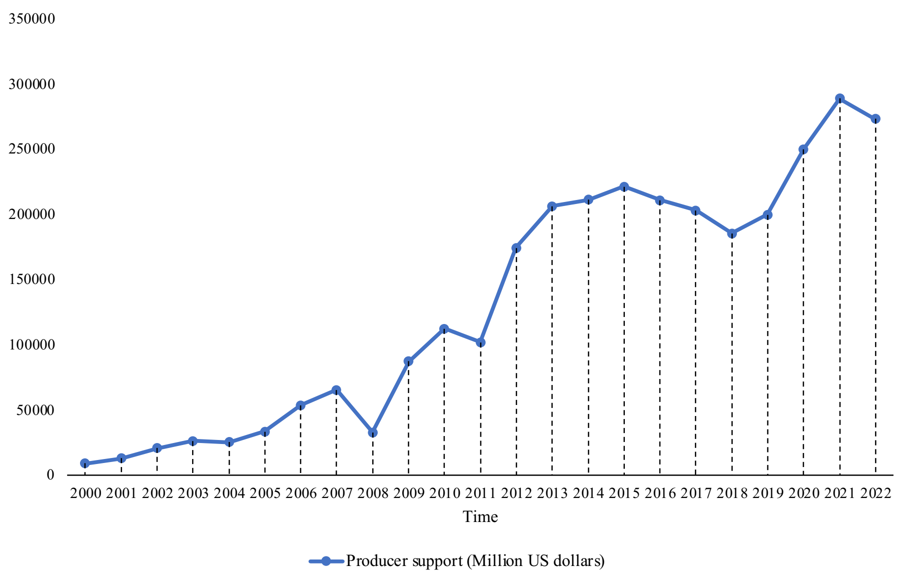

FIGURE 2 | 2000–2022 China's producer support (million US dollars); data are from the OECD database (2023).

TABLE 2 | China's Provincial Food Security Resilience (FSR) Evaluation Index system.

Target layer	Criteria layer	Weights	Indicator layer	Weights
China's provincial FSR	Grain production	0.3759	Total rice production	0.1166
			Total wheat production	0.2130
			Per capita grain occupation	0.0463
	Grain sown area	0.3084	Rice sown area	0.1197
			Wheat sown area	0.1732
			Proportion of grain sown area	0.0155
	Agricultural output value	0.1277	Gross agricultural output value	0.0675
			Per capita disposable income of farmers	0.0602
	Agricultural production conditions	0.1880	Agricultural mechanization	0.0717
			Effective irrigated area	0.0592
			Fertilizer application	0.0571

specific indicators, such as total rice production, the proportion of grain sown area, per capita disposable income of farmers, as well as agricultural mechanization. It is noted that due to the natural environment and living habits, Hainan province and Qinghai province hardly grow wheat, so their data were excluded from the sample. Refer to Table 2 for detailed information.

The Chinese administrative divisions, base maps, and other vector spatial data involved in the study were obtained from the standard map service website of the National Bureau of Surveying, Mapping and Geographic Information. The primary data source for the above indicators is the "China Agricultural Statistical Yearbook," spanning multiple years. In instances where data are missing, supplementation can be achieved through querying the National Bureau of Statistics of China database, provincial agricultural data, and other publicly available data sources.

4.2 | Weighting and Evaluation Methods

Step 1. Suppose there are M evaluation objects: $M = (M_1, M_2, \ldots, M_m)$, and each evaluation object has N evaluation indicators: $N = (N_1, N_2, \ldots, N_n)$, then the matrix $X = \{x_{ij}\}_{m\times n}(i = 1, 2, \cdots, m; j = 1, 2, \cdots, n)$ can be established:

$$X = X_{ij_{m\times n}} = \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{m1} & x_{m1} & \ldots & x_{mn} \end{bmatrix} \quad (1)$$

Step 2. Due to the different meanings, units, and orders of magnitude of each indicator, the indicators cannot be directly calculated. Therefore, to standardize the original data:

$$\text{For positive indicators:} x'_{\mathrm{ij}} = \frac{x_{\mathrm{ij}} - \min(x_{\mathrm{j}})}{\max(x_{\mathrm{j}}) - \min(x_{\mathrm{j}})} + 0.0001 \quad (2)$$

$$\text{For negative indicators:} x'_{\mathrm{ij}} = \frac{\max(x_{\mathrm{j}}) - x_{\mathrm{ij}}}{\max(x_{\mathrm{j}}) - \min(x_{\mathrm{j}}) +} + 0.0001 \quad (3)$$

where x_{ij} is the original data, and x'_{ij} is the standardized data, $\max(x_{\mathrm{j}})$ and $\min(x_{\mathrm{j}})$ represent the maximum and minimum values of the indicator j, respectively. From this, the matrix after data normalization can be obtained: $R = \{r_{\mathrm{ij}}\}_{\mathrm{m\times n}}$. All indicators in this study are positive indicators.

Step 3. Calculate the characteristic proportion of each indicator in each evaluation object:

$$Y_{ij} = \frac{x_{\mathrm{ij}}'}{\sum_{i=1}^{m} x_{\mathrm{ij}}'} \quad (4)$$

Then get the characteristic proportion matrix: $Y = \{Y_{\mathrm{ij}}\}_{\mathrm{m\times n}}$.

Step 4. Calculate the entropy value of the evaluation indicators:

$$e_j = -K \sum_{i=1}^{m} Y_{ij} \ln(Y_{ij}) \quad (5)$$

where $K = \frac{1}{\ln m}$, m is the number of evaluation objects, and $0 \le e \le 1$.

Step 5. Calculate the coefficient of variation (CV) of the evaluation indicators d_j:

$$d_j = 1 - e_j \quad (6)$$

Step 6. Determine the entropy weight of the evaluation indicators w_j:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (7)$$

According to the calculations above from (1) to (7), the weight of each indicator can be obtained, see Table 2. The following (8) to (13) are the specific calculation methods of TOPSIS.

Step 7. Combining the entropy weight w_j to construct the evaluation matrix Z:

$$Z = Z_{ij_{m\times n}} = \begin{bmatrix} w_1x'_{11} & w_2x'_{12} & \dots & w_nx'_{1n} \\ w_1x'_{21} & w_2x'_{22} & \dots & w_nx'_{2n} \\ \dots & \dots & \dots & \dots \\ w_1x'_{m1} & w_2x'_{m2} & \dots & w_nx'_{mn} \end{bmatrix} \tag{8}$$

Step 8. Determine the ideal solution. Let Z^+ be the most preferred option (positive ideal solution), and Z^- be the least preferred option (negative ideal solution):

$$Z^+ = \left(\max Z_{i1} \quad \max Z_{i2} \quad \dots \max Z_{in}\right) \tag{9}$$

$$Z^- = \left(\min Z_{i1} \quad \min Z_{i2} \quad \dots \min Z_{in}\right) \tag{10}$$

Step 9. Calculate the distance between the evaluation objects and the positive ideal solution and the negative ideal solution, respectively:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(Z_{ij} - Z_j^+\right)^2} \tag{11}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(Z_{ij} - Z_j^-\right)^2} \tag{12}$$

Step 10. Calculate the closeness of the evaluation object to the positive ideal solution:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{13}$$

The value range of closeness is 0–1. China's provincial FSR can be judged according to the ranking of closeness values over the years.

5 | Spatial and Temporal Evolutionary Characteristics of the FSR

Utilizing the EWM–TOPSIS method, we acquired FSR data for each province in mainland China from 2003 to 2020. This section follows the approach outlined by Li, Zhao, and Kong (2022) and employs both temporal and spatial perspectives for observation through the software ArcGIS. The findings are presented as follows.

5.1 | Analysis of Temporal Evolution Characteristics

This part employs a time series approach to analyze the results. Our primary methods include visualizing overall-level data, internal variation coefficients, and the kernel density estimation curve. It is important to note the following: (1) Due to space limitations, this article focuses on four representative years (benchmarks): 2003, 2009, 2015, and 2020; (2) In addition to assessing the FSR of individual provinces, we will also interpret the data for China's major economic regions based on the classification provided by the National Bureau of Statistics of China. This includes China's eastern coastal areas, northeastern region, middle region, and western region.

By combining the data from Figure 3 and Table 3, it is evident that the nationwide FSR, as well as its four major economic regions and provinces, has been consistently improving. This trend maintains over the sample period despite occasional fluctuations observed in individual samples. The national average FSR witnessed a stable increase, rising from 0.164 in 2003 to 0.238 in 2020, and its trends and values align with those illustrated in the eastern coastal areas. Notably, the average FSR in middle China has consistently outperformed other regions, advancing from 0.274 in 2003 to 0.378 in 2020. Conversely, western China exhibited a relatively modest improvement in FSR and remains at the lower end in terms of absolute values. In 2020, Henan and Shandong provinces led the rankings with FSRs of 0.667 and 0.529, respectively, highlighting their crucial role in bolstering China's food security. Contrary to expectations, the overall performance of Northeast China, known for its favorable natural conditions and a strong foundation in agricultural mechanization, was underwhelming. Traditionally considered China's "big granary," the region exhibited a slower rate of improvement in FSR, particularly in provinces other than Heilongjiang. This finding may suggest a divergence between the region's agricultural potential and its actual contributions to China's food security.

Figure 4 shows the average annual growth rate of FSR in each province of mainland China from 2003 to 2020. Notably, Beijing, Shanghai, Tianjin, and Heilongjiang have experienced an average annual growth rate exceeding 5%. This significant increase might be attributed to lower starting value and advancing agricultural technology. In contrast, the majority of provinces illustrate an average annual FSR growth rate ranging between 1% and 5%. The FSR in Guangdong, Guangxi, Sichuan, and Gansu has shown a relatively slight improvement. For Guangdong, Guangxi, and Sichuan, this modest growth could potentially be ascribed to a higher basement, limiting the scope for further significant increases. The case of Gansu, however, may involve different factors. Specifically, the FSR value of Gansu province increased from 0.101 in 2003 to 0.112 in 2020, a growth of less than 10%. The limited increase in Gansu's FSR can be attributed to its arid climate, complex terrain, and relatively underdeveloped overall economic conditions. For instance, low precipitation results in a mainly semi-arid climate in Gansu province (An et al. 2020). The scarcity of water resources adversely affects the efficiency of irrigation and the stability of grain yields (Kang et al. 2017). Additionally, the region's complex terrain, characterized by mountains, plateaus, and deserts (Fang et al. 2023), poses challenges to the development of large-scale mechanized agriculture. Furthermore, the economic conditions in Gansu are relatively weak, with farmers' incomes remaining low and showing slow growth. According to data from the China Statistical Yearbook (2023) and the Gansu

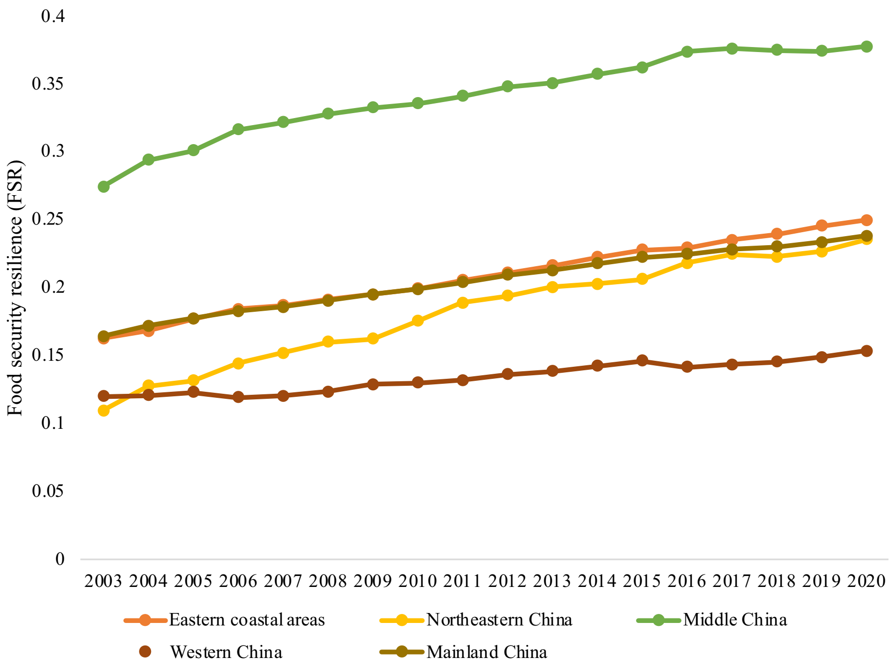

FIGURE 3 | China's regional FSR from 2003 to 2020.

TABLE 3 | Evaluation results of China's provincial FSR in 2003, 2009, 2015, and 2020.

Province/Region	2003	2009	2015	2020	Province/Region	2003	2009	2015	2020
Beijing	0.023	0.056	0.091	0.129	Hunan	0.304	0.351	0.368	0.370
Tianjin	0.025	0.046	0.087	0.118	Guangdong	0.202	0.197	0.212	0.226
Hebei	0.288	0.331	0.362	0.349	Guangxi	0.212	0.205	0.213	0.212
Shanxi	0.090	0.097	0.114	0.110	Chongqing	0.094	0.091	0.102	0.118
Inner Mongolia	0.087	0.121	0.147	0.167	Sichuan	0.267	0.276	0.291	0.279
Liaoning	0.082	0.105	0.124	0.134	Guizhou	0.093	0.091	0.109	0.127
Jilin	0.092	0.116	0.152	0.170	Yunnan	0.132	0.134	0.159	0.155
Heilongjiang	0.155	0.266	0.342	0.401	Tibet	0.037	0.033	0.046	0.069
Shanghai	0.029	0.057	0.103	0.149	Shaanxi	0.133	0.134	0.154	0.160
Jiangsu	0.295	0.380	0.425	0.453	Gansu	0.101	0.106	0.111	0.112
Zhejiang	0.116	0.124	0.144	0.167	Ningxia	0.048	0.048	0.057	0.072
Anhui	0.292	0.385	0.431	0.489	Xinjiang	0.115	0.175	0.217	0.215
Fujian	0.102	0.101	0.117	0.127	Eastern coastal areas	0.163	0.195	0.228	0.250
Jiangxi	0.234	0.289	0.300	0.310	Northeastern China	0.109	0.162	0.206	0.235
Shandong	0.385	0.461	0.510	0.529	Middle China	0.274	0.332	0.362	0.378
Henan	0.509	0.603	0.650	0.667	Western China	0.120	0.129	0.146	0.153
Hubei	0.217	0.269	0.310	0.320	Mainland China	0.164	0.195	0.222	0.238

Development Yearbook (2021), the per capita disposable income of farmers in Gansu has consistently been below the national average from 2003 to 2020 (Gansu Statistics 2021; China Statistics 2023). These adverse factors constrain the region's potential for enhancing FSR.

Figure 5 presents the internal variation change results, including each economic region and the nation as a whole. The CV refers to a normalized metric for comparing the dispersion across different data sets. A higher CV value indicates a greater dispersion in the data distribution and is mathematically defined as the ratio of

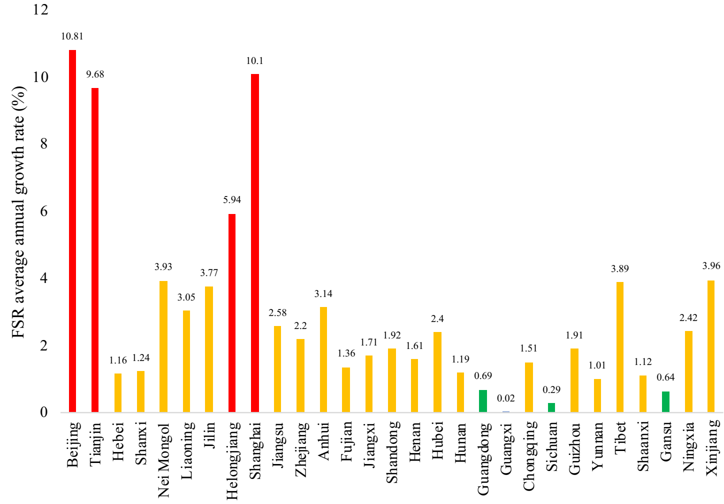

FIGURE 4 | The average annual growth rate of China's provincial FSR.

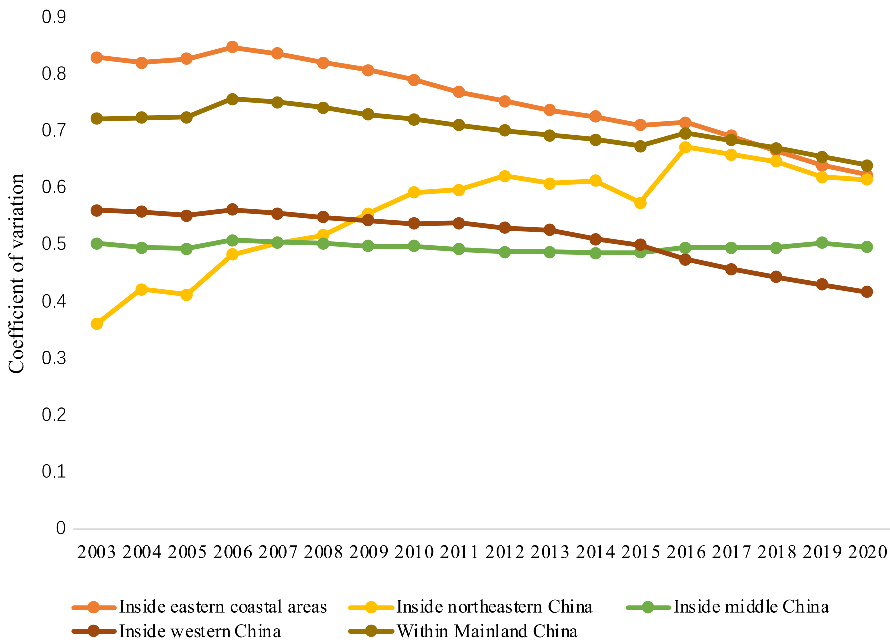

FIGURE 5 | Coefficient of variation of China's regional FSR from 2003 to 2020.

the standard deviation to the mean. In this e, the FSR in the national context, the eastern coastal areas, and the western region demonstrate greater balanced development over time, with the dispersion trend in the middle China remaining relatively constant at a 0.5 level. In contrast, the CV in northeastern China has exhibited an increasing trend, peaking at 0.673 in 2016. This suggests an intensification of disparities in FSR among its provinces, evidencing the previous finding regarding the northeastern region's contribution to China's food security. Notably, the CV curve for northeastern China displays an "M-shaped" trend, with a sharp decline in 2015. This drop may correlate with the significant developmental challenges faced by the region in that year.

Figure 6 showcases a kernel density estimation curve based on the data in Table 3, employed to analyze the changes in distribution shape, peak location, and extensibility of China's FSR, as well as to introduce the temporal evolution pattern of FSR. The figure reveals a general trend of the data distribution shifting rightward, signifying an improvement in China's food security situation. Moreover, with time, the kernel density curve broadens, indicating that while the overall level of food security has enhanced, the disparities between provinces have concurrently increased. In summary, although China's food security shows progressive improvement over time, the widening distribution of the curve highlights that this advancement is not uniformly distributed across all observed regions.

5.2 | Analysis of Spatial Evolution Characteristics

This part employs spatial visualization techniques based on the ArcGIS platform to interpret China's FSR evaluation data. The

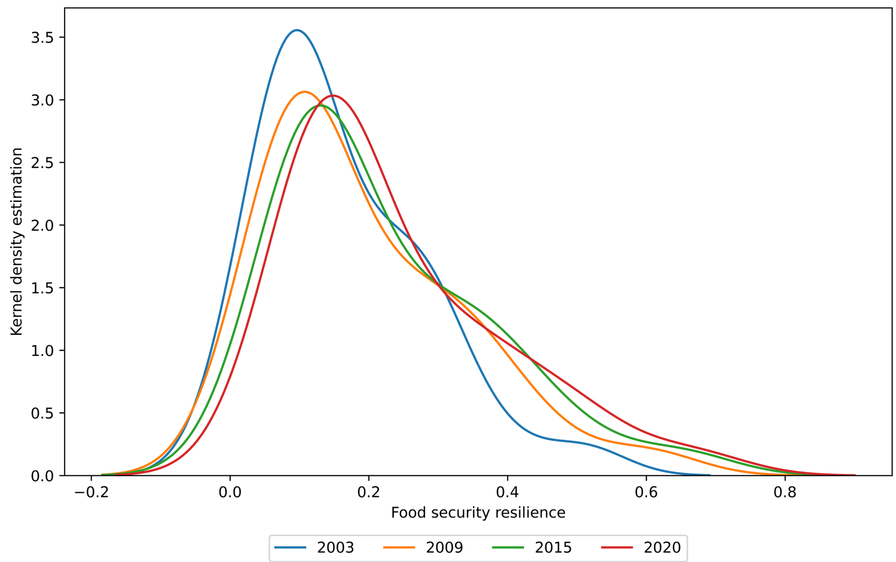

FIGURE 6 | Kernel density estimation curve of FSR in 2003, 2009, 2015, and 2020.

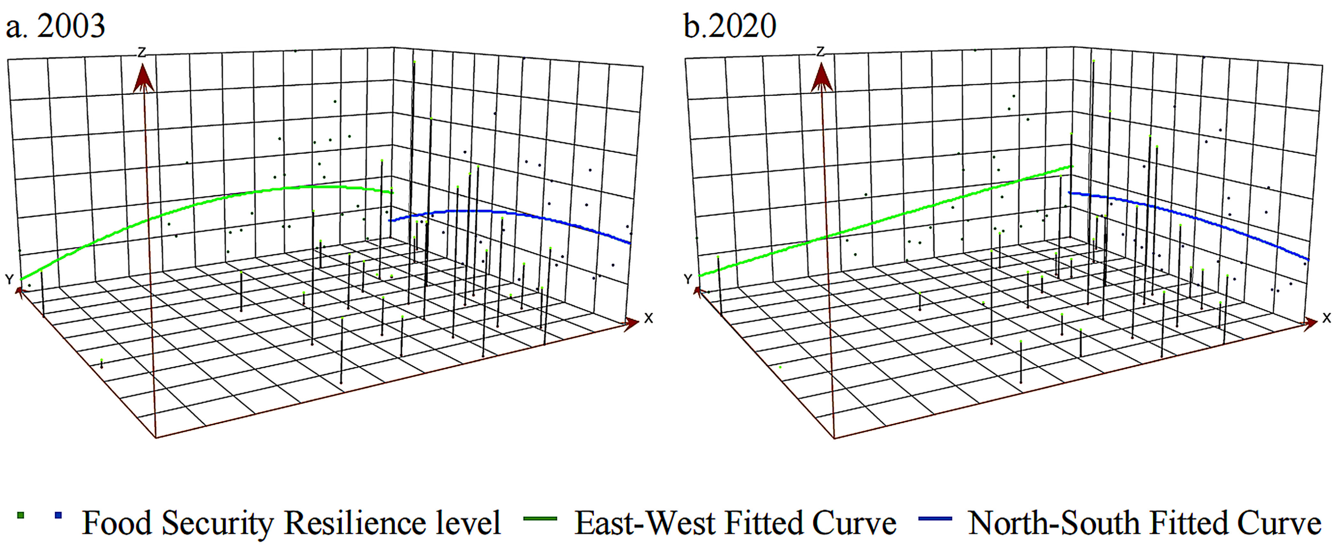

FIGURE 7 | Spatial trend surface of China's FSR in 2003 and 2020.

primary methods implemented include spatial pattern analysis and spatial trend analysis.

Figure 7 presents the outcome of a trend surface analysis, effectively visualizing the attribute values of China's provincial FSR through 3D space fitting technology. In this figure, the *X*-axis and *Y*-axis represent the due east and due north directions, respectively. From 2003 to 2020, significant changes have occurred in the spatial layout of China's FSR. Notably, as one moves from west to east, the FSR distribution, which was initially in an inverted U-shape in 2003, has transformed into a pattern of progressively increasing values toward the east. This shift emphasizes a prominent eastward movement of the primary area responsible for ensuring food security in China, simultaneously indicating a reduced significance of middle China and Sichuan, another province traditionally known as a "big granary." Conversely, when examining the trend from north to south, the spatial distribution of FSR has become more evenly balanced, altering the initial north-to-south increasing gradient that was evident in 2003. Moreover, our analysis, supplemented by maps and other datasets, pinpoints southern Henan province as a key area in supporting China's food security. Historically, Henan has served as a major grain-producing region, supplying food to the densely populated central plains (Gu et al. 2023). The southern part of the province, characterized by flat terrain and fertile soil, is particularly suitable for large-scale mechanized agriculture. According to the Henan Provincial Bureau of Statistics, the province produced 68.258 million tons of grain in 2020 (Henan Statistics 2021), accounting for 10.2% of the national total. Zhoukou, located in the southeastern part, ranked first in food production within the province. Furthermore, the southern region of Henan province has a distinct locational advantage, bordering Anhui and Hubei provinces (Gong et al. 2023), which facilitates the exchange and dissemination of agricultural information and technology. As a result, this region is not only critical in its role but also

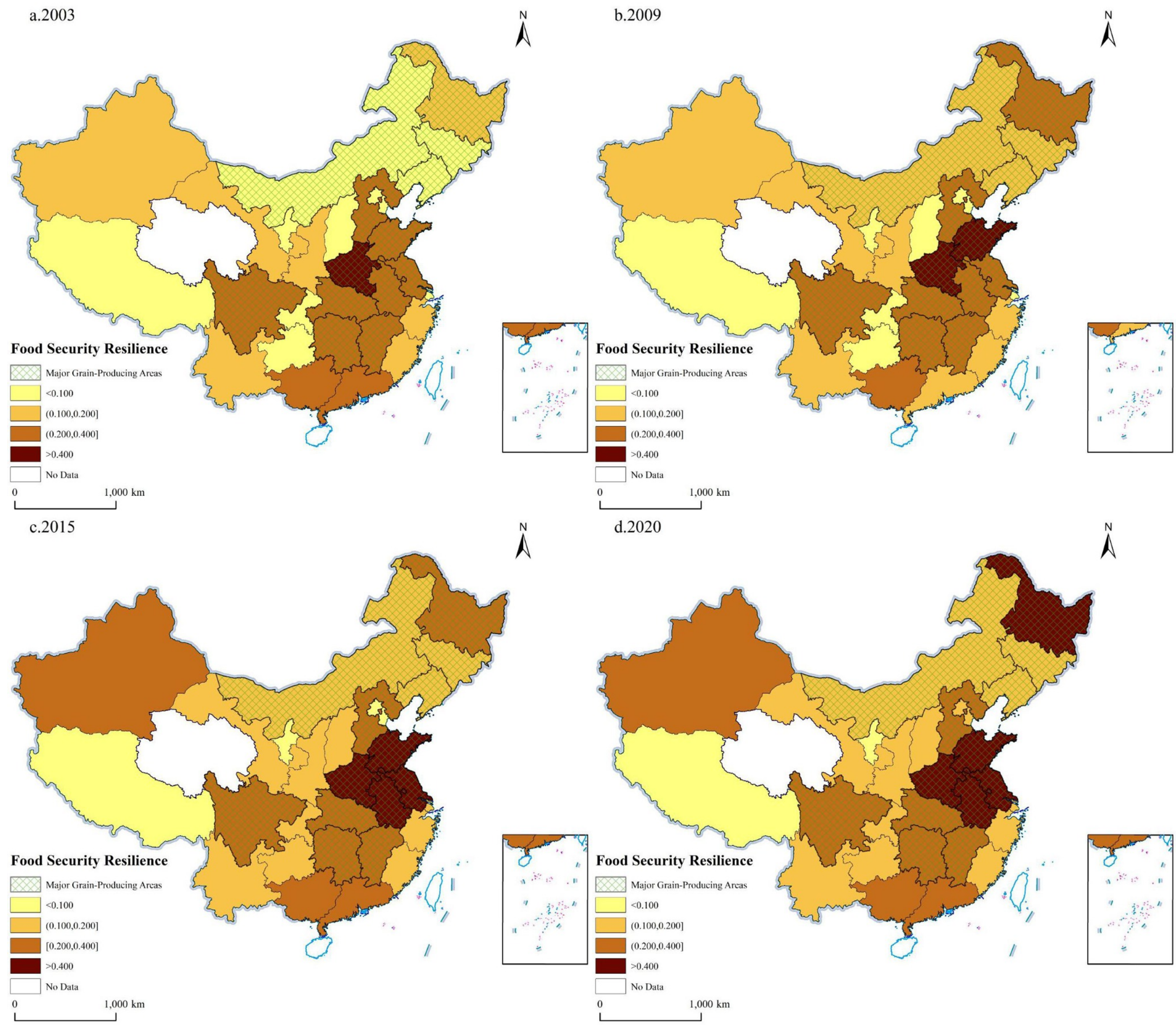

FIGURE 8 | Spatial distribution pattern of China's provincial FSR in 2003, 2009, 2015, and 2020.

generates positive spillover effects due to its strategic geographical positioning.

In the spatial pattern analysis of China's provincial FSR, four temporal benchmarks—2003, 2009, 2015, and 2020—have been chosen for discussion. The fixed value breakpoint method is applied to categorize FSR into four levels: low level, medium level, higher level, and high level, and the 13 major grain-producing areas are represented on the map with green twill squares (see Figure 8). Overall, an increase in the number of provinces categorized at the medium level or above signifies an overall enhancement in China's food security situation. Notably, Heilongjiang province has shown remarkable progress, advancing from the low level in 2003 to the high level in 2020. In addition, the positive spillover effect from Henan province has propelled the FSR levels of neighboring provinces such as Shandong, Jiangsu, and Anhui to a high level. Conversely, provinces in Southeast China (excluding Guangdong), and Northwest China (excluding Xinjiang), along with Sichuan, Beijing, and Yunnan, exhibit relatively minor changes.

In 2003, in response to the changing dynamics of grain production and distribution, the Chinese government designated 13 major grain-producing areas, including Heilongjiang, Henan, Shandong, Sichuan, and Jiangsu, among others (Hua, Chen, and Luo 2022). According to Wang et al. (2022), the grain output from these areas reached 536.03 million tons, accounting for 78.55% of China's total grain production in 2021. Analysis indicates that the FSR levels in these major grain-producing areas are higher compared to those in nonmajor ones. This observation is in line with expectations for several reasons. First, the major grain-producing areas are endowed with superior soil and climatic conditions (Chen and Zhao 2019), and many have historically been central to ensuring China's food security. Second, the Chinese government is inclined to provide more favorable policy and technical support to these major areas, helping their agricultural activities. A notable example of this approach is the implementation of crops' minimum purchase prices, a benefit restricted to the 13 major grain-producing areas and excluded individual farmers in other areas from accessing these advantages.

6 | Discussion

6.1 | Research Results

First, China's food policies are notably targeted and complementary, significantly contributing to the increase in grain production, expansion of planting scales, improvement of farmers' economic conditions, and enhancement of agricultural mechanization rates. Furthermore, the concurrent application of multiple food policies often results in a synergistic "$1+1>2$" effect. A typical case is the integration of direct grain subsidies with the crops' minimum purchase prices. This combination effectively transforms the market into a robust mechanism for regulating grain purchases, ensuring a stable grain supply, and enhancing the efficiency of market operations. Second, over time, there has been a general improvement in the FSR of China's provinces, with a steady increase in FSR values observed. The average annual growth rate of FSR in most provinces has consistently ranged between 1% and 5%. Except for northeastern China, other economic regions have demonstrated a relatively balanced development trend internally. Besides that, there exists a notable discrepancy between the agricultural potential of the northeastern region and its actual contribution to China's food security. Third, from a spatial perspective, China's FSR currently exhibits an overall pattern of being "high in the east and low in the west," with a more balanced distribution between the north and south. This indicates a clear eastward shift in the primary areas responsible for ensuring China's food security. Additionally, southern Henan, serving as the national gravity point for FSR, generates positive spill-over effects, enhancing the FSR in neighboring provinces. Last, it is unsurprising to note that the FSR in major grain-producing areas is higher compared to that in nonmajor ones.

6.2 | Policy Recommendation and Implications

Based on the above results and global food security situations, this study makes the following recommendations to the stakeholders.

The government should persist in fostering and dynamically managing food security policies that have demonstrated positive impacts. It is advisable not to over-rely on a strategy of complete self-sufficiency. Engaging in international cooperation within the realm of food trade can significantly enhance global food security. China has revised its target from 95% food self-sufficiency, moving toward importing crops for nonfood purposes (Ito and Ni 2013; Huang et al. 2017). Furthermore, it is necessary to update certain obsolete indicators. For instance, substituting "cropland area" with "harvested area" could provide a more accurate assessment of the actual state of food security (Song et al. 2022).

It is anticipated that the concept of food security will evolve beyond mere sufficiency to encompass aspects such as nutrition, diversity, and environmental protection. Large-scale producers are encouraged to improve their technological investments to supply the market with products that are not only nutritious and diverse but also cultivated with lower carbon footprints. For smaller producers, such as individual farmers, prioritizing their food security remains a critical task. The shift toward large-scale food production should be recognized as the mainstream approach, given its higher efficiency, greater resilience to risks, and more sustainable utilization of resources. Besides that, saving food is one of the simplest and most effective ways for consumers to participate in protecting food security.

Furthermore, we advocate policymakers for open, transparent, and predictable agricultural trade, underpinned by the multilateral, rules-based trading system, and science and risk-based decision-making—that keep markets open and contribute to the resilience of the global food supply chain, agricultural productivity, and sustainability. The government should build genuine partnerships scaling to scale climate resilient farming with the private sector, NGOs, and other community partners, as well as with global organizations.

6.3 | Future Research and Limitations

The current assessment of China's food security lacks comprehensive analyses from a micro perspective, an area that should be emphasized in future research endeavors. For instance, it is crucial to explore the tangible contributions of producers, particularly individual farmers, to food security. This includes examining strategies employed by villages, and considering geographic and familial (bloodline) factors, in addressing food security challenges. Moreover, future studies should endeavor to quantify the specific impacts of various policies on food security and compare the relative contributions of markets, policies, and technologies in advancing food security within emerging economies. Future research is called to investigate how cross-domain and cross-platform resource combinations can be effectively utilized and allocated to bolster food security. Due to the constrained scope and perspective of this study, the focus is primarily on China's food security policy and the exploration of the spatiotemporal dynamics of provincial FSR. However, there are limitations to this approach. First, the assessment of China's FSR is conducted at the provincial level, and the findings may not adequately reflect the nuances present at smaller administrative levels, such as cities and counties. Moreover, the dataset used in this study is limited to the period ending in 2020, partly due to the unavailability of more recent data and potential distortions in macrolevel data caused by the COVID-19 pandemic. Although our data are limited to 2020, our research provides implications for crises after 2020, such as the Russia–Ukraine war and Japanese wastewater issue. Finally, this study does not take international grain trade into the index system when considering provincial FSR. This exclusion is based on the premise that China had not started a large-scale grain trade (Fei, Shuang, and Xiaolin 2023).

In conclusion, our article offers valuable insights into the governance of global food security, with a particular focus on emerging economies. It heightens societal awareness regarding the critical nature of food security issues and to stimulate a broader range of solutions to address these challenges.

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Ethics Statement

Ethical approval was not required as the study did not involve human participants.

Consent

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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