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EDITED BY
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Amrita Vishwa Vidyapeetham (Amritapuri Campus), India

*CORRESPONDENCE
Yujun Wei
✉ weiyujun1991@163.com

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Assessing the equilibrium of food supply and demand in China's food security framework: a comprehensive evaluation, 1980–2017

Yujun Wei[1,2]*, Dan Fang[1,2], Xiaokun Wei[3] and Zhonghua Ye[4]

[1]Development Strategy and Cooperation Center, Zhejiang Lab, Hangzhou, China, [2]Zhejiang Laboratory of Philosophy and Social Sciences - Laboratory of Intelligent Society and Governance, Zhejiang Lab, Hangzhou, China, [3]Department of Applied Mathematics and Computer Science, Technical University of Denmark, Kongens Lyngby, Denmark, [4]School of Public Policy and Management, University of Chinese Academy of Sciences, Beijing, China

The continuous upward trajectory observed in total grain production serves as a fundamental pillar for guaranteeing food security. Nevertheless, relying solely on the measurement of China's overall food security status through total grain output is inherently biased and neglects to capture the comprehensive nature of food security. This study adopts a food supply and demand balance perspective and constructs an evaluation indicator system for food security based on indicators such as grain yield per unit area, *per capita* grain possession, grain inventory, and inventory ratio. The weight of each indicator in the food security system is calculated using the entropy value method, and a comprehensive evaluation of China's food security level from 1980 to 2017 is conducted. The study revealed that China's food supply and demand exhibited a discernible upward trajectory in development. Notably, the food supply demonstrated greater volatility, whereas the food demand remained relatively stable but experienced incremental growth. Between approximately 1985 and 1993, China's food supply and demand subsystem briefly experienced a state of mild imbalance, followed by a state of moderate imbalance around 2003. These imbalances were primarily attributed to insufficient effective food supply. In terms of the equilibrium between supply and demand in the context of food security, China's food supply and demand exhibit a predominantly balanced condition with a slight surplus, wherein the adequacy of food supply significantly influences food security. Furthermore, the provision of policy support serves as a robust assurance for food security, and China's existing policy framework for food security demonstrates a constructive impact.

KEYWORDS

food security, comprehensive evaluation, supply and demand balance, entropy value method, China

1 Introduction

Food security is a global issue that holds significant implications for global peace and development. Moreover, it serves as a fundamental cornerstone for the establishment of a collective future for humanity, intertwined with the prospects of sustainable development and the welfare of mankind (Rosegrant and Cline, 2003; FAO, 2017). Food plays a crucial role not

only as a fundamental means of subsistence but also as a cornerstone for fostering sustainable development within the national economic society (Pawlak and Kołodziejczak, 2020). The issue of food security holds significant implications for the national economy, livelihoods of individuals, and social stability, particularly in the context of China's substantial population of approximately 1.4 billion (Wei, 2020; Zhu et al., 2021). Consequently, the importance of ensuring food security should not be underestimated. In understanding China's approach to food security, it is instructive to consider the role of key policy directives. Historically, the Central People's Government has annually issued "Central Document No.1," a policy framework addressing agricultural, rural, and farmer-related issues, thereby underlining the government's commitment to food security (Table 1). Notably, recent iterations of the document have catalyzed shifts towards agricultural efficiency, modernization, and rural revitalization, with specific targets set for grain production and land use optimization to secure food provision (State Council of the People's Republic of China, 2017-2023).

In the context of China's ongoing rapid urbanization and industrialization, the imperative of ensuring food security extends beyond meeting basic human needs, encompassing the preservation of political, economic, and social stability (Yin, 2021; Gao and Zhao, 2023). While sustainable and stable development has emerged as a global imperative, food security remains a critical component of a nation's progress, serving as the bedrock of livelihoods and a valuable political asset, necessitating continued prioritization (Wang et al., 2021). China's grain production capacity has made significant advancements in conjunction with the deepening of institutional reform and economic development. Notably, since 2000, there has been a steady increase in overall grain production (Figure 1).

The significance of food security has consistently been underscored; however, the understanding and implications of food security are subject to perpetual evolution. Globally, food security is defined by the Food and Agriculture Organization (FAO) as a situation where "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 1996)." It encompasses four core dimensions: physical availability of food, economic and physical access to food, food utilization, and stability of the other three dimensions over time. These four dimensions must be met simultaneously to ensure that the goal of food security is realized. The World Bank defines food security in a similar way to the FAO. The United States Department of Agriculture (U.S. Department of Agriculture, 2024) defines food security as "access by all members at all times to enough food for an active, healthy life," and distinguishes between food security and the concept of "hunger", which is Hunger is a physiological condition resulting from a prolonged lack of access to adequate food and is a possible consequence of food insecurity. These international benchmarks set the stage for assessing China's food security within a global framework.

The present investigation endeavors to scrutinize the equilibrium dynamics between supply and demand in the context of China's food security over the period spanning from 1980 to 2017. Through a comprehensive analysis of historical and contemporary datasets, this study seeks to delineate the salient trends and pivotal junctures that have sculpted the contours of China's food security paradigm. Furthermore, the research delves into the examination of the interplay between agricultural productivity, policy interventions, and the evolution of dietary consumption patterns, and how these factors have collectively influenced the nation's capacity to ensure the availability of sustenance for its populace. The findings of this study are anticipated to contribute to the extant literature by providing valuable insights into the complex interdependencies that underpin the food security framework within the Chinese context.

2 Literature review

The concept of food security encompasses a complex interplay of factors that ensure the availability, access, and proper utilization of food across individual, familial, national, and global scales (Pawlak and Kołodziejczak, 2020). As an evolving notion, it demands varied methodologies for accurate assessment and effective policymaking (Baer-Nawrocka and Sadowski, 2019). Early food security research fixated on augmenting food production as a primary strategy for

TABLE 1 The "Central Document No. 1" issued by the State Council of the People's Republic of China.

Year	Central Document No. 1	Statement on food security
2023	Prioritizing work in comprehensively promoting rural revitalization	Stabilizing and preserving the supply of food and important agricultural products
2022		Stabilization of the area sown and production of grain throughout the year
2021	Comprehensively promoting rural revitalization and accelerating agricultural and rural modernization	Establishment of a food production and supply security system to enhance food production capacity and supply quality.
2020	Prioritizing work in agriculture, rural areas, and farmers to ensure achieving the goal of building a moderately prosperous society in all respects	Ensuring food security is always the top priority of governance, and food production should be stabilized, with stable policies, stable areas, and stable yields.
2019	Adhering to the priority development of agriculture and rural areas and doing a good job in agriculture, rural areas, and farmers	Strengthening the foundation of agriculture and ensuring the effective supply of important agricultural products; improve grain production and ensure that the area sown with grain is stabilized at 1.65 billion mu.
2018	The implementation of the rural revitalization strategy	"Storing grain in the ground and in science and technology" strategy; strengthen the foundation of agricultural production capacity, ensure national food security.
2017	Deepening the supply-side structural reform in agriculture and accelerating the development of new drivers of agricultural and rural growth	Stabilizing rice and wheat production to ensure absolute food security; strictly abiding by the red line of arable land and protecting and optimizing grain production capacity.

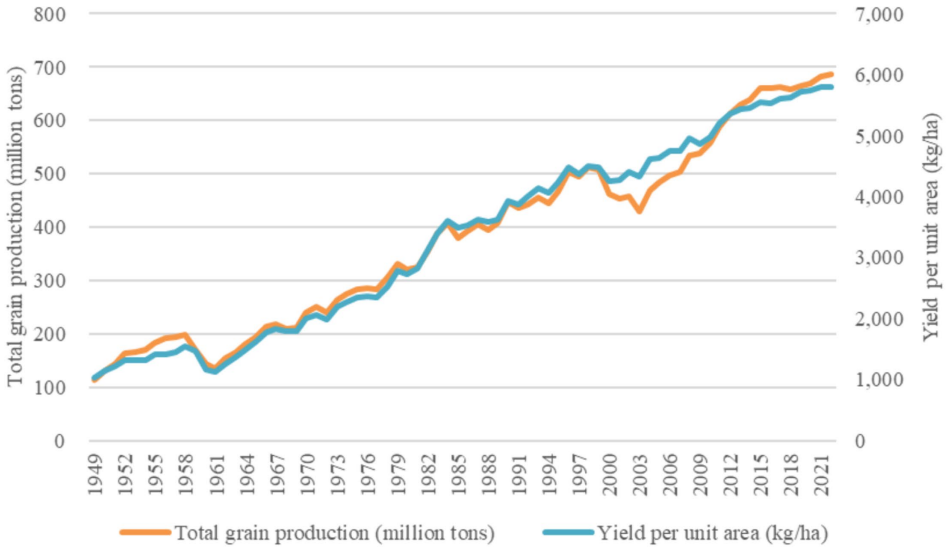

FIGURE 1
Changes in China's total grain production and yield per unit area.

ensuring sufficiency (Liu and Zhou, 2021). This focus birthed extensive analyses of resource utilization—including land, water, labor, and technology—and their impact on grain production, alongside studies on the spatial and temporal dynamics of production (Zhu et al., 2023). Scholars utilize a comprehensive approach and intricate methodologies, such as the early warning system for food security. This system classifies food security into four distinct levels (global, national, family, and individual), considering both macro and micro perspectives (Ma et al., 2001). Several studies have examined China's food security by analyzing various government macroscopic control measures such as grain production, grain storage, and grain transportation (Wang et al., 2018; Sun and Zhao, 2020). Furthermore, other studies have focused on constructing a comprehensive food security evaluation indicator system based on five dimensions: quantity security, quality security, time security, space security, and market security (Zhang et al., 2022).

However, the reliance on positive indicators such as grain production, self-sufficiency rates, and satisfaction levels for food security assessment has been identified as insufficiently comprehensive, risking biased outcomes (Cui and Nie, 2019; Santeramo, 2021; Lee et al., 2023). Besides, Food security encompasses various interconnected factors, including transportation, storage, and sales (Klychova et al., 2020). Moreover, the subjective weighting of these indicators, even when applying rigorous methods like the analytic hierarchy process, cannot entirely negate expert bias (Namany et al., 2020; Ye, 2023). Acknowledging these methodological limitations, current scholarship advocates for a holistic approach that considers the equilibrium between food supply and demand (Wang et al., 2018; Sun and Zhao, 2020). A multi-dimensional evaluation system, incorporating quantity, quality, time, spatial, and market securities, has been proposed to address these intricacies (Zhang et al., 2022). Recent literature has begun to reflect on the balance between food supply and demand. Wu et al. (2016) provided a comprehensive evaluation of China's food security from 1995 to 2012, emphasizing the role of ample grain production in securing food availability during early economic and social progress. As development progresses, they noted the increasing need to align food supply with consumption patterns to maintain food security. Xie et al. (2017) further explored this balance, assessing the elasticity of food demand security and production capacity within China's food system. Building upon the perspective of food supply and demand balance, the work by Liu et al. (2022) extends the analysis to the urban scale within the Pearl River Delta, observing a declining Food Supply and Demand Ratio (FSDR) from 2000 to 2015 and signaling a growing external dependency for food provision, particularly in major cities like Guangzhou and Shenzhen. Qi et al. (2015) offered a quantitative assessment of provincial food security risks, pointing to a projected decrease in grain self-sufficiency and a necessity for improved agricultural yields and strategic imports by 2030. Huang (2010) suggests optimizing the agricultural layout to address the heightened food supply–demand conflicts and to better utilize light, heat, and water resources for efficient agriculture. Other studies have modeled future food supply and demand balances. Gao et al. (1994) highlighted the impact of population and economic development on food consumption trends, necessitating a significant enhancement in agricultural productivity. Projections by Wang et al. (2010) noted substantial supply–demand gaps in China's arable land, advocating for improved inter-regional food circulation to alleviate these disparities.

Consequently, this study endeavors to address the shortcomings by evaluating food security from the standpoint of achieving equilibrium between food supply and demand. Besides, the entropy value method, a well-established quantitative technique used in multi-criteria decision-making (MCDM) and various fields like economics, engineering, and environmental management to determine the weight of each criterion without subjective interference (Kumar et al., 2021), has been adopted in our study to mitigate the influence of subjective biases. In recognition of the complexity, our study utilizes the entropy value method to minimize subjectivity and construct a systematic indicator system for assessing China's food security.

3 Materials and methods

The fundamental aspect of food security, namely the equilibrium between food supply and demand, serves as the foundation for the development of a comprehensive assessment framework for food security within this research. Food security encompasses various interconnected components, including production, consumption, circulation, and trade, each comprising diverse elements (Béné, 2020). However, the paramount security characteristic of food security lies in achieving a harmonious equilibrium between the availability of food and the corresponding demand for it. The smooth functioning of grain circulation and trade is contingent upon the attainment of coordination and equilibrium between supply and demand (Fischer et al., 2014; Jiang et al., 2021). Consequently, this study aims to construct two subsystems, namely the food supply subsystem and the food demand subsystem, by employing an evaluation method for assessing the balance between food supply and demand.

Based on a logical analysis of the essential constituents of the two subsystems and an extensive review of scholarly research on food supply and demand, a food security indicator system is formulated (Figure 2). The constituent elements of the food supply subsystem encompass historical grain output, grain inventory, and grain import. Meanwhile, the food demand subsystem is primarily categorized into the food demand, quantified by the annual ration consumption of residents, and the non-food demand, encompassing industrial grain, feed materials, seed grain, grain loss, and annual grain export volume.

Adequate and stable food supply is the key to ensuring food security, especially ration security. Starting from the supply side, the food supply subsystem includes three parts: total grain output, grain inventory and grain import.

3.1 Grain output

The total grain output serves as the fundamental basis of food security, while also indicating the extent of the comprehensive grain production capacity. Adequate and consistent grain output plays a pivotal role in ensuring the provision of food (Klychova et al., 2020). This study selects the total output of grain crops including corn, rice and soybeans as the representative of total grain output. Although *per capita* grain possession is indeed an important indicator, the decision to employ total grain output as the primary metric in this study is motivated by the need to maintain equilibrium between the food supply subsystem and the food demand subsystem.

3.2 Grain inventory

Grain inventory also known as carryover reserve is the amount of grain reserves that have been obtained from the crops harvested as well as food imports in the previous year at the beginning of the new year. Grain inventory assumes significant importance as it represents a country's ability to resist various possible risks of food security including but not limited to natural calamities, conflicts, and civil unrest.

3.3 Grain import

Grain import is intrinsically linked to the concept of grain self-sufficiency. It is a widely accepted scholarly consensus that a country has essentially attained grain self-sufficiency when its grain self-sufficiency rate surpasses 95% (Ghose, 2014). However, the maintenance of a specific grain self-sufficiency rate often necessitates

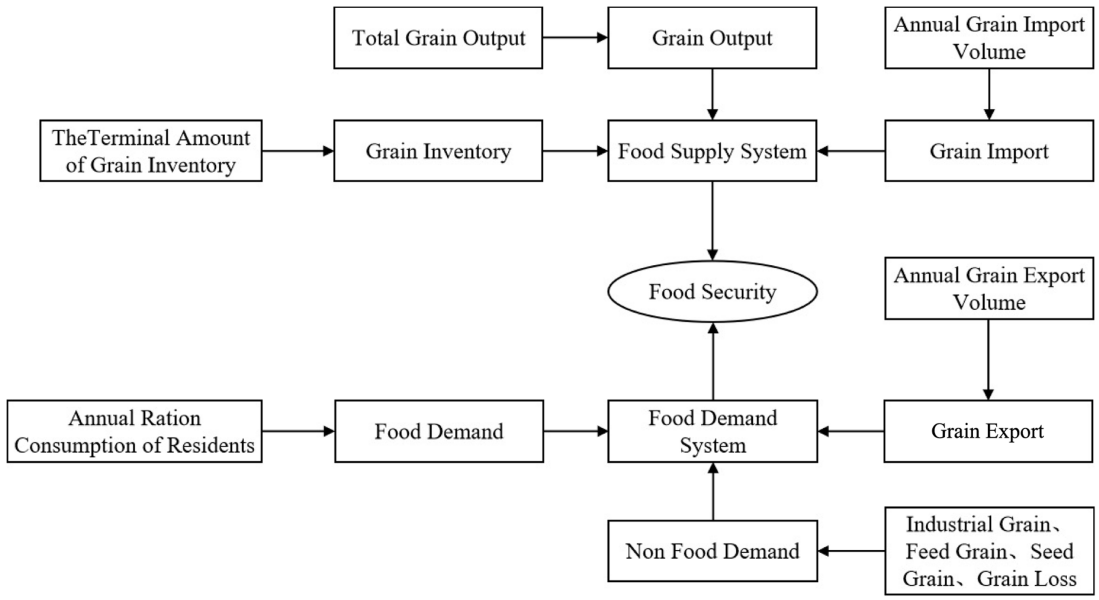

FIGURE 2
The construction of the food security indicator system.

a corresponding economic expenditure, given that both the cultivation and storage of grain demand substantial resource allocation.

Grain utilization can be bifurcated into two primary categories: food and non-food demand, with the former further subdivided into ration and feed grain (Qiu et al., 2022). Comprehensive accounting of food demand encompasses a variety of indicators, including residents' ration consumption, industrial grain usage, feed grain, seed grain, food loss, and food export. Direct grain consumption represents the fundamental demand of residents for rations. Consequently, the data pertaining to ration consumption is derived from the consumption patterns of both urban and rural residents.

$$\begin{aligned} &Ration\ Consumption = \\ &\left(\begin{array}{l} Per\ Capita\ Food\ Consumption\ of\ Urban\ Residents \times \\ Proportion\ of\ Urban\ Population + \\ Per\ Capita\ Food\ Consumption\ of\ Rural\ Residents \times \\ Proportion\ of\ Rural\ population \end{array}\right) \end{aligned}$$

Per capita food consumption data for urban and rural residents can be sourced from the China Statistical Yearbook. However, figures related to industrial grain, feed grain, seed grain, and grain loss are not typically included in these yearbooks. To address this gap, the present study employs a conversion method to estimate these indicators.

Industrial grain consumption, which is surpassed only by ration and feed grain, primarily encompasses the use of grain in alcohol and monosodium glutamate (MSG) production (Lv et al., 2013). Alcohol consumption includes Chinese spirits, beer, and other alcoholic beverages. Based on prior research, the estimated grain consumption coefficients for these products are as follows: 2.3 for Chinese spirits, 0.17 for beer, 3 for other alcohols, and 5 for MSG. Different types of grains are demanded for industrial use, with corn constituting the largest proportion at 45.79%, nearly half of the total. This is followed by wheat at 15.23%, soybeans at 14.40%, and other cereals at 14.04% (Xiao et al., 2017). Feed grain demand arises from residents' consumption of animal-based foods, including livestock, eggs, poultry, and milk. Therefore, the output of these products and their corresponding grain consumption coefficients can be used to estimate feed grain demand (Mao et al., 2016). According to previous studies, the feed conversion ratios for beef, mutton, pork, poultry, eggs, and milk are 2.6, 3.1, 2.9, 2.4, 1.7, and 0.4, respectively (Xin et al., 2015). Different types of animal foods require different types of grains. As per the research findings of Zhao et al. (2006) on feed grain demand in China, the proportions of grain required for different types of animal foods are as follows: both beef and mutton require 5% wheat and 26.25% corn; pork requires 15.77% rice, 6.7% wheat, 43.57% corn, and 18.75% beans; poultry meat requires 2.32% rice, 2.33% wheat, 50.82% corn, and 25% beans; and poultry eggs require 6.2% rice, 2.7% wheat, 40.4% corn, and 25% beans.

The computation of seed grain diverges from that of industrial grain and feed grain. Rather than necessitating a reverse calculation based on the consumption of processed products, seed grain is directly calculated based on the planting area of different grain types and the standard unit area of seed consumption (Xiao et al., 2017). The data used to calculate the total amount of seed grain in this study is sourced from the average seed grain consumption per hectare of grain crop, as reported in China's "Compilation of National Agricultural Product Cost Benefit Data" over the years. Grain loss adheres to current general standards, accounting for 5% of the total grain output (Luo, 2008). Based on the analysis of the above evaluation of food security levels, this study constructs a Chinese food security indicator system (Table 2).

In accordance with the established food security indicator system, the comprehensive indicator of food supply is derived and denoted as the FS variable (Stefanis, 2014; Fraser et al., 2015).

$$FS = a_1 S_1' + a_2 S_2' + a_3 S_3'$$

Among them, S_1', S_2', S_3' respectively represent the normalized values of the total grain output, the terminal amount of grain inventory, and annual grain import, jointly representing the food supply situation. a_1, a_2, a_3 respectively represent the weight coefficients of the above indicators, indicating the importance of food supply factors.

Similar to the comprehensive indicator of food supply, the comprehensive indicator of food demand is obtained as the *FD* variable (Jiang et al., 2021).

$$FD = b_1 D_1' + b_2 D_2' + b_3 D_3' + b_4 D_4' + b_5 D_5' + b_6 D_6'$$

Among them, $D_1', D_2', D_3', D_4', D_5', D_6'$ respectively represent the normalized values of annual ration consumption of residents, industrial grain, feed grain, seed grain, grain loss, and annual grain export volume, jointly representing the demand for food. $b_1, b_2, b_3, b_4, b_5, b_6$ respectively represent the weight coefficients of the above indicators, indicating the importance of food demand factors.

FS and *FD* are both dynamic indicators. If *FS* is equal to *FD*, it means that the food supply exactly meets its demand; If *FS* is less than *FD*, it means that the food supply cannot meet the food demand; If *FS* is greater than *FD*, it means that the food supply exceeds the food demand. The comparison between *FS* and *FD* can reflect the balance of food supply and demand, thereby reflecting the degree of food

TABLE 2 Food security indicator system.

System	Element analysis	Single indicator	Indicator representation
Food supply subsystem	Grain output	Total grain output	S_1
	Grain inventory	The terminal amount of grain inventory	S_2
	Grain import	Annual grain import volume	S_3
Food demand subsystem	Food demand	Annual ration consumption of residents	D_1
	Non-food demand	Industrial grain	D_2
		Feed grain	D_3
		Seed grain	D_4
		Grain loss	D_5
	Food Export Demand	Annual grain export volume	D_6

security. This study defines the degree of food security as the following formula.

$$FI = \frac{FS}{FD}$$

According to above formula, when FI (the Food security Index) is greater than 1, the food supply exceeds the demand. When the FI is equal to 1, the food supply and demand are balanced. When the FI is less than 1, the food supply is inadequate to meet the demand.

To categorize China's food security status, it is necessary to establish a range for the food security indicator. Wu et al. (2016) proposed a classification based on the difference ratio between grain production and consumption. They defined a difference ratio within the range of −5 to 5% as coordinated development, a difference ratio within the range of −10% to −5 and 5 to 10% as relatively coordinated development, and a difference ratio greater than 10% or less than −10% as imbalance. This study adopts this classification, in addition to the concept of ideal fiscal balance in the field of finance, which advocates for a fiscal balance with a slight surplus for the year (Chugunov et al., 2021). Consequently, the ideal state of the food supply and demand balance indicator in food security is defined in this study as a food supply and demand balance with a slight surplus.

To calculate the food security supply and demand indicator, it is first necessary to determine the weight coefficients a_1, a_2, a_3 representing food supply, as well as the weight coefficients $b_1, b_2, b_3, b_4, b_5, b_6$ representing food demand. Generally, there are two types of weighting methods: subjective and objective. The subjective weighting method is more commonly used, but it can be easily influenced by subjective factors such as personal preference. Even the widely used Analytic Hierarchy Process is based on personal preference for weight calculation. The objective weighting method, on the other hand, is based on the original data and uses a specific mathematical method to determine the weight. The entropy value method is a type of objective weighting method that assigns weights according to the fluctuation of historical data, and reflects the information hidden in the data (Shannon, 1948). The entropy value method primarily uses the degree of dispersion among variables to assign weights, which has higher credibility and accuracy than the subjective weighting method. Through weight assignment, the distinguishing significance and difference of indicators can be enhanced, thereby avoiding analysis difficulties caused by too small differences in selected indicators. Therefore, this study adopts the entropy value method to calculate food security indicator weights. In this study, the entropy value method is used to determine the weight of various indicators in the food security system.

First, evaluate China's food security situation since the reform and opening up over 40 years ago, that is, there are M evaluation objects, $M = (M_1, M_2, M_3 \cdots\cdots M_m)$. The evaluation indicator $D = (D_1, D_2, D_3 \cdots\cdots D_m)$ can form the initial data matrix of the evaluation system as X. Among them, x_{ij} represents the value of the j evaluation indicator of the i object.

$$X = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix}, X = \{x_{ij}\}_{m\times n} (1 \le i \le m, 1 \le j \le n).$$

Second, given that the food security indicator system encompasses various aspects of food supply and demand, its measurement units are not uniform. Therefore, standardization is required prior to formal calculation. The formula for standardization is as follows:

$$y_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}$$

Third, the feature proportion of the i object and the j evaluation indicator is recorded as p_{ij}.

$$p_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}$$

Fourth, calculate the information entropy of the j evaluation indicator, represented by e_j.

$$e_j = -k\sum_{i=1}^{m} p_{ij} \ln p_{ij}, 0 \le e_j \le 1$$

Among them, the constant k is equal to $\frac{1}{\ln m}$. For a certain indicator D_j, the greater the difference in y_{ij}, the smaller e_j will be. In other words, the greater the difference in the j indicator of each evaluated object, the greater the amount of information reflected by the indicator, as well as the smaller its entropy value. While the entropy value e_j is too high, it indicates that the indicator provides very little information that can be removed.

Fifth, the information utility value of a certain indicator depends on the difference between the information entropy of the indicator and 1, represented by d_j.

$$d_j = 1 - e_j$$

d_j is called the coefficient of difference of the j evaluation indicator, and its value directly affects the size of the weight. The larger the d_j, the greater the importance of evaluation as well as weight value.

Sixth, the essence of entropy value method is to use the value coefficient of indicator information to calculate weights. The higher the value coefficient, the greater the contribution to the evaluation results. The weight of the j indicator is denoted as w_j.

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}, j = 1, 2, \ldots, n$$

Seventh, the comprehensive evaluation value of each object can be calculated based on the weight of each indicator.

$$y_i = \sum_{j=1}^{n} W_j * P_{ij} (i = 1, 2, \ldots m)$$

The data employed in this study, such as total grain output, *per capita* grain possession, and grain yield per unit area, are drawn from an extensive review of annual publications including the China Grain

Yearbook, China Statistical Yearbook, and China Rural Statistical Yearbook. Additionally, detailed estimates of resident ration consumption, industrial grain, feed grain, seed grain, and grain loss have been meticulously sorted out from an array of sources, encompassing the China Rural Statistical Yearbook, Finance Yearbook of China, and related industry yearbooks. For the crucial figures pertaining to grain inventory, imports, exports, and other relevant metrics, our study relies on data from authoritative and international entities such as the official website of the United Nations Food and Agriculture Organization, the World Bank, and the China Grain Network Data Center.

4 Results

4.1 Overview of changes in food security systems and indicators

This study employs quantitative analysis to present preliminary statistics on the indicator data of the food supply and food demand subsystems (Table 3). It is observed that the standard deviation coefficient of grain import volume is the largest in the food supply subsystem, indicating the most significant fluctuation in grain import. Given China's current development situation, the reasons for the substantial changes in the scale of grain import may be twofold: On one hand, the rigid growth trend of China's food demand has led to a tight supply, and on the other hand, the inversion of food prices has undermined China's competitive advantage in food supply. In the food demand subsystem, it is observed that the food consumption of residents, i.e., ration consumption, does not exhibit significant changes. However, industrial grain, feed grain, and seed grain all display considerable fluctuations. This can be attributed to the upgrade in residents' consumption structure. The evolution of the consumption structure has led to changes in China's food demand structure, and large fluctuations in food demand will indirectly cause fluctuations in grain import to a certain extent. Additionally, in the food supply subsystem, the standard deviation coefficient of grain inventory is relatively large, indicating that grain inventory also experiences significant fluctuations.

Further analysis of the importance of different indicators in the food security system is conducted based on the weight of each indicator (Table 4). From the perspective of the food supply subsystem, the weight of grain import is the highest, which suggests that grain import is a crucial tool for ensuring food security. Moderate grain import can effectively balance China's food supply shortage, thereby enhancing the resilience of the food security system. Additionally, according to the principle of entropy weighting, the difference in grain import volume is significant, and its change is most likely to impact the entire food supply subsystem. On the other hand, it also reflects that the stability of China's food supply subsystem is largely influenced by grain import. Excluding the maximum weight of grain import, total grain output still occupies a significant proportion in the food supply subsystem, indicating that stabilizing the comprehensive production capacity of grain and ensuring sufficient grain output are the core foundations for achieving food security. The smallest proportion in the food supply subsystem is grain inventory, which suggests that China's grain inventory is relatively stable compared to other indicators. From the perspective of the food demand subsystem, the weight of industrial grain is the highest. Moreover, the data on industrial grain consumption shows a significant degree of dispersion and fluctuations over the years. Like industrial grain, feed grain data also accounts for a large proportion and exhibits significant volatility. Based on the actual situation of feed and industrial grains in China, with the continuous growth of consumption of meat, eggs, and milk, as well as industrial demand for brewing and vinegar, industrial and feed grains will continue to show a growth trend. This will, to some extent, bring greater challenges to China's food security. While comparing the weights of indicators in the food supply subsystem, it is also found that the significant fluctuations in grain import data are largely due to the significant changes in demand for industrial and feed grains. In addition, the weights of seed grain and grain loss are relatively small, which is consistent with the actual grain consumption situation.

4.2 Comprehensive evaluation of the food supply and demand balance

Based on the weights calculated above, we derive the comprehensive evaluation indicator of China's food security (Table 5). From a temporal perspective, China's overall food supply

TABLE 3 Descriptive statistics for indicators of food security system (unit: ten thousand tons).

Food system	Indicator	Observed value	Mean	Standard deviation	Standard deviation coefficient
Food supply subsystem	Total grain output	38	47549.2916	8174.5611	0.1719
	Grain inventory	38	20635.2145	11343.0005	0.5497
	Grain import volume	38	3262.6934	3350.3905	1.0269
Food demand subsystem	Resident food consumption	38	22311.6352	3024.6974	0.1356
	Grain export volume	38	610.8824	525.3453	0.8600
	Industrial grain	38	2759.8816	2152.2671	0.7798
	Feed grain	38	9800.2961	4147.7072	0.4232
	Seed grain	38	1029.3550	481.5508	0.4678
	Grain loss	38	2377.4646	408.7281	0.1719

TABLE 4 Weights of food security indicators.

Food system	Indicator	Weight
Food supply subsystem	Total grain output	0.3112
	Grain inventory	0.258
	Grain import volume	0.4308
Food demand subsystem	Resident food consumption	0.15
	Grain export volume	0.1492
	Industrial grain	0.2292
	Feed grain	0.1678
	Seed grain	0.1743
	Grain loss	0.1294

and demand have maintained a relatively stable growth trend since the reform and opening up, and the relationship between food supply and demand is essentially in a relatively stable state. Notably, there was a slight imbalance between food supply and demand around 1985 and 1993, and a moderate imbalance around 2003. Specifically, in the food supply subsystem, the food supply exhibited a fluctuating upward trend at the beginning of the reform and opening up. From 2004 onwards, the food supply began to grow steadily, and for the first time in 2012, it surpassed the food demand. This indicates that China's total food supply has gradually transitioned from long-term shortage to basic equilibrium, and the food security supply capacity has continued to improve, thereby promoting the continuous enhancement of food security supply capacity. In the food demand subsystem, the food demand consistently increased before 1995. Between 1995 and 2008, the food demand fluctuated between 1.34 and 1.54. After 2008, the food demand returned to a steady growth trend. In this sense, the rigid growth trend of China's food demand will continue. Overall, China's total food supply is becoming increasingly sufficient at present, while the food demand has undergone structural adjustment while maintaining total growth. In the future, the relationship between China's food supply and demand will continue to exhibit a tight balance, and it will be challenging to achieve a breakthrough in a short period of time.

4.3 Relationship between food supply and demand

From the perspective of supply and demand balance, an analysis of China's food security changes reveals that China's food supply experienced a short-term significant increase in the early stages of reform and opening up, followed by a decline in food supply with no significant increase until the 1990s. China's food demand has been on a steady and slow upward trend for a long time. The food supply subsystem was in a state of fluctuation before 2003, but since then, the food supply has been steadily increasing (Figure 3). Comparing the food supply subsystem with the food demand subsystem, it can be observed that the degree of fluctuation in the food supply subsystem is greater than that in the food demand subsystem. Therefore, in the future, it will be necessary to focus on ensuring the stability of grain supply. In this sense, ensuring a stable food supply is the key to achieving future food security.

TABLE 5 Changes in China's food security indicator since the reform and opening up.

Year	Food supply	Food demand	Food security indicator
1980	1.0257	1.1163	0.9188
1981	1.0357	1.1187	0.9258
1982	1.0749	1.1410	0.9421
1983	1.1126	1.1685	0.9522
1984	1.1352	1.2124	0.9363
1985	1.0891	1.2421	0.8768
1986	1.1067	1.2628	0.8764
1987	1.1539	1.2682	0.9099
1988	1.1372	1.2820	0.8871
1989	1.1557	1.2915	0.8949
1990	1.1967	1.3128	0.9116
1991	1.1851	1.3529	0.8760
1992	1.1851	1.3791	0.8593
1993	1.1833	1.3941	0.8488
1994	1.1708	1.3986	0.8371
1995	1.2454	1.3402	0.9293
1996	1.2704	1.3770	0.9226
1997	1.2492	1.4341	0.8711
1998	1.2808	1.4385	0.8904
1999	1.2910	1.4260	0.9053
2000	1.2541	1.4503	0.8647
2001	1.2490	1.4056	0.8886
2002	1.2292	1.4672	0.8378
2003	1.2086	1.4949	0.8085
2004	1.2767	1.3958	0.9147
2005	1.3057	1.4454	0.9033
2006	1.3294	1.4323	0.9282
2007	1.3468	1.5380	0.8757
2008	1.3730	1.4687	0.9348
2009	1.4030	1.4664	0.9568
2010	1.4691	1.4929	0.9841
2011	1.4923	1.5529	0.9610
2012	1.5701	1.5540	1.0104
2013	1.6270	1.6636	0.9780
2014	1.7405	1.6715	1.0413
2015	1.8737	1.6648	1.1255
2016	1.8912	1.6871	1.1210
2017	1.9963	1.7603	1.1341

5 Discussion

5.1 Food stocks and imports: the key grip besides production

In China, the accumulation of high grain inventories has been historically associated with a downward pressure on the purchase

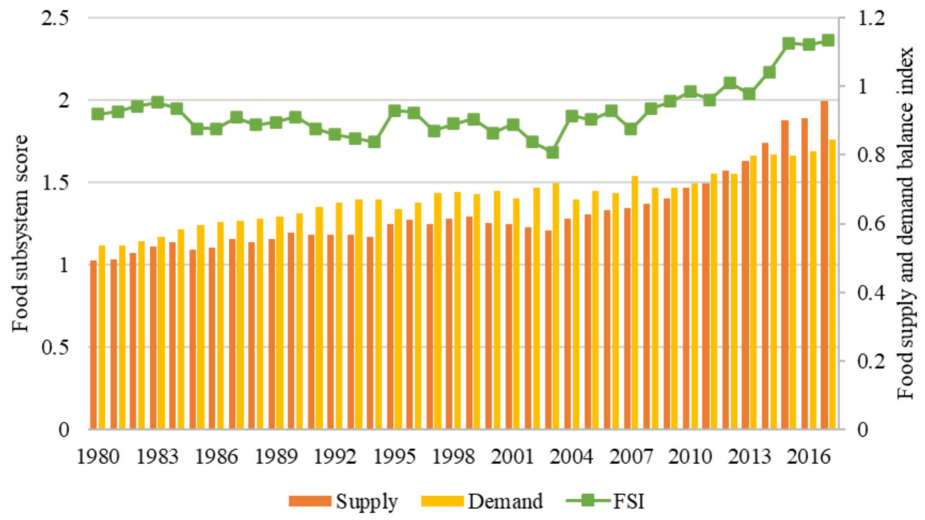

FIGURE 3
Changes in China's food security from the perspective of supply and demand balance.

prices of major cereals, with corn experiencing particularly notable declines. This phenomenon has emerged as a pivotal issue within the discourse on inventory management and food security reforms (Lyu and Li, 2019; Deuss and Adenäuer, 2020). The persistent rise in corn inventories, coupled with an observed inversion in price differentials between China and international markets, has underscored the necessity for destocking and supply-side adjustments in the corn sector (Wang et al., 2022). Consequently, the Chinese government's strategic shift towards corn destocking has garnered significant attention as a cornerstone of inventory management efforts in recent years. This includes the supply-side structural reform initiated in 2016, which is designed to alleviate the surplus in corn inventories while simultaneously safeguarding the nation's grain self-sufficiency (He et al., 2020).

In response to global grain price volatility, the Chinese government has undertaken measures to prioritize and stabilize grain inventory, addressing issues such as singular food reserve subjects and insufficient food storage capacity. These intertwined issues have accelerated the reform of the Chinese grain reserve institution and further promoted nationwide grain inventory quantity and quality inspection activities. Provincial regions in China are also actively responding to the implementation of large-scale inventory actions and incorporating the results into the assessment of provincial governor's responsibilities (Lu et al., 2022). This is done to ascertain the current grain inventory base as quickly as possible, thereby effectively promoting the improvement of China's grain inventory management level. Additionally, the government encourages grain-consuming enterprises, farmers, and other entities to actively participate in the management of grain reserves and promotes the establishment of a mechanism for sharing food reserves throughout society, with government grain reserves as the mainstay and corporate grain reserves as the supplement.

According to grain import data over the years, China's grain import was in a relatively conservative state before 2010, but after 2010, there was a sharp increase in import volume. The instability of grain import has contributed to the increasing systemic risk of the food supply subsystem. Therefore, government officials and scholars should closely monitor changes in grain import volume and be vigilant against potential obstacles and conflicts in grain trade in the future. Moreover, with the achievements of China's reform and opening up, economic development has reached a high level. Residents are no longer satisfied with a single dietary structure, with the rapid growth of consumption demand for meat, eggs, milk, animal food, and alcohol, leading to increasingly prominent structural contradictions in food demand. As an important tool for maintaining a stable food security system, grain import can, to some extent, alleviate the current contradiction between food supply and demand. Therefore, China can balance its consumption demand for industrial grain and feed grain through imports, thereby ensuring food security.

5.2 Food supply stabilization: a manifestation of China's powerful policies

The stabilization of food supply in China is a testament to the nation's robust policy interventions. During China's rural reforms, policies were frequently adjusted. Most policies favoured the continuation and deepening of reform; but some were contradictory or even led to regression in the reform process (Zhang and Brümmer, 2011).

Initially, the rural reforms and the introduction of the household contract responsibility system, coupled with incremental increases in grain purchase prices, galvanized farmers' motivation for grain cultivation (Chen, 2009). This contributed to a steady augmentation in grain production, with a relatively stable state of food supply and demand maintained until the mid-1980s. However, the early 1980s marked a pivotal shift in China's food policy. Economic considerations prompted the government to initiate market-oriented reforms in food marketing. The transition from a state monopoly to a contract-based purchase system, known as the "double-track system," introduced market mechanisms into grain transactions. Yamamoto (2000) called the shift "from a centralized government-controlled procurement

system to a government contract purchasing system". This policy transition engendered uncertainty among grain farmers, leading to a decline in their cultivation efforts and a subsequent dip in the food supply and demand balance indicator from 93.63% in 1984 to 87.68% in 1985. Throughout the late 1980s and early 1990s, strategic policy adjustments by the Chinese government, including increasing grain purchase prices and reducing procurement quotas, helped to rekindle farmers' interest in grain production (Liu and Zhou, 2021). These measures partially restored the equilibrium in the food supply and demand balance indicator, which rebounded to around 90% in the result.

Nevertheless, the financial burden of sustaining long-term food support policies began to weigh on the central government. In response, a new round of food marketing reforms was launched in 1993, expanding upon pilot projects from earlier periods. Concurrently, the implementation of exchange rate reforms led to the devaluation of the RMB, which in turn stimulated a surge in grain exports. However, this also precipitated domestic food shortages, panic buying, and a spike in grain prices. Despite efforts to stabilize prices through the release of reserve grains, the entrenched interests within state-owned grain enterprises diminished the effectiveness of these measures (Fang and Beghin, 2017). In a decisive move, the central government introduced high-intensity price protection policies, which successfully revived grain prices and production, reestablishing a balanced food supply and demand. However, the early 2000s saw a resurgence of imbalances, particularly around 2003, with the food supply and demand indicator plummeting to 80.85%, signaling a significant grain deficit. The downturn in grain production in 2003 was largely attributed to the prolonged adjustment of the agricultural structure and ecological conservation efforts, which resulted in a regression to the grain production levels of 1991. In response to the escalating agricultural product prices and dwindling grain inventories, the government deployed reserve grains to stabilize market prices (Zhang and Brümmer, 2011). Subsequently, in 2004, the government abolished agricultural taxes, introduced agricultural subsidies, and reformed the grain distribution system, embracing a market-oriented open circulation policy. These comprehensive reforms, including the enforcement of a minimum grain purchase price, have since successfully maintained a stable equilibrium between food supply and demand (Lele and Goswami, 2020).

In summary, the evolution of China's food supply stabilization is a narrative of policy adaptability and responsiveness. The Chinese government's capacity to calibrate its agricultural policies in response to emerging challenges has been instrumental in ensuring the nation's food security and the stability of its food supply chain.

5.3 Policy strong navigation amid global fluctuations

The recent international landscape has faced multifaceted disruptions, including shifts in global politics and economic crises, which have magnified grain trade protectionism. Global food insecurity has worsened since 2015, driven by conflict, the COVID19 pandemic, and the Ukraine war (Barakat et al., 2023). Major grain-exporting countries have implemented aggressive export control policies, such as bans, quotas, and tariffs, causing ripples through the interconnected global food supply chain (Su et al., 2023). These disruptions have led to market instabilities and exacerbated the challenges in global food security. Concurrently, climate change has increased the prevalence of extreme weather events, compromising agricultural productivity worldwide and revealing structural gaps in global food supply capabilities. Recent studies affirm that climate change contributes to increased frequency and intensity of extreme weather events, adversely affecting agricultural productivity, revealing vulnerabilities in the global food supply system, escalating food prices, and challenging the maintenance of global food security (Myshko et al., 2024).

In order to cope with the shocks, the overall resilience of the food supply chain needs to be improved by increasing the diversity of production and trade, maintaining food stocks and production buffers, and managing the supply chain (Davis et al., 2021). Acknowledging these global patterns, international bodies stress the need to reinforce collaboration as the cornerstone of crisis resolution, advocating for a more resilient global food supply chain and equitable distribution systems to uphold food security and deter secondary impacts such as economic downturns and inflation (Oriekhoe et al., 2024).

China's notable role as a proactive advocate and significant contributor to global food security is evidenced by its enduring stability in managing food supply and demand. Over the years, the nation has maintained a consistent surplus in food supply, effectively meeting the dietary needs of its 1.4 billion-strong population and improving nutritional standards across both urban and rural communities. This success has been pivotal in reinforcing the global food security framework (Pan et al., 2024). Such accomplishments are a direct reflection of the Chinese government's unwavering dedication to agricultural support policies. The emphasis on the "Three Rural Issues," which encompasses rural development, agricultural modernization, and the welfare of farmers, is exemplified by the annual policy endorsements and financial support provided through the "Central Document No.1." This document serves as a policy compass, guiding the nation's agricultural priorities and ensuring that rural advancement is at the forefront of governmental initiatives (Zhang et al., 2023). These strategic policy interventions have not only bolstered China's food security but have also contributed to the sustainability of its agricultural practices. By prioritizing and consistently supporting the agricultural sector through targeted policies and financial aid, China has demonstrated a commitment to long-term food security and the well-being of its vast population.

Furthermore, China's food security endeavors are underscored by initiatives to boost food production capacity, a crucial element for safeguarding food security. The government's multifaceted approach, which includes addressing land management, technological innovation, and resource optimization, has been instrumental in achieving a harmonious balance between food production and consumption (Pan et al., 2024). Recognizing food as a pivotal aspect of the national economy and livelihood, China's top legislature adopted "PRC Food Security Protection Law" aimed at ensuring the supply of grain and related products. The law, passed at a session of the National People's Congress (NPC) Standing Committee, will take effect on June 1, 2024. The "PRC Food Security Protection Law" represents a strategic advancement in China's efforts to maintain food security amidst a dynamic global environment. It reflects the nation's

proactive approach to addressing the challenges of food supply and safety, and it sets a foundation for the continuous adaptation and enhancement of its food security mechanisms in the years to come.

In summary, China's steadfast policy support for agriculture and rural development has been a cornerstone of its success in ensuring food security and enhancing the nutritional quality of life for its citizens. The continued focus on these issues through the "Central Document No.1" and other policy instruments underscores the nation's commitment to sustainable development and its integral contribution to the global food security landscape. It is projected that China will continue to exhibit a favorable trend in food security, owing to these sustained policy efforts and systemic resilience.

5.4 Dietary transitions and implications for food security in China

In this study, the food demand subsystem is primarily categorized into the food demand, quantified by the annual ration consumption of residents, and the non-food demand, encompassing industrial grain, feed materials, seed grain, grain loss, and annual grain export volume. Food demand, encompassing industrial grain, feed materials, seed grain, grain loss, and annual grain export volume. And the relevant measurement coefficients refer to previous studies by many scholars (Zhao et al., 2006; Mao et al., 2016; Xiao et al., 2017), but it has to be admitted that the measurement coefficients provided by these studies may not exactly match with the dietary structure of the current Chinese population.

With rising incomes and improved living standards, the dietary patterns of Chinese residents have shifted from the traditional grain-based diet to a more diversified one that includes more meat, dairy products and other non-grain foods. This change is indicative of a nutrition transition, where the traditional diet, rich in carbohydrates and fiber, is being replaced by one that is more energy-dense and protein-rich (Wang et al., 2023). The inclusion of more meat and dairy products suggests a growing preference for foods that are perceived as markers of a higher socio-economic status and improved quality of life. Moreover, Urbanization and increased exposure to global food trends have accelerated this shift.

However, this shift in dietary habits, especially the increase in the consumption of non-starchy foods, has led to an increase in both water consumption and land occupation in the average diet of Chinese residents (He et al., 2018), a change that affects not only the type and amount of food, but also demand for land, water resources, and other factors of agricultural production (He et al., 2019), and thus such a changes in dietary structure also have implications for food security. On one hand, the increased demand for meat and dairy products has driven the expansion and intensification of livestock production, which has the potential to increase the overall efficiency and productivity of the agricultural sector. On the other hand, this transition poses challenges for the sustainable use of resources, particularly water and land, as animal production typically requires more of these resources compared to plant-based agriculture.

Deng's team (Deng et al., 2022) modeled various food security scenarios for China in the medium- to long-term future, pointing out that with the rapid economic and social development and the continuous improvement of people's living standards, the improved dietary structure, especially the increase in the consumption of animal-source foods, has led to a declining trend in food self-sufficiency, and the future dietary structure is more likely to continue to develop in the direction of increasing consumption of animal-source foods, which will pose a certain threat to food security. In the future, the dietary structure is more likely to continue to develop in the direction of increased consumption of food of animal origin, which will pose a certain threat to food security.

The dietary shift among the Chinese population is a complex phenomenon with far-reaching consequences for food security. It necessitates a comprehensive approach to agricultural planning and policy formulation that takes into account the changing dietary preferences, nutritional requirements, and environmental impacts. Future research and policy interventions should focus on promoting sustainable dietary patterns that can support both the health of the population and the long-term viability of the food system.

6 Conclusion

This study constructs a food security evaluation indicator system that includes factors such as grain output, *per capita* grain possession, and grain inventory, all from the perspective of balancing food supply and demand. The weight of each indicator is calculated using the entropy method, which allows for a comprehensive evaluation of China's food security level over the past 40 years. The study finds that, overall, China's food supply and demand have been on the rise. However, the food supply has experienced noticeable fluctuations, while the growth in food demand has been relatively steady and slow. According to the calculation results of China's food security indicator, there was a brief, slight imbalance between food supply and demand around 1985 and 1993, and a moderate imbalance around 2003. The root cause of these short-term imbalances is the shortage of effective food supply. It is posited that food supply largely determines food security.

This study, when combined with national macro policies, reveals that policy support can effectively regulate the balance of food supply and demand, thereby ensuring a robust state of food security. Each year, the Chinese government issues the "Central Document No.1" to comprehensively deploy work related to agriculture, rural areas, and farmers. This document clarifies the task objectives and policy guidelines for each stage, based on the real situation of China's food security. Reflecting on the development trend of China's food security over the past decade, it is evident that the relationship between food supply and demand has consistently been in a relatively ideal state, with a roughly balanced supply and demand of food and a small surplus. This indicates that China's macro food security policy has had a positive effect. In terms of future food security guarantees, policy support is a key factor. According to Todaro's theoretical analysis, the focus of future policies should not be limited to policy preferences and subsidies for food security, such as production and infrastructure. Instead, it should start with the industrial economy brought about by food and rely on policies to carry out market-oriented reform of food. Furthermore, the food strategy of "Storing Grain in the Ground and in Science and Technology" should be accelerated to upgrade the food market into a new, high-quality market that can attract more employment.

Data availability statement

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

Author contributions

YW: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. DF: Conceptualization, Formal analysis, Validation, Writing – original draft, Writing – review & editing. XW: Validation, Visualization, Writing – original draft. ZY: Project administration, Supervision, Writing – review & editing.

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Conflict of interest

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

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